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Timely Correction of Misplaced Endotracheal Tubes:
A Model for Studying Critical Radiology Result Communication

A Thesis Submitted to the Yale University School of Medicine
in Partial Fulfillment of the Requirements for the
Degree of Doctor of Medicine

by

Philip Johannes Butler

2010

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Abstract

Clinical management of misplaced endotracheal tubes provides a compelling model to study the communication of critical radiology results: abnormal findings are clearly defined, require a narrow range of actions, and can be followed in subsequent radiographs. In this study, we assessed rates of endotracheal tube correction following misplacement and correlated those rates with communication practices.

A manual screen was done of radiology reports from 11/2008-6/2009 at Yale New Haven to identify patients with endotracheal tube misplacement. Patients were included in the study if misplacement was verified by image measurement, if there was evidence of endotracheal tube placement for more than 24 hours following misplacement, and if they had radiographic follow-up. An endotracheal tube was determined to be corrected by image measurement on subsequent chest x-rays within 30 hours.

21,277 chest x-ray reports were screened and 224 patients with endotracheal tube misplacement were identified. 119 patients had misplacement on initial intubation; 69 (58.0%) had evidence of correction within 30 hours. 105 patients had misplacements subsequently in the ICU; 59 (56.2%) had evidence of correction within 30 hours. Correction rates were not associated with explicit recommendations in the report text [OR=1.36, 95% CI=0.65-2.86, p=0.45 for initial misplacement, OR=1.36, 95% CI=0.63-2.94, p=0.55 for subsequent misplacement] or with additional radiologist-clinician communication [OR=1.36, 95% CI=0.65-2.86, p=0.45 for initial misplacement, OR=1.36, 95% CI=0.63-2.94, p=0.55 for subsequent misplacement].

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Introduction

Breakdowns in communication are a significant cause of preventable medical errors. The Joint Commission determined that 70% of sentinel events in accredited health care organizations are due to communication errors.¹ A review of medical malpractice cases reflects this as well: communication was a causative factor in 80% of cases filed.² In radiology specifically, the findings are similar: communication was cited as the fourth most common cause of malpractice claims³ and 25% of radiologists surveyed reported that they had been involved in a malpractice suit that involved allegations related to the presentation of radiology results.⁴

Communication breakdowns in radiology reporting can occur either in the report itself or in the processes used to bring attention to important findings. Referring clinicians report being generally dissatisfied with both aspects of radiologist-clinician communication, and there is an active debate about potential improvements.⁵⁻⁷

The Radiology Report

Clinger et. al surveyed 251 referring physicians and asked them to rate the quality of the radiology reports that they were receiving.⁵ 40% found that reports were occasionally confusing and 49% reported that the reports did not sufficiently address the clinical questions that were posed.

The language used in radiology reports may be contributing to the confusion that referring clinicians experience. Sobel et. al classified the terminology used in 822 chest radiographs of patients hospitalized for congestive heart failure, acute myocardial

infarction, or pneumonia.⁶ There was a wide variation in the terms used to describe clinical abnormalities. For example, twenty five different terms were used to signify pulmonary vascular congestion: “central congestion, congestive changes, gross pulmonary venous hypertension or congestion, hypervascularity, pulmonary hilar vessels, veins, venous pressure, artery, vascular markings, bronchovascular markings, bronchovascular shadows, vasculature with cephalization, congestion, distention, engorgement, extension, hyperemia, hypertension, hypervascularity, increase, overload, plumpness, prominence, or redistribution”.⁶ The authors also found variability in the terms used to convey the radiologist’s confidence in the findings of report. Twenty-three phrases were classified as being indicative of an abnormality, three terms were classified as being indicative of no abnormality, and thirty phrases were classified as being possibly indicative of an abnormality. The terms used included: “cannot be excluded, could represent, few, likely, possible, probably, questionable, should be entertained, slight, small, suggesting. Terms used to convey that an abnormality is present included: “compatible with, consistent with, evidence for, presumably representing, suspect.”

The use of differing terminology presents a potential source of communication error, as there is interobserver disagreement on the meaning of some terms used in radiologic reports. Khorasani et al. surveyed radiologists on their interpretation of the 15 most commonly used terms to convey certainty.⁸ The radiologists were asked to order the terms from most certain to least certain, and their responses were compared to those of the group. There was agreement as to the most certain term (*diagnostic of*, $\kappa=0.95$) and as to the least certain term (*unlikely*, $\kappa=0.45$). However, there was poor agreement

between observers as to the level of certainty conveyed by the terms in between ($\kappa=0.27$).⁸

These findings were reinforced by a similar study on terminology used by pathologists.⁹ Pathologists were first asked to rate how frequently they used each of the 13 most common terms used to describe certainty. Surgeons were then asked to rate whether they liked the each term or whether they found it confusing. Pathologists varied widely in their preference of terms to convey certainty, with a large distribution among the 13 different terms. But more remarkably, the three most common terms used by pathologists were rated as confusing by 45%, 30% and 65% of surgeons, respectively.

Other language used by radiologists can be confusing and potentially unhelpful in guiding clinical management. Patterson and Sponaule administered a survey to assess the clinical utility of the word “infiltrate”.¹⁰ The survey consisted of three questions: what conditions are implied by the use of “infiltrate”, whether the term is helpful in guiding therapy, and whether the term implies a definite etiology. More than half (54%) of clinicians associated six or more clinical conditions with “infiltrate”, less than half (36%) felt that it was helpful in clinical care, and almost no one (3.0%) felt that it implied an etiology.

Clinician understanding of the content conveyed in reports may also be a source of communication breakdown. In a study of surgeons’ understanding of pathology reports, Powsner et. al presented six representative reports to 34 attending surgeons and trainees. The surgeons were given a questionnaire that assessed their understanding of the terms and phrases used throughout the reports.¹¹ Surgeons understood the meaning of

the reports just 70% of the time. There was increased understanding with increasing levels of training, but there was still significant misunderstanding among attending physicians. Surgeons with advanced training understood more (75%) than housestaff (69%) and medical students (63%).

It has also been hypothesized that confusion on the behalf of referring physicians may stem from a lack of consistent structure and clear recommendations in radiology reports. Naik et. al retrospectively reviewed 272 radiology reports for the presence of specific report elements: clinical indication, mention of comparison study, pertinent negatives, and the radiologist's opinion and recommendations.¹² They found a large variability in the inclusion of elements in different reports: clinical indications were only noted in 27% of reports, for instance. Also, clear guidance was lacking in the majority of reports: only 48% included an explicit recommendation by the radiologist.

The value of clear recommendations is illustrated in a review of 10 cases by Berlin, where the use of vague terms in a radiology report led to a delayed diagnosis of malignancy.¹³ He starts out by discussing a CT report from a 68 year old woman: "There is a nodular appearance of the pancreas. No definite mass is seen, but if there is any clinical suspicion of neoplasm, an endoscopic retrograde cholangiopancreatogram may be warranted." No follow-up studies were ordered and 7 months later the patient presented with severe jaundice and CT showed a large tumor coming from the head of the pancreas. The case was brought to trial and the plaintiff's expert witness testified that the language used lacked certainty: the radiologist should have "recommended" further tests rather than merely saying that additional testing "may be warranted." In the nine other cases,

the radiologists also refrained from giving explicit recommendations, choosing instead to defer to the clinician with phrases such as “if clinically indicated may be of value” and “may be of benefit.” While the sampling of cases does not provide evidence of the effectiveness of explicit recommendations, it highlights the unclear language that is often used in place of more definitive clinical guidance.

The clinical value of clear recommendations has also been demonstrated in the evolution of reporting in breast imaging. With the increase in mammography in the 1980s, the wide variation in practice structure led to concerns about consistency and quality. The AMA was critical of the language used in reports, pointing out “unintelligible descriptions and ambiguous recommendations”.¹⁴ The ACR responded, convening experts to set guidelines for mammography reporting and management. Out of this discussion came the Breast Imaging Reporting and Data System (BI-RADS), which set guidelines for language and structure, and assigned assessment categories with management recommendations. The BI-RADS committee specified that mammography imaging should be “decision-oriented,” and the assessment categories reflected this in that each category came with specific treatment guidelines.¹⁵ In addition to increased clarity for the referring physician, consistent guidelines allow for further improvement in radiology reporting. Clinical outcomes, such as positive pathology after biopsy, can be readily correlated with radiology findings. This process can help refine the terminology and assessment categories, providing even more clinical benefit to the referring physicians. Additional outcomes, such as callback rates for screening examinations, can be assessed as well and can allow for targeted quality improvement projects.¹⁶

Attempts have been made to determine how to adjust radiology reports to improve clinician understanding. Naik et. al assessed clinician preferences with respect to report structure.¹⁷ The authors took three radiology reports and formatted them in two ways: first in a narrative format and second in an itemized format. The six reports were sent to clinicians - a mix of primary care providers, surgeons, and specialists - who rated their preference for each report. Referring clinicians overwhelmingly preferred the itemized reports, choosing them between 85-93% of the time.

Despite a clear preference by referring clinicians for itemized reports, these reports may not be more effective at transferring information. Siström and Honeyman-Buck designed an experiment to test how accurately and quickly clinicians can extract relevant information from radiology reports.¹⁸ They presented 12 radiology results either as structured reports or narrative reports and asked medical students to answer 10 corresponding multiple choice questions. The software used was able to register how long it took to answer questions, giving data both on the number of correct responses and the number of correct responses/minute. Surprisingly, they found no difference between the two report formats in the score or the efficiency of the students. The finding may be of limited value due to the use of medical students, as they may not be as attuned as referring physicians are to the critical parts of different radiologic studies.

In practice settings, structured reporting may fare worse than narrative reporting. In a cohort study examining the relative value of narrative and structured reporting, 25 MR imaging cases were given to 34 residents at a university radiology program. On first read, the residents were asked to give narrative-style reports. Four months later, the

residents were split between two groups: the first group re-read the studies using a narrative format while the second group re-read the studies using a structured reporting format. The resident-generated reports were then graded by an attending radiologist for completeness and accuracy. While the group that re-read the images using a narrative report style increased in accuracy (91.4% to 92.4%) and completeness (67.8% to 71.7%), the group that re-read the images using a structured report style decreased in accuracy (91.5% to 88.7%) and completeness (68.7% to 54.3%). There are some clear limitations of this study, the most notable being that the residents were likely accustomed to reading narrative reports and may not have been prepared to structure their reports in a new way. But along with the previous study on information-transfer rates, it does cast doubt on whether transitioning to structured reporting represents a clear benefit.¹⁹

Communication of Radiology Results

Some radiologic findings necessitate that the radiologist initiate communication in addition to producing a written report. In 1989 the Arkansas Supreme Court issued a ruling in a case regarding a radiologist who had noted a displaced endotracheal tube but had failed to contact the referring clinician:

“When a patient is in the peril of his life, it does him very little good if the examining doctor has discovered his condition unless the physician takes measures and informs the patient, or those responsible for his care, of that fact . . . Common knowledge is all that is needed to determine that the x-rays read by [the radiologist at a later hour] clearly demanded that the extubation required immediate attention rather than the normal routine”.^{20,21}

Shortly afterwards, the ACR issued guidelines for radiologists to follow with respect to additional communication.²² The guidelines have been updated several times since then, and in the most recent form three situations were outlined where “non-routine communication” may be required²³:

- “ i. Findings that suggest a need for immediate or urgent intervention
- ii. Findings that are discrepant with a preceding interpretation of the same examination where failure to act may adversely affect patient health
- iii. Findings that the diagnostic imager reasonably believes may be seriously adverse to the patient’s health and are unexpected by the treating or referring physician”.

Direct communication also brings attention to clinical findings that may be overlooked. In a survey of primary care physicians, the average physician spent 74 minutes a day managing lab and imaging results.²⁴ In the context of this volume of results, a clear finding may not be sufficient to induce clinical action. Nepple et. al studied the frequency with which clinicians at a VA hospital responded to an abnormal PSA value.²⁵ They reviewed charts of patients who went on to develop prostate cancer and analyzed the work up of their initially elevated PSA values. Patients were classified as having appropriate follow-up if there was documentation of the elevated PSA value in the chart, an order for further evaluation, treatment for prostatitis, or a urology referral. Of the 327 patients studied, 51 (15.6%) did not have follow up within 180 days. While the reason for missed follow-up could not be determined from this study, it is likely that some of these patients did not undergo appropriate follow up because their PSA results were overlooked by the primary care physician.

In addition to receiving a large volume of test results, primary care physicians report being dissatisfied with the systems that they have in place to notify them of abnormal laboratory and imaging results. In a survey of 140 primary care physicians who used electronic medical records, less than one-third were satisfied with the systems to manage abnormal results. Over ninety percent of those surveyed felt that additional automated systems to track results would be a useful addition to their practices. It is possible that the level of satisfaction has increased since then, as the survey was conducted in 2003. However, it reflects a desire from primary care physicians for more automation and for more help in managing important results.⁷

To assess how frequent missed test results are, Wahls et. al conducted a survey of VA physicians, nurses, and trainees. The healthcare providers were asked to report whether they had observed a missed test result that contributed to a delay in diagnosis or treatment within the last 2 weeks. Thirty seven percent of providers had observed at least one instance, with 15% reporting two or more instances of delays.²⁶

Initiating communication following a critical result is not sufficient; the radiologist is also responsible for ensuring that the result is successfully received. Berlin reviews a case where the radiologist unsuccessfully attempted to notify the referring physician of a clinical finding.²⁷ The interpreting radiologist reviewed a chest radiograph of a 23-year-old with Crohn's disease who had a subclavian catheter placed that appeared more medially than expected. The radiologist initially instructed the radiological technician to contact the surgeon; however, calls to the surgeon's answering service went unreturned. The radiologist then contacted the nursing team, verified that there was good

blood return from the catheter, and went home for the weekend. Later on Friday, hyperalimentation fluid given through the catheter filled the patient's pleural space, and the patient died.

A malpractice suit was brought against the radiologist, alleging that his failure to successfully notify the surgeon of his concerns was negligent. In pre-trial discovery, the surgeon confirmed that if he had become aware of the result, he would have proceeded to replace the catheter. A radiology expert retained by the plaintiff testified that the interpreting radiologist was in dereliction of his professional duties by not properly ensuring that the referring clinician was aware of this critical result.

Requiring radiologists to successfully notify the referring clinician poses a practical problem in modern radiology practices. A private practice radiologist from Philadelphia expressed his concerns about the ACR guidelines in the following letter: "In the new radiology millennium, it is sometimes extremely difficult, if not impossible, to notify our clinical colleagues when abnormalities are found on studies they order. Histories are often vague and almost always incomplete. Radiographs are ordered by physicians who may or may not be in our network or our area. Telephone numbers are often not available, and, when they are, a computer or answering machine often answers. It is not uncommon to spend 20-30 minutes trying to reach a "body" only to find that the one who answers is unaware of anything about the patient. . . This happens in an environment that is extremely hectic and becoming more so."²⁸

Technologies that shift the burden of notifying clinicians from radiologists to non-radiologists have helped improve rates of communication. A Georgia-based practice

described their experiences with setting up systems to have non-radiologists notify providers of critical results. The first system that they introduced in 2001 relied on the reading radiologist to physically drop off requisition forms on studies that required direct communication. Soon after 2002, they acquired a commercial system (Anatheum[®], Phyquest LLC, Atlanta, GA) that allowed radiologists to electronically flag a report as critical during the time of dictation. A staff employee - hired to communicate critical results - identifies flagged results and reports them to the appropriate clinicians. Shifting from the paper system to the electronic increased the number of studies being called into referring clinicians from 800/year to 12,000/year. The increase in communication corresponded with a decrease in complaints from referring physicians, which went from being “common” to “nonexistent”.²⁹

The presence of automated notification systems does not ensure that all results are received, however. Singh et. al describe the electronic system for reporting critical results at the VA hospital in Houston.³⁰ Radiologists flag significant unexpected findings electronically, which are then displayed in the referring physician’s “View Alert” window. This window is made prominent to the physician, coming to the forefront of the screen when the physician is logged on as well as when the physician switches patient records. The alerts will continue to be displayed until the physician acknowledges the results individually. The authors tracked 1,017 transmitted results, defining a result as being unacknowledged if it had not been cleared at the end of the week. Despite the prominence given to the alert window, 367 of those alerts (36%) went unacknowledged. The missed results were followed up using two methods: first, the chart was examined

for presence of appropriate clinical follow up and documentation, and second, the clinicians were called and asked if they had received the result. Of the 367 unacknowledged results, 45 (12.3%) were reported not to be received by the referring clinician and lost to follow-up.

A later study at the same institution examined the reason for unacknowledged results as well as the rate of appropriate clinical action following an alert. In this study, the authors applied a different methodology to determining which alerts were unacknowledged: if an alert was not cleared by the clinician two weeks after being generated, it was defined as unacknowledged. There was a lower rate of unacknowledged results in this study compared to the previous one (18% vs. 36%). This likely reflects the difference in methodology, as the way the authors measured unacknowledgement in this study was more conservative. By measuring over the length of time between alert generations it does not generate the false positives or negatives that come from looking at unacknowledged results at fixed intervals. Risk factors for results being unacknowledged included the ordering physician being a trainee (OR = 5.58, 95% CI=2.86-10.89) and the alert going out to multiple providers (OR = 2.02, 95% CI = 1.22-3.36).³¹

The impact of the alerts on patient care was assessed by examining the records for appropriate clinical follow-up within four weeks of the alert. Ninety-two alerts (7.7%) lacked timely follow-up. Alerts going out to multiple providers was also associated with lack of timely follow-up (OR, 1.99; 95% CI, 1.06-3.48), and additional verbal communication used by the radiologist was associated with better rates of timely follow-

up (OR, 0.12; 95% CI, 0.04-0.38). While there was an association between verbal communication and appropriate clinical action, the authors did not control for the types of results that would be more likely to necessitate such communication. Verbal communication may have been more frequent in studies or findings to which clinicians would give more attention. The authors were able to demonstrate, however, that despite an automated computer system in place for results management, several radiologic findings continued to lack appropriate follow-up.

Management of Misplaced Endotracheal Tubes

In the previously discussed studies, the authors studied the effectiveness of tools to promote radiologist-clinician communication by looking at the volume of alerts generated, clinician satisfaction, and the rate of appropriate follow-up after the finding of a potential malignancy. The limitation of studying the volume of alerts as well as clinician satisfaction is that these metrics do not necessarily translate to improved clinical outcomes. Measuring appropriate follow-up in the context of imaging findings suggestive of malignancy is clinically more meaningful; however, it measures responses over the period of weeks and does not effectively describe how more urgent results are received.

The assessment of misplaced endotracheal tubes offers a compelling model to study the impact of radiology result reporting on a time-critical process. Abnormal findings are clearly defined, require a narrow range of actions, and can be followed in subsequent radiographs.³²⁻³⁴

This model is also clinically feasible, as the incidence of endotracheal tube misplacement is relatively common and is associated with significant clinical complications. In a prospective study of 354 intubation events, Zwillich et. al examined eighteen separate complications of assisted ventilation and associated them with patient survival. Right mainstem intubation occurred in 34 patients (9.6%) and was one of three complications associated with decreased patient survival (endotracheal tube malfunction and alveolar ventilation were the other two). Furthermore, mainstem bronchus intubation was associated with a significant increase in atelectasis, tension pneumothorax and hyperventilation.³⁵ Kollef et. al retrospectively assessed the rate of endotracheal tube misplacement for all intubated patients at their hospital over one year.³⁶ Twenty-two patients (7.9%) had at least one episode of endotracheal tube misplacement documented in the charts or radiology reports. Five of these patients (23%) had serious complications: anoxic encephalopathy, atelectasis and respiratory failure, gastric aspiration, pneumothorax, and hypoxemia. Notably, three of the five patients who had complications from misplacement had misplacements that did not occur at the time of initial intubation.

Specific Aims and Hypotheses

Hypotheses

1. In cases of endotracheal tube misplacement, an explicit recommendation to move the endotracheal tube in the radiology report increases the rate of timely correction.

2. In cases of endotracheal tube misplacement, direct communication between radiologist and clinician - either through verbal contact or through an automated critical results reporting system - increases the rate of timely correction.
3. Intensive care units that hold daily morning rounds with chest radiologists have higher rates of timely endotracheal tube correction.
4. Patients who have timely endotracheal tube correction may differ from patients who do not based on location of intubation, location of ICU stay, and demographics.
5. Patients who have timely endotracheal tube correction may have improved clinical outcomes.

Specific Aims

1. To identify endotracheal tube misplacements occurring at Yale New Haven Hospital from 11/2008-6/2009 by examining report texts and verifying with manual measurement of x-ray images.
2. To describe rates of endotracheal tube correction by examining follow-up chest x-rays images.
3. To correlate rates of endotracheal tube correction with patient characteristics and communication practices.

Materials and Methods

Critical Radiology Results Reporting System

Yale University's Department of Diagnostic Radiology introduced a system in October 2008 for managing critical radiology result communication. This system,

Veriphy[®] (Nuance, Burlington, MA; previously Vocada, Dallas, TX), is tightly integrated into the PowerScribe[®] (Nuance, Burlington, MA) voice recognition system used at our institution for report dictation. When a radiologist wishes to notify the referring clinician of a critical finding, the result can be dictated directly within the PowerScribe[®] interface. The appropriate clinician is then paged through the Veriphy[®] system with a phone number and a secure code tied to the result. Dialing the number and code will allow the clinician to hear the dictated result and will close the notification process.

Veriphy[®] is designed to allow triaging of radiology results based on their severity. When dictating a result, the radiologist also tags the result as red, orange, or yellow from most to least severe. Each level of severity is associated with a time period in which the clinician should receive notification of the result. If notification is not confirmed within the appropriate time period, the system recontacts the clinician and notifies the Veriphy[®] administrator who can take appropriate action to ensure that the result gets to a member of the clinical team.

Data Collection

Imaging report data for all chest x-rays from 11/1/2008-6/6/2009 was retrieved from Yale New Haven Hospital's IDX[®] database (GE Healthcare, Fairfield CT). The data included all non-image data associated with each chest x-ray: patient demographic information, report timing and location, ordering and interpreting physician information, and full report text. The data were retrieved in Microsoft Excel[®] (Microsoft, Redmond, WA) format and loaded into Filemaker Pro[®] (Filemaker Inc, Santa Clara, CA) for further

interpretation. Imaging report data for each chest x-ray was stored as an Filemaker Pro® record with fields corresponding to the image-specific data.

To narrow down the database to focus on reports relevant to endotracheal tubes, a Filemaker search was done on the “ReportText” field. Records with any of the following terms in their “ReportText” field were included: “endotracheal”, “tube”, and “ETT”.

Endotracheal Tube Misplacements on Initial Intubation

Screening for endotracheal tube misplacements on initial intubation was done by a manual search of the narrowed imaging report database. In the screening process, reports were included if they 1) showed misplacement of the endotracheal tube and 2) were not preceded by an earlier report demonstrating presence of an endotracheal tube. Misplacement was defined according to the standards put forward by Goodman et. al³⁷ and Kollef et. al.³⁶ Goodman set properly placed tubes at between 3-7 centimeters from the carina or overlaying T3 or T4 while Kollef et. al defined the upper level of the tube as being “at or above the upper level of the clavicles”.

The decision to only include the first instance of misplacement was made to avoid clustering errors in subsequent statistical analyses which could come from analyzing multiple misplacements from the same patient (J. Dzuira, personal communication).

In preparation for the screen, reports were first sorted by MRN and then by date. A display window was set up in Filemaker Pro® to blind the observer to all information except for MRN, accession number, date, and report text. Reports were sequentially analyzed by MRN and those that fulfilled the above criteria for endotracheal tube misplacement and timing were flagged for further consideration.

Chart Review of Endotracheal Tube Misplacements on Initial Intubation

The review of patient charts was done at Yale New Haven Medical Records under the supervision of S. Roberts. Data collected from the medical charts included: location of intubation, location of ICU stay, date and time of intubation, and date and time of extubation. Records were excluded at this point if the length of intubation was less than 24 hours.

ICU length of stay and mortality were calculated by examining admission and discharge data kept in paper records at each ICU. Mortality was coded if the patient passed away during his or her current ICU stay. For the surgical ICU, similar data are kept electronically, and were obtained from a database maintained in the Department of Surgery (C. Norway).

Subsequent Endotracheal Tube Misplacement in the ICU

Endotracheal tube misplacement that occurred later in the ICU was examined as well. To avoid clustering effects, only the first misplacement was considered. Patients who were included in the group who had endotracheal misplacement on initial intubation were therefore not eligible for inclusion in this group.

The screening process was similar to that used to determine endotracheal tube misplacement on initial intubation. A more extensive search was done to narrow down the Filemaker Pro[®] database containing the imaging-related data from all chest x-rays done between 11/1/2008 and 6/6/2009. Records were included if they contained the following terms in "ReportText": "endotracheal", "tube", or "ETT". These records were

further narrowed by a search of the field “LocationCode” for the ICUs at Yale New Haven Hospital: “51”, “51A”, “3CT”, “3CTA”, “54M”, “NICU”, “TICU”, “SICU”.

A manual search was done for reports that conveyed misplacement of an endotracheal tube according to the standards set out above. For reports where there was misplacement, all previous chest x-ray reports were examined to ensure that it was the first occurrence of misplacement. Two additional criteria needed to be fulfilled as well: the previous chest x-ray report and image needed to demonstrate normal position of the tube and there needed to be a chest-x ray done more than 24 hours following that showed an endotracheal tube in place.

Measurement of Endotracheal Tube Position

Endotracheal tube position was determined by manual inspection of all chest x-ray images. From the database of imaging data, accession numbers were obtained for both the initial chest x-ray and for the follow-up chest x-ray. The follow up chest x-ray was defined as the latest chest x-ray done up to 30 hours following the initial chest x-ray. Any patients with no follow-up x-rays were excluded from the study at this point.

Accession numbers corresponding to the chest x-ray reports were randomized and loaded into a separate Filemaker Pro® database. A display window was set up in filemaker to enter in distance between the endotracheal tube and the carina while being blinded to other patient and report information.

Before measurements were made, the senior medical student (P. Butler) was trained by an attending chest radiologist (A. Rubinowitz) to identify endotracheal tube and carina position on 25 randomly chosen chest x-rays. All chest x-rays were scored for

length from carina by the medical student; questionable x-rays were read by the attending radiologist as well. After all reports were scored, 25 random chest x-rays were re-read by the attending radiologist for quality control. Patients with normal endotracheal tube position - 3-7 cm above the carina³⁷ - as measured in the initial chest x-ray were excluded from the study at this point.

Outcomes

A patient was classified as having correction of a misplaced endotracheal tube when the endotracheal tube was found to be within 3-7 centimeters of the carina on the follow-up x-ray. Otherwise, the patient was classified as having non-correction of the tube.

Radiologist-Clinician Communication

Evidence of radiologist-clinician communication was determined from two sources. First, the report text was examined for documentation of verbal communication or Veriphy[®] use. Second, all patients without documentation of radiologist-clinician communication in the report text were manually queried in the Veriphy[®] database to see if use of the system occurred (P. Butler and J. Luther, Yale New Haven Hospital). If the report text suggested that the communication may have involved another finding, the recorded Veriphy[®] alert was listened to for confirmation.

Statistical Analysis

Continuous variables were tested for difference using a Welch two-sample t-test. Univariate analysis of risk factors was tested using a two-tailed Fischer Exact tests. Statistical analysis was carried out using the R[®] statistical package (Vienna, Austria).

Division of Work

All data collection, analysis, and statistics were carried out by P. Butler. The imaging data was downloaded from the main hospital database by D. Tabor. All relevant charts were retrieved by S. Roberts. A. Rubinowitz was involved in training P. Butler in identifying the endotracheal tube and carina on chest x-rays. Statistical guidance was provided by J. Dzuira. M. Siegel and H. Forman provided input at all stages of study design and execution.

Human Investigative Committee Approval

Approval from the Human Investigative Committee was obtained for the duration of the study (HIC # 0902004755).

Results

Endotracheal Tube Misplacement on Initial Intubation

21,277 radiology reports were screened, which led to 324 charts being reviewed to identify patients with misplaced endotracheal tubes on initial intubation. Of these patients, 119 satisfied the criteria for inclusion. Sixty nine patients (58.0%) were found to have appropriately placed endotracheal tubes on follow-up chest x-ray within 30 hours.

Characteristics and Outcomes of Patients with Endotracheal Tube Misplacement on Initial Intubation

Patients who had correction of their endotracheal tubes within 30 hours were compared to those who did not have correction (Table 1). There was no statistical difference with respect to demographics: age, gender, height, and weight were within statistical limits. Those who had correction of their endotracheal tubes also did not differ

with respect to the clinical outcomes measured: ICU length of stay [13.0+/-14.3 days for correction vs. 15.0+/-16.0 days for non-correction, $t=-0.68$, $p=0.50$] or days of mechanical ventilation [7.51+/-11.80 days for correction vs. 7.30+/-7.03 days for non-correction, $t=0.11$, $p=0.91$]. Additionally, the location of intubation was not associated with rates of endotracheal tube correction (Table 2).

Subsequent Endotracheal Tube Misplacement in the ICU

13,029 radiology reports were screened from a narrowed database. 256 patients were flagged for further study and 105 patients met the criteria for inclusion. Of the 105 patients with endotracheal tubes misplaced during the ICU stay, 59 of these patients (56.2%) were found to have a correctly placed tube within 30 hours.

Adjustment rates were not found to differ between patients who had endotracheal tube misplacement on initial intubation and those who had misplacement subsequently in the ICU (58.0% vs. 56.2% OR=1.07, 95% CI=0.63-1.82, $p=0.79$). No difference in correction rates was found between the two groups at varying levels of misplacement severity (Table 4).

Association of Communication Practices with Endotracheal Tube Correction

Of the report characteristics and communication practices that were assessed, none were found to be associated with endotracheal tube correction. Statistical significance was not reached for the following metrics in either population of endotracheal tube misplacement: explicit recommendation for movement within the report text [OR=1.86 95% CI=0.83-4.17, $p=0.15$ for initial misplacement, OR=1.56, 95% CI=0.54-4.53, $p=0.58$ for subsequent misplacement], additional communication between

radiologist and clinician [OR=1.36, 95% CI=0.65-2.86, p=0.45 for initial misplacement, OR=1.36, 95% CI=0.63-2.94, p=0.55 for subsequent misplacement], and hospitalization in an ICU that participates in daily ICU rounding [OR=1.63, 95% CI =0.78-3.14, p=0.26 for initial misplacement, OR=1.41, 95% CI = 0.65-3.05, p=0.43 for subsequent misplacement]. (Tables 3 and 5)

Validation of Medical Student Measurements

Twenty-five chest x-ray images with measurements were reviewed by the attending chest radiologist for validation. Twenty-four of the images were found to have consistent measurements; one image required an adjustment of 1.2 cm.

Discussion

In this study we detail the rate of timely correction following endotracheal tube misplacement at an academic medical center. Radiographic evidence of endotracheal tube correction within 30 hours was found in 58.0% of patients who had misplacement on initial intubation and in 56.2% of patients who had misplacement later in the ICU.

The rate of endotracheal tube correction in this study is lower than the rate of clinical response to radiographic and lab findings found in previous papers. In a study of VA patients with elevated PSA values, 84.4% received a clinician response within 180 days.²⁵ In 395 patients with radiographic evidence of malignancy, 360 (91.1%) had appropriate clinical follow up over two weeks. The lower rate observed for endotracheal tube correction likely reflects the additional time constraint that our model imposed: clinical action was required within 30 hours of the finding, rather than over the course of weeks or months.

We also examined the association between communication practices and correction rates. Specifically, we focused on whether report clarity (through explicit recommendations) and direct radiologist-clinician communication (through documented communication or hospitalization in an ICU unit that participates in daily radiology rounds) were associated with increased rates correction. These factors were not found to be associated with increased rates of timely endotracheal correction.

The lack of association between radiologist-clinician communication and endotracheal tube correction is consistent with findings in previous studies on the clinical impact of radiology communication. At a Houston VA, 1196 radiology reports with radiologist-generated computer alerts were tracked for appropriate clinical follow-up. The computer alerts could be assessed for whether they were acknowledged by the clinician or not, which was used as a marker for clinician-radiologist communication. The authors found no statistically significant difference in the rate of appropriate follow-up in acknowledged (7.3%) and unacknowledged (9.7%) results.³¹

Despite the lack of association between communication and outcomes in our study, there are additional benefits to using Veriphy[®] for critical results reporting. Shortly after the implementation of Veriphy[®] at Yale, a survey was given to housestaff and hospitalists to assess their experiences with Veriphy[®] (Butler et. al, unpublished data). The results showed that clinicians felt that they were more aware of critical results in a timely manner (42% more aware vs. 4.8% less aware) and felt that they were more timely in responding to critical results (39% more timely vs. 7.3% less timely). Despite spending more time on dealing with radiology reports after Veriphy[®] (48% more time vs.

15% less time), clinicians felt that Veriphy® was an improvement over not having an automated system for critical results (41% preferred Veriphy® vs. 29% preferred previous system).

Additionally, using Veriphy® may provide the Department of Diagnostic Radiology with additional gains in productivity. After shifting to a non-radiologist provider for critical results reporting, a private practice group reported saving more than 1,000 radiologist hours annually.²⁹ Based on the current size of their group,³⁸ the time savings amounted to almost 25 hours per radiologist per year. While we did not examine the use of Veriphy® for all critical results reporting, Veriphy® accounted for a large amount of the critical results communication for misplaced endotracheal tubes. For instance, of the 64 misplaced endotracheal tubes in the ICU that led to additional radiologist-clinician communication, 58 (91%) involved the use of Veriphy®.

The notification of clinicians through an automated system does introduce potential sources of error. Perhaps the most serious is the possibility that the incorrect physician is contacted about a critical result. With the Veriphy® system, this type of error would lead to the communication loop inappropriately being closed, as a returned page would register the message as received. In the survey of housestaff and hospitalists, 56.1% felt being contacted about other clinicians' patients was "very much" or "somewhat" of a problem.

Berlin details a case in which a radiology result was communicated to wrong provider, leading to a missed diagnosis and a subsequent lawsuit. Preceding a routine urologic procedure, a chest x-ray showed a "possible small tumor in the right mid-lung

field, suspicious for carcinoma". A clerical error in the hospital led to the report being sent to the wrong physician, who dismissed the report. Twenty-one months later, the patient presented with a cough and a follow-up chest x-ray revealed that the tumor had markedly increased in size. Eight months later, the patient passed away. A suit was brought against the radiologist, the urologist and the hospital, alleging that they had failed to properly communicate the findings. The suit was settled before trial for \$3.25 million dollars.³⁹

Limitations

The use of a defined carina-endotracheal tube distance to quantify misplacement is a limitation of this study. Endotracheal tubes were determined to be misplaced if they were outside of 3-7 cm above the carina and were not determined to be corrected unless they were found in that range on follow-up. Clinicians may have adjusted some endotracheal tubes that were still registered as misplaced: for instance on review of the data, there was one endotracheal tube that was moved from 11.9 cm above the carina to 7.02 cm above the carina. The clinical team had likely received the radiology result and had acted on it; however the tube remained marginally misplaced and was considered a non-correction. The position of the endotracheal tube can also vary by patient position, which may lead to variability in the measurements of the endotracheal tubes. In a study of 20 intubated patients, flexion and extension of the neck led to an average movement of 1.9 cm while lateral head rotation led to an average movement of 0.7 cm.⁴⁰ As we did not take into account patient position when documenting endotracheal tube position, there was likely some unaccounted variability in the carina-endotracheal tube measurements.

The method of data collection also likely underestimated the true number of endotracheal tube misplacements. Patients were identified in a screening process based on review of radiology report text. A more thorough review that focused on chest x-ray images would have likely yielded more documented misplacements. In a separate paper, endotracheal tube misplacements were identified first through a retrospective chart review that relied on clinical notes and radiology reports, and subsequently through prospective manual inspection of images. While both the retrospective chart review and prospective image review were done over the same time period, the image review identified almost twice as many endotracheal tube misplacements as the chart review.³⁶

Delays to radiologic interpretation could also be a confounding factor in this study. Radiographic reports that were not timely would likely be associated with low rates of endotracheal tube correction regardless of other factors. Two systems are in place at this hospital to mitigate this possibility. First, the Department of Diagnostic Radiology at Yale recently implemented a system of having in-house 24 hour attending coverage. All ICU films generated in off-peak hours are read by an in-house attending overnight, who is able to initiate appropriate contact with clinical teams. Second, report dictations are handled through a voice-recognition system, which eliminates delays caused by transcription. Experiences from the Department of Radiology in Mayo Clinic showed that after switching from transcription to voice recognition, report turn around times fell from two hours to one minute and these reports were available to all clinicians within two minutes.⁴¹

While the sample size in this study was large, a more extensive study may have been able to detect differences that did not reach statistical significance here. Data collection was primarily limited by the need to manually inspect a large number of report texts: 21,277 for misplacement on initial intubation and 13,029 for subsequent misplacement in the ICU. The use of narrative reports precluded a focused narrowing of reports, as the language to convey the presence of a misplaced endotracheal tube can vary widely. Additional tools that use natural language processing (NLP) or rule-based queries to determine report intent be have been able to automate some of the processes⁴², allowing for a larger data set to be analyzed in a reasonable time frame.

Future Directions

The assessment of the timely correction of endotracheal tubes could be used to further study the impact of the introduction of Veriphy[®] on radiology results management. By comparing the rates of endotracheal correction before and after the introduction of Veriphy[®], it may be possible to assess how Veriphy[®] changed communication practices and whether the introduction of Veriphy[®] was associated with higher rates of endotracheal tube correction.

The rates of timely endotracheal tube correction on initial intubation (58.0%) and subsequently in the ICU (56.2%) suggest that endotracheal tube management could be a target for quality improvement initiatives. Kollef et. al detail such an initiative that followed a sentinel case in which a misplaced endotracheal tube was missed.³⁶ A retrospective review was conducted of all endotracheal tube misplacements at their hospital in the past year. Of 278 patients requiring intubation, 21 patients (7.9%) had at

least one endotracheal tube misplacement. Serious complications were associated with misplacement in five patients (23%). Over the next year, they targeted endotracheal tube misplacements by having a physician make twice-daily rounds through the ICU with the purpose of assessing endotracheal tube position in all intubated patients. Misplaced endotracheal tubes were followed up by the physician to ensure that timely corrections were made. Of the 246 patients who underwent endotracheal intubation in the following year, none were found to have complications associated with misplacement.

The VA in Ann Arbor Michigan also instituted a rigorous system for critical oncologic results following a communication failure where a potential cancer was missed. A 58-year old who presented for a surgical resection of his toe had a routine pre-operative x-ray showing pulmonary nodules. The radiologist recommended further follow-up with CT and conveyed this message to the resident on call. The resident documented the follow-up plan in his note, but did not forward the note to the attending physician. When the patient was readmitted to the hospital five months later, a chest x-ray was done which confirmed the earlier finding. Further work-up revealed that the nodules were likely benign, but it precipitated a quality improvement process to identify root causes and ways to improve the reporting system at the hospital.⁴³ In their root cause analysis, they found that all ACR guidelines had been accounted for: an unexpected and significant result had been found and was reported to the clinical team in charge of the patient's care. It was only afterwards that communication broke down: the resident received the result and documented it in his note, but appropriate follow-up was not initiated.

In a collaboration with the oncology and radiology departments, the VA hospital instituted a system where significant unexpected findings were both communicated to the appropriate clinician and coded electronically. A nurse practitioner was then assigned to follow up all coded findings to confirm that the appropriate clinical action had been taken. In their analysis, 395 imaging cases were given coded. In 35 of those cases (8.9%), no clinical follow up was documented after 2 weeks. In 8 of these cases, the clinician was unaware of the radiologic finding: 5 of these patients went on to have confirmed malignancy. The nurse practitioner was able to identify these patients and ensure that appropriate follow-up was conducted. Through implementing an electronic system for critical result communication and additionally having a care-provider follow up all critical results, the authors were able to show clinical benefit to thorough, rule-based tracking of radiology results.⁴⁴

Our study suggests that a similar quality improvement may be feasible at Yale New Haven Hospital. A non-physician healthcare provider could be trained to manually measure endotracheal tube position on chest x-ray images, much like was done by the senior medical student in this study. The high rate of interobserver agreement between the senior medical student and the attending chest radiologist (96%) suggests that accuracy could be high after a brief period of training. By having a staff member account for endotracheal tube position in a systematic way, correction rates of endotracheal tubes may improve.

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Tables and Figures

Table 1. *Characteristics of Patients with Endotracheal Tube Misplacement on Initial Intubation*

	Corrected (n=69)	Uncorrected (n=50)	p value
Age	62.6+/-18.1	59.4+/-22.2	0.40
Gender	39.1% Male	36.0% Male	0.85
Height	65.0+/-5.10	66.3+/-4.59	0.35
Weight	77.0+/-24.9	81.1+/-22.0	0.39
Days of Mechanical Ventilation	7.51+-11.80	7.30+/-7.03	0.91
Length of ICU Stay	13.0+/-14.3	15.0+/-16.0	0.50
Mortality	16(23.1%)	9 (18.0%)	0.65

Table 2. *Location of Intubation for Patients with Endotracheal Tube Misplacement on Initial Intubation*

Location of Intubation	Corrected (n=69)	Uncorrected (n=50)	p value
Floor	18 (26%)	13 (26%)	1.00
Intensive Care Unit	17 (25%)	11 (22%)	0.83
Emergency Department	19 (28%)	17 (34%)	0.55
Operating Room	77.0+/-24.9	81.1+/-22.0	0.39
OSH/EMS	7.51+-11.80	7.30+/-7.03	0.91
All floors	13.0+/-14.3	15.0+/-16.0	0.50

OSH: Outside Hospital, EMS: Emergency Medical Services

Table 3. Association between Communication Practices and Correction of Endotracheal Tube Misplacement on Initial Intubation

	Corrected (n=69)	Uncorrected (n=50)	p value
Recommendation for Movement in Radiology Report	54 (78%)	33 (66%)	0.15
Radiologist-Clinician Communication	45 (65%)	29 (58%)	0.45
Radiologist-Clinician Communication (Verbal)	20 (29%)	14 (28%)	1.00
Radiologist-Clinician Communication (Veriphy®)	25 (36%)	15 (30%)	0.56
ICU with daily radiology rounds	33 (48%)	18(36%)	0.26

ICU: Intensive Care Unit

Table 4. *Comparison of Correction Rates Between Endotracheal Tubes Misplaced on Initial Intubation and Endotracheal Tubes Misplaced Subsequently in the ICU*

Location of endotracheal tube	Correction rate following misplacement on initial intubation	Correction rate following misplacement subsequently in the ICU	p value
All	58.0% (119)	56.2% (105)	0.79
0-1 cm above the carina	57.1% (35)	55.6% (9)	1.00
1-2 cm above the carina	57.1% (35)	35.3% (17)	0.24
2-3 cm above the carina	65.4% (26)	73.1% (26)	0.76
7 cm or more above the carina	52.1% (23)	52.9% (51)	1.00

ICU: Intensive Care Unit

Table 5. *Association Between Communication Practices and Correction of Endotracheal Tubes Misplaced Subsequently in the ICU*

	Corrected (n = 59)	Uncorrected (n = 46)	p value
Recommendation for Movement in Radiology Report	52 (88%)	38 (83%)	0.58
Radiologist-Clinician Communication	34 (58%)	23 (50%)	0.55
Radiologist-Clinician Communication (Verbal)	2 (3.4%)	2 (4.4%)	0.40
Radiologist-Clinician Communication (Veriphy®)	37 (63%)	21 (46%)	0.11
ICU with daily radiology rounds	28 (48%)	18 (40%)	0.43

ICU: Intensive Care Unit