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The Effect of Teleradiology on Interpretation Times for CT Pulmonary Angiography Studies

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The Effect of Teleradiology on Interpretation Times for CT Pulmonary Angiography Studies

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Abstract

THE EFFECT OF TELERADIOLOGY ON INTERPRETATION TIMES FOR CT PULMONARY ANGIOGRAPHY STUDIES. Scott T.O. Kennedy, Mythreyi Bhargavan, Jonathan H. Sunshine, and Howard P. Forman. Department of Diagnostic Radiology, Yale University School of Medicine, New Haven, CT; Research Department, American College of Radiology, Reston, VA.

The purpose of this study was to evaluate the impact of a teleradiology service on the timely interpretation of computed tomography (CT) pulmonary angiography studies.

A survey of clinical and imaging physicians was performed to develop achievable goals for interpretation of CT pulmonary angiography studies. Percentages of studies given preliminary written reports within these thresholds were compared for 1,102 pulmonary angiography CT studies from three months before teleradiology was implemented to three months after. Identical control data were matched over the same periods for 1,638 CT brain studies. Data are reported as averages and percentages. Statistical significance was evaluated with two-tailed t-tests.

The median of the optimal time for the preliminary written interpretation of a pulmonary angiography CT reported by radiology chairs or their designees was 60 minutes versus 20 minutes for emergency medicine physicians, who also reported a 40-minute limit for an acceptable interpretation time. There were statistically significant improvements in the percentage of these studies interpreted within 60-minute (51 percent to 62 percent) and 20-minute (nine percent to thirteen percent) optimal time thresholds, within the 40-minute acceptable time threshold (34 percent to 43 percent), and in the

percentage of studies taking greater than 40 minutes (67 percent to 57 percent). No statistically significant improvement occurred with control CT brain studies.

The use of teleradiology to interpret off-hours inpatient imaging can improve imaging study interpretation times. By establishing an agreed-upon time standard for preliminary written reports of such exams, radiologists and treating physicians can collaborate to ensure prompt diagnosis and treatment of potentially lethal illnesses, such as pulmonary embolism.

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Introduction

Pulmonary Embolism[1]

Pulmonary embolism (PE) is a dangerous medical condition that can lead to acute right ventricular failure and death within one to two hours without treatment [1, 2]. Although a study by Horlander et al. on the epidemiology of pulmonary embolism from 1979-1998 found that approximately 500,000 patients were diagnosed with pulmonary embolism resulting in approximately 200,000 deaths over this 20-year period [3], the true prevalence of pulmonary embolism is unknown as more than half of all patients with the condition are thought to be undiagnosed.

Pulmonary embolisms are generally classified as either massive or submassive. Massive PE is defined as pulmonary embolism with arterial hypotension and cardiogenic shock [4]. Arterial hypotension consists of systolic blood pressure of less than 90 mm Hg or a decrease in systolic arterial pressure of at least 40 mm Hg from baseline for a minimum of 15 minutes [4]. Shock is characterized by signs and symptoms of hypoperfusion and hypoxia including altered mental status, oliguria, and/or cold, pale extremities [4]. Any pulmonary embolism that does not meet the criteria for arterial hypotension and cardiogenic shock is consequently defined as submassive pulmonary embolism [4]. For example, saddle pulmonary embolisms (i.e. pulmonary embolisms located at the bifurcation of the main pulmonary artery into the right and left pulmonary arteries) are classified as submassive pulmonary embolisms [5]. Indeed, Ryu et al.

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[1] Thompson, BT and Charles A. Hales' "Overview of acute pulmonary embolism," and "Diagnosis of acute pulmonary embolism," published in *UpToDate* Version 16.1, January 2008, were used in both the written organization of this section as well as in finding the relevant citations and studies.

showed in a retrospective study of 546 patients that only two out of 14 patients with a saddle PE had hypotension and thus could be classified as having a massive PE [5].

Pulmonary embolisms generally arise from thrombus formation in the deep veins of the lower extremities, with iliofemoral thrombi the source of most PE that result in signs and symptoms of the illness [6, 7]. While the majority of pulmonary emboli arise from the deep venous system of the lower extremities, they also may develop in the upper extremity venous system and the pelvic and renal veins. Common to these locations is the presence of decreased blood flow that may result from abnormalities such as vein bifurcations.

If a thrombus propagates through the venous system of the lower extremities, it may lodge at the bifurcation of the main pulmonary artery or the smaller lobar branches and cause gas exchange impairment. In addition to the mechanical obstruction of the vascular bed by thrombi causing changes in the ventilation and perfusion ratio, impaired gas exchange is also caused by an inflammatory response to thrombi, resulting in surfactant dysfunction, atelectasis, and intrapulmonary shunting [8]. Indeed, pleuritic chest pain, one of the most common clinical signs of pulmonary embolism, arises from smaller pieces of thrombi propagating further along in the arterial system and initiating an inflammatory response in the parietal pleura.

Hypotension, as seen in massive pulmonary embolism, is caused by thrombi increasing pulmonary vascular resistance both by obstructing the pulmonary vascular bed as well as causing vasoconstriction of blood vessels through hypoxia and the inflammatory response. Increased pulmonary vascular resistance results in diminished cardiac output as the right ventricle’s output and the left ventricle’s preload are decreased. For example, Benotti et al. showed that if there is a 75 percent obstruction of the vascular bed by thrombus, the right ventricle may not be able to generate a systolic blood pressure of greater than 50 mm Hg to preserve pulmonary perfusion and will consequently fail [9]. Luckily, however, while most pulmonary emboli are multiple and occur in the lower lobes of the lungs, only approximately ten percent of these will be massive and cause infarction of the myocardium [10].

The clinical manifestations of pulmonary embolism are similar to those of many other illnesses, thus complicating their use in a differential diagnosis. In the Prospective Investigation of Pulmonary Embolism Diagnosis II (PIOPED II) trial, the most common symptoms of pulmonary embolism were found to be dyspnea at rest or with exertion (73 percent), pleuritic chest pain (44 percent), cough (34 percent), orthopnea (28 percent), calf or thigh pain (44 percent), calf or thigh swelling (41 percent), and wheezing (21 percent) [11]. The most common signs were tachypnea (54 percent), tachycardia (24 percent), rales (18 percent), decreased breath sounds (17 percent), increased pulmonic heart sounds (15 percent), and jugular venous distention (14 percent) [11]. Finally, signs and symptoms of deep venous thrombosis (e.g. tenderness, edema, and erythema of the lower extremities) were also common at 47 percent [11].

For patients presenting with signs and symptoms of pulmonary embolism that actually have the condition, most are also characterized by one or many risk factors for development of venous thrombosis. Such risk factors include: immobilization; surgery within the last three months; stroke, paresis, or paralysis; a history of venous thromboembolism; malignancy; smoking; central venous access within the last three months; a preexisting respiratory disease; chronic heart disease; and travel of greater than four hours duration in the last month [11, 12]. Women have additional risk factors, including obesity, cigarette smoking in excess of 25 cigarettes per day, and hypertension [13]. Pulmonary embolism is also common in patients who have been diagnosed with deep venous thrombosis [10, 14, 15]. Indeed, Girard et al. showed in a study of 350 patients with imaged deep venous thrombosis that 56 percent also had pulmonary embolism diagnosed on nuclear medicine or computed tomography (CT) scan [14]. Finally, there are many patients with pulmonary embolism who do not have any risk factors but have other conditions that may increase their tendency to form thrombi, such as a Factor V Leiden mutation, increased factor VIII in the blood, or an inherited thrombophilia [16, 17]. These patients are further classified as having idiopathic or primary venous thromboembolism.

Given the ambiguous nature of the signs and symptoms of pulmonary embolism, accurate diagnostic imaging tests have become essential. The importance of accurate diagnosis is highlighted by the fact that PE can have a mortality rate as high as 30 percent without treatment, whereas proper diagnosis and subsequent treatment with anticoagulants decreases the mortality rate to between two and eight percent [3, 10, 18-21]. While the gold standard test for diagnosing an acute pulmonary embolism has been invasive pulmonary angiography, alternative imaging modalities including chest radiography, lower extremity ultrasound, ventilation/perfusion (V/Q) scanning, magnetic resonance angiography (MRA), echocardiography, and spiral computed tomography (CT).

Chest radiographs are generally first-line imaging obtained on patients with suspected pulmonary embolisms. They are of limited utility, however, due to their lack of specificity for the condition. Indeed, one prospective study conducted by Stein et al. noted atelectasis and pulmonary parenchymal abnormalities in 69 percent and 58 percent of patients with and without pulmonary embolism, respectively, as well as pleural effusion in 47 percent and 39 percent of patients with and without pulmonary embolism, respectively [22, 23]. As only 12 percent of the chest x-rays in patients with pulmonary embolism in this study were found to be normal, however, obtaining a chest film is still considered a standard of care [22, 23], as an abnormal chest radiograph will generally cause the clinician to request further diagnostic imaging to determine a cause of the patient's signs and symptoms.

Lower extremity ultrasound is often performed early in the diagnostic process to detect thrombus in the lower extremity venous system and begin anticoagulation treatment without further testing, thus saving the patient from further cost and side effects that he or she may encounter with alternative methods of imaging. While low rates of false positive and false negative results have been reported in some studies [24], other studies have shown that imaging the entire lower extremity venous system including the calf venous system decreases the incidence of false negative deep venous thrombosis [25, 26]. As such, complete lower extremity ultrasound, performed by experienced technicians, has significant utility for patients with suspected pulmonary embolism.

Ventilation/perfusion (V/Q) scanning has been assessed in the Prospective Investigation of Pulmonary Embolism Diagnosis trial [12]. With clinical probability being determined by the treating clinician before scanning, it was found that patients with a high clinical probability and high probability V/Q scan had a 95 percent likelihood of having PE, patients with a low clinical probability and a low probability V/Q scan had a 4 percent likelihood of having PE, and any patient with a normal V/Q scan was theoretically without PE [12]. The same study, however, showed that 72 percent of patients had a combination of clinical and lung scan probability that was insufficient to confirm or exclude pulmonary embolism, thus necessitating the use of other imaging modalities for diagnosis [12].

Magnetic resonance angiography (MRA) has moderate sensitivity for detecting pulmonary embolism, as one study by Oudkerk et al. of 118 patients with suspected PE found that MRA was positive in 77 percent of these patients [27]. Due to the fact that MRA can be limited by motion artifact, poor resolution, and magnetic effects from the air-containing lung, however, MRA is seldom used at the present time for detecting pulmonary embolism [28]. The added cost and time necessary for magnetic resonance studies also makes alternative imaging methods, such as spiral CT, preferable.

Echocardiography is also of limited utility in patients with suspected pulmonary embolism. Echocardiographic findings that may indicate pulmonary embolism, including increased right ventricular size, decreased right ventricular function, and tricuspid regurgitation, are present in only 30 to 40 percent of these patients [29-31].

Finally, computed tomography (CT) pulmonary angiography using intravenous contrast, often known as spiral CT or CT-PA, has increasingly replaced the gold standard invasive pulmonary angiogram as well as the aforementioned imaging modalities as the test of choice in the acute care setting [32-34]. Benefits cited by many studies for the use of pulmonary angiography CT over other diagnostic modalities include its ability to examine the entire pulmonary system for abnormalities that may be causing the patient's symptoms [35-37], as well as its safety, speed, and high sensitivity and specificity.

Indeed, in the Prospective Investigation of Pulmonary Embolism Diagnosis II (PIOPED II) trial with 824 patients, sensitivity and specificity for pulmonary angiography CT were found to be 83 percent and 96 percent, respectively, with 90 percent sensitivity and 95 percent specificity with the addition of venous-phase imaging [38]. As such, given the limitations of other imaging modalities (e.g. chest radiography, lower extremity ultrasound, ventilation/perfusion (V/Q) scanning, magnetic resonance angiography (MRA), and echocardiography), pulmonary angiography CT has become the most important imaging modality in patients with suspected pulmonary embolism.

In this study, we have chosen to use pulmonary embolism to represent an important, time-sensitive disease process that would benefit from attempts to improve the speed of diagnosis given the ambiguous nature of its signs and symptoms as well as the potential for death without proper treatment. Moreover, we use pulmonary angiography CT as our means of diagnosing pulmonary embolism for this study due to the many benefits previously listed that have made it the preferred imaging study at most medical centers.

Teleradiology and Process Improvement

The transfer of radiological images electronically to distant locations throughout the world, otherwise known as teleradiology, has become widespread and even essential to the practice of radiology [39]. Indeed, teleradiology was used by approximately two thirds of radiology practices in the United States in 2003 where, at the same time, almost four fifths of United States radiologists were employed by practices that used teleradiology for the interpretation of imaging [40]. Perhaps the best example of the use of telemedicine in the United States [40], teleradiology has accounted for an increased ability for treating clinicians to receive interpretations of time-sensitive imaging studies at all hours of the night. Indeed, at institutions such as Yale-New Haven Hospital, clinicians are able to obtain final interpretations on certain studies that before would have been interpreted the following morning, such as inpatient chest radiographs and extremity plain films. Some diagnostic radiologists have welcomed the introduction of teleradiology, as outsourcing the interpretation of off-hours imaging not only has eliminated the need for many radiologists to take overnight call [41], but has created an additional demand for radiologists' services. This additional demand has spawned a lucrative private sector of companies offering this service [39], with companies such as NightHawk Radiology Services leading the pack and employing numerous radiologists in its international offices across the globe.

The importance of teleradiology, however, extends beyond the convenience it affords radiologists through improved call schedules [41] and clinicians in their ability to obtain interpretations on studies often left until morning. Given the need for quick and accurate diagnoses for many illnesses, such as pulmonary embolism, especially in the context of a heightened focus on physician performance and quality improvements in recent years [42], many hospitals have increasingly looked to teleradiology services to assist in providing off-hour radiological interpretations for both emergent (e.g. CT pulmonary angiography) and non-emergent (e.g. pre-operative inpatient chest x-ray) imaging. In this regard, teleradiology has in many ways become one of the best examples of a process improvement in the medical field, as it has created benefits for diagnostic radiologists, treating clinicians, hospitals, and most importantly, patients, who now are able to receive appropriate care with the concrete knowledge of imaging results at all hours of the day. As the field of radiology lends itself well to the study of process improvement given the inherent nature of the work (i.e. the time necessary to perform an imaging study as well as interpret the findings are easily quantifiable processes), it has been the subject of numerous studies looking at how to classify the relevant processes [43] as well as how to maintain quality in the field [44, 45].

In our own institution's attempt at improving processes involved with the practice of radiology and thus ensuring quality for clinician and patient alike, we have experimented with an in-house hybrid or internal off-hours teleradiology service model [46], which uses attending staff radiologists at an off-site but local location to provide written interpretation of any inpatient imaging study performed between 6 PM - 12 PM on weekdays and 2 PM – 7 PM on weekends (40 hours per week). Before implementation of this service in October 2006, all inpatient imaging studies were given final written interpretations by the off-hours, in-house attending radiologist (with the assistance of the on-call resident) who simultaneously interpreted emergency department studies. As the early evening hours are often the most hectic for radiologists, due to both increased end-of-day volume and decreased end-of-day staffing, these limited teleradiology hours were a priority for trial of the service. Therefore, we studied how the use of teleradiology during certain high-volume, high-demand hours represents a significant process improvement for radiologists, treating clinicians, and patients.

In summary, by analyzing whether teleradiology increased the efficiency of written interpretations for time-sensitive pulmonary angiography CT studies to prevent possible death from pulmonary embolism, we sought to prove the hypothesis that teleradiology is indeed a valuable process improvement for the field of diagnostic radiology.

Statement of Purpose

In this study, we analyzed interpretation times for pulmonary angiography CT studies to ascertain whether the implementation of a teleradiology service actually accomplished a process improvement. If it did, a similar change might be valuable in other medical institutions. We first undertook a survey of clinicians and radiologists to determine target benchmarks for interpretation times for pulmonary angiography CT studies. We then assessed the impact of a hybrid model of image interpretation on achieving these various benchmarks and sought to draw conclusions on the benefits of such a model. More specifically, we aimed to show that the implementation of a hybrid teleradiology service could improve the percentage of time-critical CT pulmonary angiography studies given preliminary written reports within these clinical benchmarks obtained by survey of the relevant physicians.

Methods

Time Standards

To obtain information on radiologists' perceptions of interpretation time benchmarks, a survey (Appendix A) was emailed to 75 radiology administrators of academic radiology departments who belonged to the national organization of the Association of Administrators of Academic Radiology Departments (AAARAD), a parallel organization to the Society of Chairman of Academic Radiology Departments (SCARD). By contacting chairs via their clinical administrators, we surveyed whether there were specific departmental standards from the time of CT pulmonary angiography study completion to preliminary written report.

To obtain similar information on treating clinicians' perceptions of these benchmarks, a separate survey (Appendix B) was emailed to all 31 emergency medicine attending physicians at Yale-New Haven Hospital. The survey asked demographic information of the respondents, including gender, years of practice, board certification, and type of practice (i.e. adult, children, or both). In addition, it asked respondents to quantify how much time they thought radiologists spent interpreting and dictating a pulmonary angiography CT. Finally, it asked them for an optimal time and an acceptable/unacceptable time limit for a preliminary written report of the findings by a radiologist.

Importantly, our survey made the clear distinction between the concept of "reporting," which generally signifies a "wet" or verbal interpretation of an imaging study given to a clinician, and a "report," which in our survey and subsequent analysis below was defined as a preliminary or final *written* interpretation of the findings by a radiologist.

The Effects of Teleradiology

The subjects for this retrospective study were all patients who underwent CT pulmonary angiographies or CT studies of the brain without contrast at Yale-New Haven Hospital in a three-month period before full-scale teleradiology implementation in October 2006 (May 2006 to July 2006) and a three-month period after full-scale teleradiology implementation (January 2007 to March 2007). We did not use the month of teleradiology implementation or the two months before and after implementation in order to avoid possible confusion from transitional effects. Exemption from requiring consent from each participant was granted by the Human Investigation Committee at Yale University School of Medicine. These studies were accessed using the Synapse Picture Archive and Communication System (PACS) program (Fujifilm; Minato, Tokyo, Japan).

For each of the 1,102 pulmonary angiography CT scans and 1,638 CT scans of the brain without contrast completed and interpreted during these two intervals, three times were recorded from the Synapse PACS: the time of exam completion, the time of preliminary written (i.e. not “wet” or verbal) interpretation, and the time of final written (i.e. not “wet” or verbal) interpretation. From these times, an exam completion to preliminary written interpretation time and an exam completion to final written interpretation time were calculated. The number of studies completed per day was also recorded. All data were entered into an Excel spreadsheet by one author, SK. To ensure the accuracy of the data manually transcribed from Synapse PACS, a different data system, Imagecast (previously IDX Systems Corporation, now General Electric; Fairfield, Connecticut), was used to generate a computer report of corresponding completion, preliminary written interpretation, and final written interpretation times, as well as the times for exam completion to preliminary and final written interpretations, for both types of studies.

We calculated the absolute number and percentage of both the experimental (CT pulmonary angiography) and control (CT brain without contrast) studies that were interpreted within the optimal, acceptable, and unacceptable time standards suggested by our surveys. We concentrated our analysis on the number and percent of studies meeting these time thresholds because, having been suggested by physicians, these metrics are much more clinically important than a measure of central tendency (e.g. mean or median). Moreover, outliers minimally skew these clinical metrics compared to the mean.

Whereas CT pulmonary angiographies have a uniform urgency in importance, CT scans of the brain are very heterogeneous in terms of urgency, ranging from post-operative neurosurgery patients, which merit very speedy interpretations--perhaps within fifteen minutes--to patients with much less severe symptoms, for whom twelve hours might be an acceptable time until interpretation. Hence, we analyze improvements (or lack thereof) across these two time thresholds for our control study. Importantly, the teleradiology service was not applied to this segment of our practice, making it useful as a control for our analysis.

In general, depending on the type of data, we report averages and percentages**.** Statistical significance was evaluated with two-tailed t-tests.

Results

Time Standards

There were 28 responses from chairs of academic radiology departments or their designees out of 75 total requests for a 37.3 percent response rate (Table 1). Twelve of the 28 (42.9 percent) stated that there was an established standard for the time between CT pulmonary angiography study completion and time of preliminary written report at their academic institution. The median of this standard was 60 minutes (Table 1).

Twenty-three of 31 (74.2 percent) emergency medicine attending physicians at Yale-New Haven Hospital responded to our survey (Table 1). Fourteen of the 23 (60.9 percent) were male; nine of the 23 (39.1 percent) were female. The respondents had practiced for a median of 6.0 years as attending physicians in the emergency medicine setting. Twenty-two of the 23 (95.7 percent) were board-certified in emergency medicine; the remaining physician's certification was pending. Fourteen of the 23 (60.9 percent) practiced on both adults and children, compared to eight of the 23 (34.8 percent) and one of the 23 (4.3 percent) who limited their practice solely to adults or children, respectively. The median of our respondents' estimates of the time it took radiologists to interpret a pulmonary angiography CT was seven minutes; the median estimate of the time it took radiologists to transcribe the study was three minutes. When queried as to an optimal time between the completion of a pulmonary angiography CT study and a written report of the findings, the median of their responses was 20 minutes (Table 1). We also surveyed attending physicians regarding at what time point they would make a disposition and/or management decision based solely on clinical grounds if the preliminary written interpretation of a pulmonary angiography CT scan were not available. The median response was 40 minutes (Table 1). Consequently, we established 40 minutes as the cutoff for an acceptable time of preliminary written interpretation for CT pulmonary angiographies.

Table 1. Time Standards for Preliminary Written Interpretations of Pulmonary Angiography CT Studies as Stated by Chairs of Academic Radiology Departments (or Their Designees) and Emergency Department Attending Physicians.

Group	Response Rate	Median Optimal Time (Minutes)	Median Acceptable Time (Minutes)	Median Unacceptable Time (Minutes)
Chairs of Academic Radiology Departments (or Their Designees)	37.3% (28/75)	60	N/A	N/A
Emergency Department Attending Physicians	74.2% (23/31)	20	40	> 40

The Effect of Teleradiology on Meeting Optimal Time Standards

485 inpatient and Emergency Department pulmonary angiography CT scans were completed at Yale-New Haven Hospital in the studied three-month period before

teleradiology was implemented compared to 617 similar studies in the three-month period after teleradiology was implemented, for a total sample size of 1,102 (Table 2).

Table 2. CT Pulmonary Angiographies Completed Three Months Before and Three Months After Teleradiology Implementation.

Time Period	N (# Studies Completed)	Mean (# Studies/Day)	Standard Deviation (# Studies/Day
Three Months Before Teleradiology Implementation (May 2006 – July 2006)	485	5.27	2.37
Three Months After Teleradiology Implementation (January 2007 – March 2007)	617	6.86	2.63
Total	1,102		

Using as a standard the median optimal time of 60 minutes determined from our survey of chairs of academic radiology departments or their designees, we found that 62 percent (382 out of 617) of CT pulmonary angiographies were given a preliminary written interpretation within 60 minutes in the three-month period after teleradiology had been implemented (Table 3). This was a statistically significant improvement ($p < 0.01$) compared to the three-month period before teleradiology was implemented, when 51 percent (246 out of 485) of CT pulmonary angiographies were given a preliminary written interpretation within 60 minutes of completion (Table 3). Our results using the alternative data from Imagecast were similar.

Table 3. Percentage of CT Pulmonary Angiography Interpretations Completed in 60 Minute Optimal Time Standard Suggested by Chairs of Academic Departments of Radiology or Their Designees.

Time Period	N (# Studies Completed In 60 Minutes)	% Completed In 60 Minutes	Standard Error (%)	P-Value
Three Months Before Teleradiology Implementation (May 2006 – July 2006)	246	51% (246/485)	2%	N/A
Three Months After Teleradiology Implementation (January 2007 – March 2007)	382	62% (382/617)	2%	0.000

Using as the standard the median optimal time of 20 minutes determined from our survey of emergency medicine attending physicians, we found that thirteen percent (82 out of 617) of CT pulmonary angiographies were given a preliminary written interpretation within 20 minutes in the three-month period after teleradiology had been implemented (Table 4). This was also a statistically significant improvement ($p < 0.05$) compared to the three-month period before teleradiology was implemented, when nine percent (42 out of 485) of CT pulmonary angiographies were given a preliminary written interpretation within 20 minutes of completion (Table 4). Our results using the alternative data from Imagecast were similar.

Table 4. Percentage of CT Pulmonary Angiography Interpretations Completed in 20 Minute Optimal Time Standard Suggested by Emergency Department Attending Physicians.

Time Period	N (# Studies Completed In 20 Minutes)	% Completed In 20 Minutes	Standard Error (%)	P-Value
Three Months Before Teleradiology Implementation (May 2006 – July 2006)	42	9% (42/485)	1%	N/A
Three Months After Teleradiology Implementation (January 2007 – March 2007)	82	13% (82/617)	1%	0.016

The Effect of Teleradiology on Meeting an Acceptable Time Standard

Using the median acceptable time standard of 40 minutes determined from our survey of emergency medicine attending physicians, we found that 43 percent (267 out of 617) of CT pulmonary angiographies were given a preliminary written interpretation within 40 minutes in the three-month period after teleradiology had been implemented

(Table 5). This was a statistically significant improvement ($p < 0.01$) compared to the three-month period before teleradiology was implemented, when 34 percent (163 out of 485) of CT pulmonary angiographies were given a preliminary written interpretation within 40 minutes of completion (Table 5). Our results using the alternative data from Imagecast were similar.

Table 5. Percentage of CT Pulmonary Angiography Interpretations Completed in 40 Minute Acceptable Time Standard Suggested by Emergency Department Attending Physicians.

Time Period	N (# Studies Completed In 40 Minutes)	% Completed In 40 Minutes	Standard Error (%)	P-Value
Three Months Before Teleradiology Implementation (May 2006 – July 2006)	163	34% (163/485)	2%	N/A
Three Months After Teleradiology Implementation (January 2007 – March 2007)	267	43% (267/617)	2%	0.001

The Effect of Teleradiology on Interpretations Taking an Unacceptable Amount of Time

Using an interpretation time of greater than 40 minutes as unacceptable per our survey of emergency medicine attending physicians, we found that 57 percent (350 out of

617) of CT pulmonary angiographies were not given a preliminary written interpretation within this acceptable amount of time in the three-month period after teleradiology had been implemented (Table 6). This is exactly the mirror image of the less than or equal to 40 minutes acceptability standard and thus also was a statistically significant improvement ($p < 0.01$) compared to the three-month period before teleradiology was implemented, when 67 percent (323 out of 485) of CT pulmonary angiographies were not given a preliminary written interpretation within 40 minutes of completion (Table 6). Our results using the alternative data from Imagecast were similar.

Table 6. Percentage of CT Pulmonary Angiography Interpretations Completed in Over 40 Minutes--An Unacceptable Amount of Time--as Suggested by Emergency Department Attending Physicians.

Time Period	**N (# Studies Completed In Over 40 Minutes)**	**% Completed In Over 40 Minutes**	**Standard Error (%)**	**P-Value**
Three Months Before Teleradiology Implementation (May 2006 – July 2006)	323	67% (323/485)	2%	N/A
Three Months After Teleradiology Implementation (January	350	57% (350/617)	2%	0.001

2007 – March 2007)				

The Effect of Teleradiology on a Control: CT Scans of the Brain

954 CT scans of the brain without contrast were completed at Yale-New Haven Hospital in the studied three-month period before teleradiology was implemented compared to 684 in the three-month period after teleradiology was implemented, for a total sample size of 1,638 (Table 7).

Table 7. CT Scans of The Brain Without Contrast Completed Three Months Before and Three Months After Teleradiology Implementation.

Time Period	**N (# Studies Completed)**	**Mean (# Studies/Day)**	**Standard Deviation (# Studies/Day**
Three Months Before Teleradiology Implementation (May 2006 – July 2006)	954	33.10	6.82
Three Months After Teleradiology Implementation (January 2007 – March 2007)	684	37.29	7.11
Total	1,638		

Using a threshold of fifteen minutes, such as might be necessary for a post-operative neurosurgery brain CT, we found that seven percent (46 out of 684) of these studies were given a preliminary written interpretation within fifteen minutes in the three-month period after teleradiology had been implemented. This was compared to six percent (58 out of 954) in the three-month period before teleradiology was implemented. This difference was not statistically significant.

Using a longer interval for brain CT interpretation of twelve hours, as might be used for patients who had less severe symptoms, we found that 70 percent (479 out of 684) of interpretations were completed with twelve hours in the three-month period after teleradiology was implemented compared to 68 percent (644 out of 954) before. This difference, again, was not statistically significant.

Discussion

Time Standards

Our survey results provided us with subjective estimates of optimal, acceptable, and unacceptable time thresholds for the preliminary written interpretation of a common and important imaging study, the pulmonary angiography CT for acute PE. Moreover, it highlighted how different such an estimate can be depending on the source (i.e. a radiologist or an emergency medicine physician). We were not at all surprised that the median optimal time for interpreting a pulmonary angiography CT suggested by emergency medicine physicians, who order the study, was different from and less than that estimated by radiologists, who must interpret the study. We were surprised, however, that there was a three-fold difference. This suggests radiologists and clinicians should have more interaction with each other to arrive at a more uniform understanding of what is desirable from the patient care standpoint and what is feasible from the radiology department process standpoint.

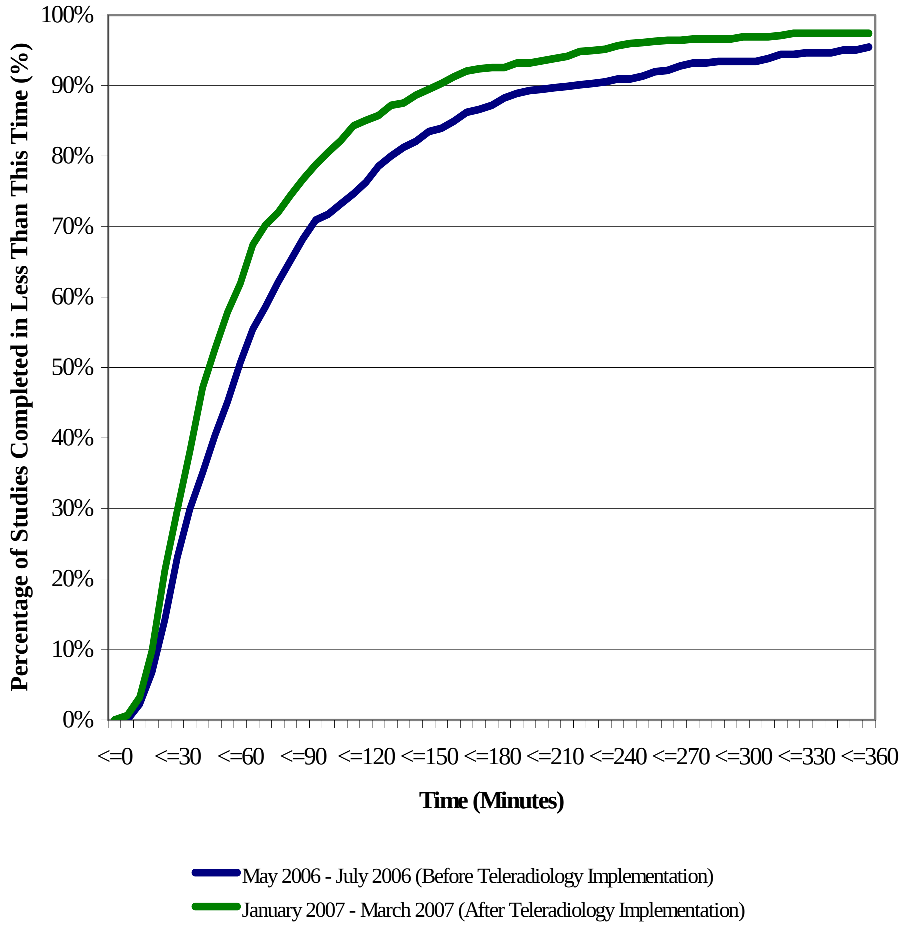
In this general context, it is interesting that, given the importance of a quick and accurate diagnosis in the patient suspicious for PE, less than half of the respondents representing academic departments of diagnostic radiology stated that they actually had standards for interpretation time. Given that our sample of emergency medicine physicians determined 40 minutes to be a cutoff time when the written report of a CT pulmonary angiography would have clinical value (and thus has been interpreted in an acceptable amount of time), departments without such standards might consider this a suitable standard to adopt at their institution.

The Effects of Teleradiology

Our results support our original hypothesis that with the implementation of a teleradiology service at Yale-New Haven Hospital in October 2006, there would be an overall improvement in interpretation times for CT pulmonary angiographies. More specifically, we found that even with a teleradiology service operating only 40 high-priority hours a week, the improvements in the percentages of studies meeting clinical targets for time suggested by both radiologists and emergency medicine physicians were statistically significant (Fig. 1).

Admittedly, the improvements were not as substantial as one would hope. The small size of the improvements was probably partly because the teleradiology service only covered 40 hours per week (six hours per weekday and five hours per weekend day) out of a possible 168 hours or 23.8 percent of the time. In addition, the process improvement occurred from an already-improved interpretation time base established with the introduction of a department time standard and heightened staff awareness over the time-sensitivity of PE studies. Despite the relatively small improvements, however, our results do suggest that the addition of a teleradiology service can have a statistically significant impact on meeting certain quality standards. In the case of PE, where death can occur within one to two hours without treatment [1, 2], even a marginal improvement can have a profound effect on survival.

Fig. 1-Percentage of Studies Interpreted Before and After Teleradiology Implementation.



More generally, it must be emphasized that improvements in turnaround time are both locally and nationally important. Obviously, suspected PE is not the only acute and life-threatening condition in which speed can significantly improve health outcomes. Indeed, studies have demonstrated the morbidity and mortality benefits to improvement in door-to-balloon times for acute myocardial infarctions (MI) [47-49]. Moreover, even for non-urgent cases, speedy interpretation can allow definitive treatment to commence sooner, reducing the time the patient spends with discomfort and in impaired condition. It can also reduce unnecessary hospital days, thereby reducing expense.

This process improvement study illustrates the point that a novel staffing model (i.e. teleradiology) can improve patient care in an era of distributive imaging. As was later corroborated by our survey of emergency department attending physicians, the radiology department at our institution felt it was not adequately meeting the needs of treating clinicians with respect to certain types of imaging studies. By evaluating the impact of this novel staffing pattern on one such study, the pulmonary angiography CT, we were able to show that a rather modest solution (i.e. the addition of 40 hours of teleradiology per week) had a significant effect. Indeed, the teleradiology service has been retained and slightly expanded since the time of our study to now include 45 hours per week, reflecting perhaps both an increased demand for the inpatient interpretation service as well as a welcome addition to the emergency department radiologists who are freed from inpatient imaging to focus on more urgent emergency department studies.

The results of this study are also an example of the benefits telemedicine can offer in an era that demands rapid communication between primary clinicians and their subspecialist counterparts when physical proximity may not be possible. Another example of such a benefit of telemedicine is in acute stroke, where primary care physicians now can communicate with neurologists at different medical centers through video conferencing of neurological exams [50]. The short window of opportunity for treatment with intravenous thrombolytics in the case of acute stroke has made such a service valuable.

Finally, we must recognize as physicians that in order to improve the quality of healthcare through process improvements such as the implementation of a teleradiology service, there must be a breakdown of departmental isolation and a willingness to innovate. Indeed, results from studies in the case of acute MI show that hospitals can achieve process and quality improvement, such as improvements in door-to-balloon time, through interdisciplinary collaboration and an organization's willingness to change [48]. Cooperation between radiologists and treating clinicians should be facilitated at the institutional as well as departmental level to optimize patient care.

Limitations

An important limitation of this study is the limited response rate, 38 percent, for chairs of academic radiology departments or their designees. This was much lower than the response rate for emergency department attending physicians (74.2 percent). It is possible that this could indicate that chairs of academic radiology departments were less concerned than their emergency department attending physician counterparts about speed of interpretation in cases of suspected PE. Alternatively, it could indicate that radiology department chairs from outside our institution had less inclination and/or time to respond to our survey than did rank-and-file emergency department attending physicians from within our institution. As the absolute number of responses between the two groups (28 for the former and 23 for the latter) were similar, however, we still believe the comparison to be useful.

While the implementation of a teleradiology service increased the percentage of preliminary written interpretations meeting certain clinical targets, in principle, such enhancements could be due to a uniform, general improvement in turnaround time. We tested and rejected this possibility by using turnaround time for brain CT studies as a control. In addition, the findings could be at least partly due to the particular groups of attending radiologists, fellows, and residents that were interpreting the relevant examinations during the studied periods. Indeed, at academic hospitals, such as the location of this study, there is significant staff turnaround, especially given the fact that fellows work many off-hours shifts and their fellowships last often only a single year. Finally, it is quite difficult to ascertain the exact effect of any one process in the complicated web of hospital operations. It is impossible to control every variable in a study such as ours, given the need to diagnose and treat patients according to the established (i.e. non-experimental) standards of care. As a result, our findings are inherently debatable.

Additionally, our study made a clear distinction between a written preliminary or final report and the notion of a “wet” or verbal “read” that is often communicated to physicians. The dictation of a positive or negative finding on a pulmonary angiography CT into the form of a written report generally, assuming the emergency department clinician is eagerly awaiting the result and thus available by phone, takes longer than a “wet” or verbal “read” of “positive for PE” or “negative for PE.” Our results, therefore, might be more reliable had we used the time to “wet read” rather than time to written report as our variable. The fact that the times to preliminary and final written report can be logged using Synapse PACS and Imagecast, however, made this a preferable method. Indeed, in the world of quality and process improvement, where numerous changes should be made and the search for improvement should be continuous, it is better to have a decent and easy-to-obtain metric than an ideal metric that can only be garnered (if at all) with a large investment of staff time.

Conclusions

The use of a teleradiology service to interpret off-hours inpatient imaging can improve imaging study interpretation times. By establishing an agreed-upon time standard for preliminary written reports of such exams, radiologists and emergency medicine physicians can collaborate to ensure prompt diagnosis and treatment of potentially lethal illnesses, such as pulmonary embolism.

Appendix A. Survey of Chairs of Academic Radiology Departments or Their Designees.

Purpose of Study

Thank you for your participation in this survey. As part of a study on the effects of the implementation of a teleradiology service on interpretation times for certain diagnostic imaging modalities, we are seeking information on radiologists' attitudes toward interpretation times for pulmonary angiography CT scans (CT scans designed to diagnose or exclude pulmonary embolus). The survey has been tested and takes less than one minute to complete on average. Your response is greatly appreciated.

1.) Do you have a standard for the time between CT pulmonary angiography study completion and preliminary written dictation?

Yes: _____

No: _____

2.) If yes, what is that standard?

30 Minutes: _____

60 Minutes: _____

90 Minutes: _____

120 Minutes: _____

Other (Please Specify): ____

3.) Please share any additional information that is relevant to this survey inquiry.

____

Appendix B. Survey of Emergency Department Attending Physicians.

Purpose of Study

Thank you for your participation in this survey. As part of a study on the effects of the implementation of a teleradiology service on interpretation times for certain diagnostic imaging modalities, we are seeking information on Emergency Department attending physicians' (or their equivalents') attitudes toward interpretation times for pulmonary angiography CT scans (CT scans designed to diagnose or exclude pulmonary embolus). The survey has been tested and only takes 2-3 minutes to complete on average. Your response is greatly appreciated.

Demographic Information

1.) Are you a clinically active Emergency Department attending physician or the equivalent? If not, please stop here.

Yes: _____

No: _____

2.) If yes, do you practice on adults, children, or both?

Adults: _____

Children: _____

Both: _____

3.) How many years have you been practicing as an Emergency Department attending physician or the equivalent?

Please round to the nearest positive whole number: _____

4.) What is(are) your board certification(s)? (Please choose all that apply.)

Emergency Medicine: _____

General Surgery: _____

Internal Medicine: _____

Pediatrics: _____

Other (please specify): ____

5.) How do you identify yourself?

Male: _____

Female: _____

Time Estimates

For the following questions, please keep in mind that answers of “0” are not useful to this study because of their unrealistic nature. What the study is examining is how much time Emergency Department attending physicians or their equivalents allow for the following categories. Your answers to questions 6 and 7 below are important to us as far as they are included in the subsequent time estimates in questions 8 and 9, so please include these estimates in your final answers to questions 8 and 9.

6.) How much time do you assume a radiologist spends interpreting a pulmonary angiography CT (a CT designed to diagnose or exclude pulmonary embolus)?

Please enter your answer in MINUTES: _____

7.) How much time do you assume a radiologist spends dictating or transcribing a pulmonary angiography CT (a CT designed to diagnose or exclude pulmonary embolus)?

Please enter your answer in MINUTES: _____

8.) What do you consider to be a target/optimal time between the completion of a pulmonary angiography CT (a CT designed to diagnose or exclude pulmonary embolus) and a written report of the findings by the radiologist?

Please enter your answer in MINUTES: _____

9.) At what point would you need to make a disposition and/or management decision solely based on clinical grounds if the interpretation of a pulmonary angiography CT (a CT designed to diagnose or exclude pulmonary embolus) were not provided?

Please enter your answer in MINUTES: _____

End of Survey

Thank you for your time and thoughtful input.

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