Use of Health Information Technology to Improve Communication and Follow-Up of Critical Results

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This manuscript represents ongoing work at the Center for Evidence Based Imaging related to communication of critical results. Dr. O’Connor has been involved in several of these investigations; the resultant two published manuscripts and one manuscript under review are highlighted in the text.

1. BACKGROUND AND SIGNIFICANCE

1.1. Review of the Clinical Problem

Timely communication of critical test results is a well-known patient safety issue. Healthcare providers are inundated with test results, some spending an average of 74 minutes each clinic day just managing results (1). Full time primary care providers (PCPs) receive an average of 60 pathology or radiology reports each week (2). With this high volume of reports, it is easy to see how a critical value may slip through the cracks. Results from tests ordered for ambulatory patients may be at higher risk for oversight, as they are finalized hours to months after a patient visit and the provider must remember to check for them. As providers transition from a paper-based system where results are processed as they arrive via fax or mail, to an electronic system, new methods must be created to make them aware of results (3). Providers recognize the need for better systems, with 59% of internal medicine physicians surveyed being unsatisfied with how they manage test results (1).

Failures in critical result communication can delay appropriate management and/or treatment and lead to patient harm and malpractice suits. Multiple studies document a delay in provider knowledge of results, with 83% of internal medicine providers reporting at least one delay in reviewing test results during the prior two months (1) and 33% of providers being unaware of imaging findings concerning for cancer 5-6 days after they were available(4). Delayed awareness leads to delayed care, with 30% of PCPs encountering at least one patient in the past 2 weeks with a delay in diagnosis or treatment due to a missed test result(5). Missed results may result in patient harm, including delayed antibiotic treatment (6) or failure to diagnose a pelvic mass prior to metastatic spread (7). Inadequate
communication was the third most common reason for a malpractice claim against radiologists (8), contributing to 5-6% of suits related to diagnosis (9,10). Although some radiologists feel that a finalized report should be sufficient for critical result communication, the current standard of care is that all urgent, significant, and/or unexpected findings must be directly communicated to the referring physician (11).

National organizations have sought to improve critical result communication through the formation of guidelines and recommendations. A National Patient Safety Goal of the Joint Commission is to “report critical results of tests and diagnostic procedures on a timely basis” (12) and the Veterans Health Administration has echoed this admonition, saying it is “committed to the reporting of test results in a timely manner so that appropriate and effective therapeutic action may be taken” (13). The American College of Radiology (ACR), in the Practice Parameter for Communication of Diagnostic Imaging Findings, echoes this sentiment and addresses the method of communication, stating that non-routine communication may be warranted not only when immediate or urgent intervention is needed, but also when non-immediate intervention is needed (14). The Agency for Healthcare Research and Quality advises patients that “no news [on test results] is not good news” and that they should ask their healthcare providers to review all their test results (15). The National Quality Forum now includes patient death or serious injury from failure to follow up or communicate laboratory, pathology, or radiology test results as a Serious Reportable Event in Healthcare (16).

1.2. Quality Improvement Initiative without Health Information Technology (HIT)

The first step in improving communication of critical test results is to develop a clear policy, defining critical results, setting time intervals and appropriate methods for their communication, and establishing responsibility for follow-up of results. There are no national guidelines as to what constitutes a critical result—the Joint Commission and other authors suggest that this determination is
made at the local level. While explicit rules can be generated to assign an appropriate level of urgency for quantitative results such as chemistry laboratory values, rules need to be less explicit when clinical judgment is part of test interpretation as with radiology, pathology, and cardiology reports. At our institution, results are considered critical when a finding is new or unexpected and “could result in mortality or significant morbidity if appropriate diagnostic and/or therapeutic follow-up steps are not undertaken.” Results are also considered critical if there is a significant change in the interpretation of an exam and the difference in interpretation could alter diagnostic workup or management. The ACR considers both of these types of critical results as “situations that may warrant nonroutine communication” in the above referenced Practice Parameter.

Critical results should be divided into graded levels of urgency and policies regarding timelines and methods of communication can differ between the levels. Our institution uses three levels of urgency: Level 1 (red)—findings that require immediate attention (including tension pneumothoraces), Level 2 (orange)—findings that require urgent attention (including intra-abdominal abscesses), and Level 3 (yellow)—findings that are not immediately life-threatening or urgent but could result in serious patient harm without appropriate intervention (including pulmonary nodules). As some of these results do not need immediate attention, others refer to them as "clinically significant" rather than "critical". Results in the final group may be the most important to include in policy, as they are the most frequent and at highest risk for failure in communication. Each level of urgency can have a maximum amount of time allowed to complete communication, ranging from hours for Level 1 alerts to days or weeks for Level 3 alerts.

Although methods may vary between levels, any means for critical result communication must ensure receipt of the message, to facilitate timely patient care and to avoid malpractice. Radiologists are almost always held liable when critical findings are not communicated in a way that verifies message
receipt(22). When acknowledgement is not required, alerts may go unread, as in an electronic health record-based system where 18% of abnormal radiology results go unacknowledged(23) and 30% of primary care providers have missed test results that led to delayed patient care(24) or an email-based system where 25% of abnormal radiology reports were not viewed(25). When acknowledgement is required, 100% closed-loop communication can be achieved, though not always within the target timeline(26).

Individuals responsible for notification and follow-up of critical results should be unambiguously identified through policy (7,27). A single person should be identified for each result, as notifying multiple people muddies the waters and decreases the likelihood that a result will be acknowledged and followed-up in a timely manner(23). When a provider receives an alert he/she feels would be better addressed by a different provider, transfer of responsibility for the critical result should be closed-loop, such that the original provider remains responsible until the new provider explicitly accepts responsibility(7). This allows for appropriate care while protecting primary care providers from excessive alerts for services ordered by others(28). Closed-loop transfer of responsibility is especially important on the inpatient wards and in the emergency department, as patients in these settings are less likely to receive appropriate follow-up of important but non-urgent findings than those seen in the outpatient setting (29,30). Finally, policy should include an escalation process which identifies who should be contacted when initial attempts do no result in timely communication.

Policy should specify proper documentation for the process of communication, including the individual initiating, the individual receiving, and the date and time of the critical result communication. When this data is routinely recorded, it can help root out the cause of communication break downs, help to avoid repeating mistakes and objectively establish the course of events for malpractice suits, especially when there are contradictory claims from referrers(20).
Establishing, publicizing, and enforcing a clear policy can improve critical results communication. At our institution, policy implementation and enforcement increased compliance from 29% to 90% over 4 years, with most of the improvement seen in the first 2 years after implementation (21). Reports were considered compliant if critical results were communicated and all three elements of communication (sender, receiver, and date/time) were documented. Actual closed-loop communication was likely higher than 90%, as some non-compliance was likely due to a failure in documentation rather than a failure in communication. This is in contrast to other critical result communication policies, such as those that require that an alert is created, but do not require the recipient to acknowledge the alert and close the communication alert. In studies of systems with these policies, the rate of closed loop communication is in the 75-78% range (25,31).

1.3. Opportunities for HIT Interventions

Policy alone may prove insufficient for addressing critical result communication. Many results must be communicated, as 10% of all radiology reports (21) and at least 12% of abdominal CT and MRI examinations (4) contain critical results. It is not only the volume of results to be communicated, but also the “frustration of wasting substantial time trying to contact the referring physician and sometimes even being unable to do so” (26) that burdens radiologists. At our institution, radiologists were required to open one system to identify the appropriate provider to contact, another system to contact the provider, and yet a third to document the communication. Additionally, reports were either not finalized until after communication had been completed so that it could be documented, prolonging report turnaround time, or radiologists would finalize reports without documentation and try to remember to addend their reports after communication had occurred, increasing the risk of noncompliance. Finally, audits of critical result communication were arduous and time consuming, requiring manual review of individual radiology reports.
2. HIT CRITICAL RESULT COMMUNICATION SOLUTION

2.1. Alert Notification of Critical Results (ANCR): Architecture and Design


The Alert Notification of Critical Results software (ANCR) is a web-based application developed to facilitate communication of critical results in compliance with institutional policy (32). As with the manual system, the urgency of an alert is based on the radiologist’s judgment within the context of the information at hand, including exam indication, findings, and the patient’s clinical information (Figure 1a). Automating the identification of critical findings is not the primary goal of ANCR—that remains the domain of the radiologist. Rather, once a radiologist identifies a critical finding, ANCR facilitates alert creation, communication and acknowledgment, tracking and reminders, documentation, and analysis. This has been described in detail (32); here, several design decisions are highlighted and discussed.

2.1.1. Alert Creation

ANCR is integrated with the PACS workstation using standard third-party integration tools. This allows for the unidirectional automatic sharing of patient and examination context from PACS to ANCR, removing the need for manual data entry, increasing efficiency and decreasing the risk of human error. To automate the process further, Windows Middle Management (WMM) uses the “event” of opening a new study in PACS as a trigger to update patient and examination information within ANCR, keeping this information in sync and allowing for immediate alert creation when a critical finding is identified (Figure 1b).
The next step is identifying the provider who can act quickly on a critical alert, termed the responding clinician (Figure 1c). At our institution, an enterprise patient list system contains the current care team for inpatients and is updated at every shift change. ANCR uses web services to query this system so that alerts can be assigned to the responding clinician with a single click. For outpatients, the radiologist identifies the ordering provider from the electronic radiology requisition, generated from the computerized provider order entry (CPOE) system. CPOE systems allow for easy identification of the ordering physician, making communication easier(3) and, this information may be available even if CPOE is not fully deployed, as third party payers may require ordering provider identification for reimbursement(2). A type-ahead feature in ANCR displays matching names of providers in the ANCR user database, so the radiologist can choose the ordering provider from a drop-down menu. This increases efficiency and decreases the risk of typographical errors.

2.1.2. Alert Communication and Acknowledgment

When ANCR alerts are created, they are in pending status until acknowledged and the communication loop is closed. As per policy, urgent critical results require immediate, interruptive notification, whereas less urgent results may be communicated via other means if message receipt is ensured. ANCR sends alerts via web services to the paging system, without requiring the radiologist to logon to a separate system. After speaking with the responding clinician, the radiologist completes documentation of closed-loop communication by acknowledging the alert in ANCR.

While traditional synchronous communication methods (pager and phone call) are necessary for critical findings needing immediate or urgent attention, there is a demand for asynchronous communication for Level 3 findings. Providers prefer to email to phone contact for Level 3 radiology findings in general (25,26) and for potential new cancers(4), and asynchronous communication allows providers to process alerts during designated non-face-to-face time, avoiding interruptions and
potentially reducing errors(33). However, email alone cannot verify receipt of an alert and is not sufficient for closed-loop communication(12). ANCR provides a process for asynchronous alert notification by sending email alerts via web services to the simple mail transfer protocol (SMTP) server; email alerts contains links back to the ANCR system for referring provider alert review and acknowledgment. The alert detail screen not only presents patient/exam information and critical result description, but also the radiologist contact information providers want for easy provider-to-provider communication if questions arise(26).

2.1.3. Alert Tracking and Reminders

ANCR tracks all alerts through the communication process, from creation through acknowledgement. Unacknowledged alerts are presented as a worklist to each provider upon logon to the ANCR system (Figure 2). Worklists provide radiologists with quick and easy access to alert details when responding clinicians return notification pages and provide responding clinicians with an alternate means to view unacknowledged alerts rather than saving pager or email notifications. Filters on worklists can be changed to view previously acknowledged alerts, providing the easy access to critical result data considered absolutely required for safe and efficient patient care(24). Clinical administrators can monitor worklists for alerts created by all radiologists, providing an additional layer or protection against lost or delayed alerts. This is especially important when the responding clinicians are trainees, as alerts sent to these individuals are at high risk for being missed(34,35). Clinical administrator monitoring of unacknowledged alerts is also helpful when physicians are on extended vacation or permanently leave an institution.

As per policy, each level of alert urgency has an acceptable window of time to complete closed-loop communication. When alerts have not been acknowledged with this window, they are considered overdue. Reminder pages are sent for overdue Level 1 and 2 alerts and reminder emails are sent for
overdue Level 3 alerts. To reduce alert fatigue, a single reminder email is sent to providers with multiple overdue Level 3 alerts. Reminders continue until alerts are acknowledged, completing the communication loop.

2.1.4. Alert Documentation

All information relevant to alert communication—level of urgency, critical result, radiologist, responding clinician, and date and time of alert creation, notification, and acknowledgement—is recorded in the ANCR SQL database and ANCR is considered part of the medical record for details of closed-loop critical result communication. Therefore, radiologists use a macro in the dictation system stating, “Critical results were communicated and documented using the Alert Notification of Critical Results (ANCR) system” and finalize radiology reports immediately, rather than waiting for a response from the responding clinician. This is especially valuable for Level 3 (yellow) alerts, which constitute the majority of alerts and have the longest permissible time to complete closed-loop communication.

2.1.5. Alert Analysis

ANCR provides data to our radiology quality analytics system on a daily basis(36). The data is granular in nature, enabling critical result communication policy compliance at the institution, responding clinician practice, radiology section, or individual provider level. Alerts can be filtered by creation date/time, alert level, or the timeliness of acknowledgement (e.g. on time, late, pending).

2.1.6. Impact

The impact of ANCR has been measured in terms of changes in compliance with critical result communication policy and user assessment of utility and functionality. Policy adherence for all critical results (whether communicated via ANCR or other methods) increased from 91% prior to ANCR implementation to 95% over the four years after implementation (p<0.0001), with 97% of alerts communicated via ANCR being adherent(37). Nearly half of all users were satisfied with ANCR and agreed that it reduced medical errors and improved patient care quality(32).

2.1.7. Next Steps

While ANCR implementation was successful, it created a radiology critical result communication workflow which was separate from the laboratory critical results workflow. Laboratory test result tracking has been facilitated by a results management application developed as part of our EHR by our enterprise information systems group. With rule-based designation of result abnormality, it allows providers to easily identify, sort, and acknowledge results within their queue(2). While the application's rules can identify radiology reports with abnormal BIRADs classifications, the vast majority of radiology reports cannot be evaluated. This application is widely used by primary care providers (PCPs) to review, acknowledge, and track test results(31). Although ANCR is considered part of a patient's medical record, ANCR-generated alerts are not available to providers within the EHR.

2.2. Electronic Health Record Integration

This project evaluated an intervention to integrate ANCR and the results management application in the EHR. After the intervention, primary care providers (PCPs) could view and acknowledge non-urgent, clinically significant ANCR-generated alerts from their EHR queues (‘standard’ workflow for essentially all PCPs at our institution), or from within ANCR itself. Radiology reports were designated with the same level of urgency in ANCR and in the EHR, and acknowledgement in one system was reflected in the other. We hypothesized that integrating ANCR with the EHR would provide an alternative method for acknowledging non-urgent, clinically significant imaging results and that integration would not adversely impact rates of closed loop communication or follow-up of these imaging results.

2.2.1. Objective

Assess whether integrating critical radiology result management software (ANCR) with an electronic health record (EHR) results management application impacts rates of closed-loop communication and follow-up of non-urgent, clinically significant radiology results by primary care providers (PCPs).

2.2.2. Materials and Methods

2.2.2.1. Study Design

This institutional review board-approved study was performed at a 793-bed tertiary academic medical center with a radiology department performing over 600,000 exams annually. Non-urgent, clinically significant alerts received by 171 PCPs working at 13 affiliated outpatient practices during a 12-month pre-intervention and 24-month post-intervention period were included in the study. Inclusion and exclusion criteria for the study cohort are summarized in Figure 3 and are discussed as the components of the system are described.
Alert Notification of Critical Results (ANCR)

This web-based system, developed at our institution to facilitate closed-loop communication of critical test results, including non-urgent, clinically significant results, has been previously described(32). When a radiologist identifies a critical result, they categorize it as immediately life threatening (Level 1), urgent (Level 2), or non-urgent, clinically significant (Level 3), as per institutional policy(17,19). The referring provider is notified via pager for Level 1 and 2 alerts and via pager or email for Level 3 alerts. The referring provider for an outpatient exam is the provider who placed the order, while the referring provider for inpatient and emergency department (ED) exams is the provider currently caring for the patient. If the patient has been discharged from the hospital or ED, the responsibility reverts to the ordering provider. In general, referring providers return pages for Level 1 and 2 alerts and the radiologist acknowledges the alert on their behalf. Referring providers can opt for the same workflow for Level 3 alerts, or they can follow a secure link in the ANCR notification email to review alert details and acknowledge the alert within the ANCR on any tethered or mobile device using a web browser. Level 3 alerts must be acknowledged within 15 days and an escalation policy which holds both the referring provider and radiologist accountable for overdue alerts enforces this requirement. To ensure acknowledgement in the EHR was an option for the referring provider, Level 1 and 2 alerts were excluded from the study cohort.

Results Manager, Electronic Health Record

The results management application, developed by our enterprise information systems group to facilitate laboratory test results tracking, is accessible within our web-based EHR and has also been previously described(2). Providers are only required to acknowledge results with the highest level of urgency—acknowledgment of test results with lower levels of urgency can be used for record-keeping, but is not required. The results management application was designed for and is used by PCPs; it is
variably used by specialists. Inpatient and emergency department providers use other systems dedicated to those workflows(38). This study was limited to alerts generated on outpatient radiology exams ordered by PCPs. As PCPs ordered the exams, they received the alerts for non-urgent, clinically significant results and they could acknowledge these alerts in the EHR.

**ANCRI-EHR Integration**

The radiology department and enterprise information systems group collaborated to modify and create web services for transfer of data between ANCR and the EHR. When an ANCR alert is created, a web service notifies the EHR, which searches its archives for a radiology exam with the same accession number. Level 1 and 2 ANCR alerts flag test results with the highest urgency level (!!!) and Level 3 (non-urgent, clinically significant) ANCR alerts flag test results as second-highest urgency (!!). The ANCR alert text appears in the "Alerts and Guidelines" section of the results details screen (Figure 4). If the provider acknowledges the critical result in the EHR, the acknowledgment is communicated to ANCR via a web service and the alert becomes automatically acknowledged in ANCR. Conversely, if the alert is acknowledged in ANCR, ANCR uses a web service to acknowledge the alert in the EHR. PCPs were notified of ANCR-EHR integration via email although no specific additional training was provided.

**2.2.2.2. Measurements**

**System Adoption**

System adoption, our primary outcome, was measured as the proportion of non-urgent, clinically significant (Level 3) ANCR-generated alerts acknowledged in the EHR. Adoption was measured for each PCP and for all PCPs in aggregate.

**Alert Follow-up (Actionable and Actioned Alerts)**
We identified non-urgent, clinically significant ANCR alerts generated for 171 PCPs from May 2011-April 2012 (pre-intervention) and June 2012-May 2014 (post-intervention). Our secondary outcome was the rate of alert follow-up, defined as the proportion of actionable ANCR-generated alerts that were acted upon appropriately (‘actioned’). A multidisciplinary team developed criteria for actionable and non-actionable ANCR alerts (Table 1).

Table 1. Criteria for Actionable Alerts

<table>
<thead>
<tr>
<th>Actionable alert</th>
<th>Relevant action*</th>
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</thead>
<tbody>
<tr>
<td>Intervention recommended (biopsy, aspiration, surgery)</td>
<td>Intervention performed</td>
</tr>
<tr>
<td>Imaging recommended (same modality, different modality, comparison with priors)</td>
<td>Imaging performed (any modality, if addresses critical finding)</td>
</tr>
<tr>
<td>Clinical assessment recommended (specific history or physical question, referral to specialist, labs, follow-up on specimen required)</td>
<td>Documentation of clinical assessment, consult note, labs, documentation of result review</td>
</tr>
<tr>
<td>Description of condition with obvious treatment (infection, fracture, etc.)</td>
<td>Antibiotics, splinting/casting for fracture</td>
</tr>
<tr>
<td>Possible new malignancy with no specific recommendations</td>
<td>Imaging, biopsy, surgery, labs, consult, chemotherapy or radiation</td>
</tr>
</tbody>
</table>

Non-actionable alert

<table>
<thead>
<tr>
<th>Description of finding(s) without mention of a condition that could harm a patient and no clear action to be taken</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal findings, return to normal care</td>
</tr>
</tbody>
</table>

*In all cases, an alert was considered acted upon if a provider's note mentioned the alert and why it was not acted upon or that the patient refused further action.
Using these criteria, a radiologist with 3 years of experience (SDO) categorized a random sample of alerts as actionable or not, created chart abstractions containing relevant follow-up actions and/or notes, and categorized actionable alerts as having been actioned or not. A radiologist with 6 years of experience (VAS) and an internist with 10 years of experience (AKD) then independently reviewed the alerts and abstractions, and any disagreements between the 3 physicians were deliberated until reaching consensus. All physicians were blinded to the method and timing of alert acknowledgement. If the timing of the alert was such that the action should occur after the time of record review (such as an alert from six months prior to record review recommended a CT in one year), the alert was removed from the actionable alert cohort.

Power and Sample Size Calculation: In a review of 50 random alerts in the pre-intervention cohort by one radiologist (SDO), 47 (94%) acknowledged alerts were actionable and 44 (89%) actionable alerts were actioned. Therefore, to detect an increase in the rate of actionable alerts that were actioned from 89% to 99% (a 10% absolute increase), with 80% power and alpha of 0.05, a sample size of 182 acknowledged alerts would be needed. To be conservative, we randomly sampled 200 acknowledged alerts for review; patient characteristics for the study cohort and sample are presented in Table 2.

Table 2. Patient Demographics

<table>
<thead>
<tr>
<th></th>
<th>Cohort (n=4805)</th>
<th>Sample (n=199)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>57 ± 15</td>
<td>57 ± 15</td>
</tr>
<tr>
<td>Female</td>
<td>74%</td>
<td>76%</td>
</tr>
</tbody>
</table>

Time to Acknowledgement
Time to acknowledgement was measured as the interval between alert generation by the radiologist and acknowledgement by the PCP. Wilcoxon Rank Sum was used to compare time to acknowledgement for alerts in the pre- and post-integration periods as well as between ANCR-acknowledged and EHR-acknowledged alerts in the post-integration period.

2.2.2.3. Statistical Analysis

Alert follow-up, as defined above, was compared for alerts in the pre- and post-intervention periods using Fisher’s Exact Test and the Cochran Armitage Trend Test was used to evaluate for a trend across the three years in the study. To determine the maximum theoretical impact of the intervention, we compared follow-up rates for alerts acknowledged in the EHR versus ANCR in the post-intervention period. A two-sided p value of < 0.05 was used to determine statistical significance. System adoption was analyzed over time using a p-type statistical process control chart.

2.2.3. Results

2.2.3.1. Study Cohort

Of 100,672 alerts sent via ANCR in the 12-months pre- and 24-months post-implementation, 6,841 (6.8%) were sent to PCPs. After excluding alerts not in the EHR and alerts generated on inpatients and emergency department patients, 6,440 alerts remained. The 5,931 Level 3 (non-urgent, clinically significant) alerts, comprising 92% of alerts generated for PCPs on outpatient exams, formed the study cohort (Figure 3). The 171 PCPs received 1-200 alerts each (median 41 alerts, interquartile range (IQR) [19, 69]).

2.2.3.2. System Adoption

The EHR was used to acknowledge 15.5% (688/4,428) of alerts generated in ANCR in the post-intervention period (Table 3). A statistical process control chart (Figure 5) demonstrated that the
month-to-month variation in this proportion was not statistically significant(39). Providers acknowledged 0-100% of their alerts in the EHR (median 4%, IQR [0, 15]).

**Table 3. Acknowledgement of ANCR*-generated Alerts**

<table>
<thead>
<tr>
<th></th>
<th>Total Alerts</th>
<th>Alerts Acknowledged in ANCR*</th>
<th>Alerts Acknowledged in EHR</th>
<th>Total Acknowledged Alerts</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pre-intervention</strong></td>
<td>1503</td>
<td>1503 (100%)</td>
<td>0 (0%)</td>
<td>1503 (100%)</td>
</tr>
<tr>
<td><strong>Post-intervention</strong></td>
<td>4428</td>
<td>3740 (84%)</td>
<td>688 (16%)</td>
<td>4428 (100%)</td>
</tr>
<tr>
<td><strong>Year 1</strong></td>
<td>1979</td>
<td>1669 (84%)</td>
<td>310 (16%)</td>
<td>1979 (100%)</td>
</tr>
<tr>
<td><strong>Year 2</strong></td>
<td>2449</td>
<td>2071 (85%)</td>
<td>378 (15%)</td>
<td>2449 (100%)</td>
</tr>
</tbody>
</table>

* ANCR = Alert Notification of Critical Results software; EHR = Electronic Health Record Results Manager

**2.2.3.3. Alert Follow-up**

Using a random sample and by consensus review, 90% (95% Confidence Interval [95CI] 83-94%) of alerts pre-intervention and 84% (95CI 76-90%) of alerts post-intervention were actionable (p=0.2931, Table 4). PCPs acted on 94% (95CI 88-98%) of actionable alerts pre-intervention and 94% (95CI 87-97%) post-intervention (p=1.00). In the post-intervention period, PCPs acted up on 79% (11/14, 95CI 52-92%) of actionable alerts acknowledged in the EHR and 97% (68/70, 95CI 90-99%) of actionable alerts acknowledged in ANCR (p=0.0308).

**Table 4. Estimates of Actionable and Actioned Alerts**

<table>
<thead>
<tr>
<th></th>
<th>Sample Size</th>
<th>Actionable Alerts</th>
<th>Actioned Actionable Alerts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>% [95% CI]</td>
<td>N</td>
</tr>
<tr>
<td><strong>Pre-intervention</strong></td>
<td>100</td>
<td>90/100</td>
<td>90% [83-94]</td>
</tr>
</tbody>
</table>
No significant difference between the proportion of actionable alerts acted upon pre-integration and post-integration (p=1.00 for pre- vs post-, p=0.79 for trend from pre- to Year 1 post to Year 2 post).

Percentages are given with 95% Confidence Interval (CI).

### 2.2.3.4. Time to Acknowledgement

The median time to acknowledgement was 0.6 hours (IQR 0.03, 20.5 hours) pre-intervention and 0.6 hours (IQR 0.03, 6.9 hours) post-intervention (p=0.0003). The median time to alert acknowledgement was 7.0 hours (IQR 1.1, 46.4 hours) in the EHR, and 0.3 hours (IQR 0.02, 3.3 hours) in ANCR (p<0.0001).

### 2.2.4. Discussion

Integrating a critical radiology results management system (ANCR) with an EHR-based results management application provided an alternate method for managing critical results but was not associated with a change in the rate of closed-loop communication or the proportion of actionable alerts acted upon by primary care providers (PCPs). Although adoption of the integrated ANCR-EHR system was immediate and sustained, PCPs continued to acknowledge the majority of critical radiology results in ANCR post-intervention. Compared to the EHR, PCPs acknowledged alerts in a significantly shorter duration of time when using ANCR. Nevertheless, the follow-up rate for actionable alerts acknowledged via the EHR and ANCR were still similar.

We have several potential explanations for these findings. First, although PCPs have established workflows that can take advantage of ANCR-EHR integration (e.g., reviewing test results in the EHR,
results management application while seeing patients in clinic) and may prefer notification in the EHR over email notification(4), this is not a consistent preference(38). Second, ANCR relies on “active” external notification (e.g., notifications are sent to the referring provider’s pager or network email inbox) as opposed to “passive” internal EHR notification (e.g., providers must access the EHR to view and acknowledge alerts). Providers may not accept a system that requires them to actively seek test results, especially if that system does not fit with their workflow(38). Third, ANCR offers a mobile workflow—referring providers can open a secure hyperlink from a notification email that directs them to view and acknowledge an alert. Fourth, ANCR enforces the enterprise policy of 100% closed-loop communication of critical results(7) by automatically reminding radiologists and referring providers of outstanding alerts until they are acknowledged. Finally, providers can launch the computerized provider order entry (CPOE) application from the alert detail page in ANCR, facilitating ordering of follow-up imaging.

Our study builds on the findings of prior studies. We describe the follow-up of non-urgent but clinically significant (Level 3) radiology results, and include all alerts with this level of urgency rather than concentrating on unexpected findings of possible malignancy. The follow-up rate we observed is higher than in other studies of abnormal findings(4,40) and follow-up recommendations(41,42) in radiology reports, but it is consistent with other critical result alert systems(23,43). Additionally, our findings confirm that results management applications work best when designed to support enterprise-wide policies. A recent study at our institution found that PCPs acknowledged no more than 78% of the Level 3 (non-urgent but clinically significant) alerts via the EHR(31), whereas the rate of rate of acknowledgement via ANCR at baseline and post-intervention was consistently 100%.

We acknowledge limitations of this study. First, it was performed at one academic center with a single combination of critical radiology results software and EHR-based results management application. However, multiple critical result communication systems have been built external to local
EHRs(25,26,30,43) and many EHRs have test result management tools(2,44); the benefits of integrating these systems has not been thoroughly investigated. Second, although ANCR alerts could be sent by radiologists at our community hospital as well as those at our main hospital, the intervention only integrated alerts generated at the main hospital with the EHR. PCPs were required to continue to acknowledge alerts from the community hospital via ANCR and may have been reluctant to use parallel workflows, preventing greater adoption of ANCR-generated alert acknowledgement in the EHR. Additionally, notifications of critical results from the two hospitals were identical, so, even if they were willing to use two workflows, PCPs did not have an easy way to determine which results they could acknowledge in the EHR. Next, there was wide variation in the proportion of ANCR-generated alerts each PCP acknowledged in the EHR, raising the question of whether there was variation in the impact of the intervention on alert follow-up by each PCP. As alerts were distributed amongst a large number of PCPs with most providers each receiving less than 1% of all alerts, the clustering effect would be minimal. Therefore, we chose to use a simple model that did not include the PCP as a covariate. Some of the variation in adoption may have been due to lack of training and adoption rate may have been improved with additional training. Finally, this study uses pre-/post-intervention analysis rather than a randomized trial design, so we cannot control for changes in follow-up of actionable alerts due to factors other than our intervention. However, as no other interventions targeting follow-up of non-urgent clinically significant radiology findings were introduced at our institution during the study period and the proportion of ANCR-generated alerts acknowledged in the EHR was constant in the 2 years post-intervention, it is unlikely that such factors significantly affected our findings.

2.2.5. Conclusion

Integration of ANCR-generated alerts into the outpatient EHR provided an alternate method for non-urgent, clinically significant results management and did not adversely impact the rate of closed-
loop communication or non-urgent, clinically significant radiology results that were appropriately acted upon by PCPs.

2.2.6. Next Steps

In the above study, six percent of alerts with actionable findings were not acted upon, despite 100% acknowledgement. This is consistent with prior studies, which found 36% of women with abnormal mammograms requiring 6 month follow-up did not receive appropriate care(40), 2% of radiology exams with unexpected findings suspicious for malignancy at risk for loss-to-follow-up without an experimental follow-up system (43), and 8% of abnormal imaging results lacking appropriate follow-up at 30 days(23). Communication and acknowledgement of critical results are insufficient to ensure follow-up, as demonstrated in studies with electronic notification(45,46) and physician-to-physician notification(40).

Follow-up testing that should occur in the future is especially problematic. Ordering follow-up testing is not sufficient, as 9% of malpractice claims for missed or delayed diagnoses include tests that were ordered but not performed (47). Although highly desired, systems to monitor for completion of testing are lacking with only 25-32% of physicians having a system to monitor if their patients complete ordered follow-up testing(1,4). Electronic systems to remind physicians to perform actions in the future are similarly desired(24,28), as many providers resort to hand-written notes or other systems to remind themselves to follow-up on critical finding alerts(48).

2.3. Future Directions

2.3.1. Follow-up Recommendations

Critical results and follow-up recommendations are intimately related, with 65% of level 3 alerts at one institution containing a recommendation for additional imaging(26) and follow-up
recommendations being one of five data elements recommended for critical results communication(20). Therefore, to help improve coordination of patient care, the next step in the evolution of ANCR will be to implement a follow-up recommendation alert module. Radiologists will create structured recommendations using guidelines (Figure 6a) or their clinical judgment (Figure 6b) and the module will require interaction between the radiologist and ordering provider to choose the most appropriate follow-up plan (Figure 6c). Once a plan is established, ANCR will track the patient until plan completion and will notify the providers if follow-up is not performed. Impact will be measured in terms of number and specificity of follow-up recommendations and completion of recommended follow-up examinations.

3. CONCLUSIONS

Timely communication and follow-up of critical results is an important and well-known patient safety issue. Policies should be developed and implemented to define critical results and establish criteria for appropriate communication. Monitoring and enforcement of these policies can improve communication performance. Integrated electronic systems further improve communication while reducing burden and increasing efficiency. Integration with the EHR provides an additional method for managing critical alerts while maintaining closed-loop communication and the rate at which results are followed-up. Critical results communication software can be enhanced through the addition of a follow-up recommendation module which has the potential to increase the rate of appropriate follow-up imaging while helping radiologists understand when follow-up imaging is considered unnecessary by referring providers.

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REFERENCES


5. Wahls TL, Cram PM. The frequency of missed test results and associated treatment delays in a highly computerized health system. BMC Fam Pract. 2007;8:32.


FIGURES

Figure 1. ANCR Alert Creation
a. Level: Radiologists choose a level of urgency based on their clinical judgment. b. Result: When alerts are created at a PACS workstation, patient and exam information is pre-populated and the radiologist
enters the critical finding description. c. Contact: The responding clinician is selected through EPL integration or manual entry.

**Figure 2. ANCR Worklist**

![ANCR Worklist](image)

Worklist of unacknowledged alerts is presented upon logon to ANCR.

**Figure 3. Study Cohort**
*ANCR = Alert Notification of Critical Results software; PCP = Primary Care Provider, EHR = Electronic Health Record Results Manager

Figure 4. Electronic Health Record Results Manager Test Result Details Screen
a. After integration, radiology reports are flagged with the degree of urgency of associated ANCR alerts,

b. When PCPs use this button to acknowledge radiology reports, acknowledgement is reflected in ANCR,

c. ANCR alert text appears in the alerts and guidelines box.

**Figure 5. Proportion of ANCR* Alerts Acknowledged in the Electronic Health Record**
* ANCR = Alert Notification of Critical Results software, UCL = Upper Control Limit, LCL= Lower Control Limit, EHR = Electronic Health Record

**Figure 6. Follow-up Recommendation Module**
Alert Notification of Critical Results

### Context
- **Patient Name (Last, First)**: DETEST, CATHY
- **Patient DOB (mm/dd/yyyy)**: 01/01/1940
- **Patient MRN**: 12345678
- **Exam ID**: 96765432
- **Description**: CT Abd/Pel
- **Exam Time**: 08:00 AM
- **Exam Date (mm/dd/yyyy)**: 03/25/2012

### Follow-Up Recommendation *
- **Findings**: Breast, Pulmonary Nodule, Renal Mass, Other
- **Procedure**: Select one or more suggested procedures
- **Anatomy**: Head/Neck/Neuro, Chest, Abdomen/Pelvis, Cardiovascular
- **Timeframe**: Days, Weeks, Months, Years

Follow-up Details (provide additional specifics to ensure proper follow-up): *
Follow-up Recommendations may be based on established guidelines (a) or a radiologist’s clinical judgment (b). Ordering providers respond to these recommendations by agreeing to, modifying, or marking them unnecessary (c).