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ORIGINAL REPORT

Characteristics and Predictors of Missed Opportunities in Lung Cancer Diagnosis: An Electronic Health Record–Based Study

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ABSTRACT

Purpose
Understanding delays in cancer diagnosis requires detailed information about timely recognition and follow-up of signs and symptoms. This information has been difficult to ascertain from paper-based records. We used an integrated electronic health record (EHR) to identify characteristics and predictors of missed opportunities for earlier diagnosis of lung cancer.

Methods
Using a retrospective cohort design, we evaluated 587 patients of primary lung cancer at two tertiary care facilities. Two physicians independently reviewed each case, and disagreements were resolved by consensus. Type I missed opportunities were defined as failure to recognize predefined clinical clues (ie, no documented follow-up) within 7 days. Type II missed opportunities were defined as failure to complete a requested follow-up action within 30 days.

Results
Reviewers identified missed opportunities in 222 (37.8%) of 587 patients. Median time to diagnosis in cases with and without missed opportunities was 132 days and 19 days, respectively ($P < .001$). Abnormal chest x-ray was the clue most frequently associated with type I missed opportunities (62%). Follow-up on abnormal chest x-ray (odds ratio [OR], 2.07; 95% CI, 1.04 to 4.13) and completion of first needle biopsy (OR, 3.02; 95% CI, 1.76 to 5.18) were associated with type II missed opportunities. Patient adherence contributed to 44% of patients with missed opportunities.

Conclusion
Preventable delays in lung cancer diagnosis arose mostly from failure to recognize documented abnormal imaging results and failure to complete key diagnostic procedures in a timely manner. Potential solutions include EHR-based strategies to improve recognition of abnormal imaging and track patients with suspected cancers.

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INTRODUCTION

Missed and delayed cancer diagnoses are associated with substantial disability and costs[1-10] and are a frequent cause for ambulatory malpractice claims.[11] Lung cancer is both common and lethal and has a particularly poor prognosis if not diagnosed early.[12,13] Although efforts to promote earlier diagnosis and treatment of lung cancer have not yet demonstrated improved survival outcomes, research is underway to evaluate the benefits of screening in high-risk patients.[14]

Early diagnosis hinges on timely recognition and action on clinical clues.[15-18] Although patient care-seeking delays are well documented,[19-23] treatment delays may also be related to the diagnostic process following the patient's first presentation with signs and symptoms.[9,12,16,18,21,22,24-27] Prolonged waiting times after the initial presentation are less well understood, but some contributing factors have been documented.[16,18,28-30] For instance, busy frontline providers might miss early signs and symptoms of lung cancer. Scheduling delays for diagnostic tests, poor communication of abnormal results, or test misinterpretation may also impede the diagnostic work-up. Finally, patients may not adhere to scheduled appointments or procedures after the initial work-up, or they may seek care in a different health system where their test results are not available. Therefore, missed opportunities for early diagnosis of lung cancer can occur due to failure to recognize potential diagnostic clues or failure to complete the diagnostic work-up in a timely manner.

Previous literature offers limited information on the nature of missed opportunities for earlier lung cancer diagnosis. Many studies have relied on information extracted from paper-based medical records, which may be difficult to evaluate for evidence of breakdowns in communication and care coordination.[10,12,18,22,24,26,31-33] Integrated electronic health records (EHRs), on the other hand, can provide ready access to progress notes, documentation of abnormal findings, and exchanges of information (eg, test results, referrals, and so on) among front-line primary care providers, consultants, and other diagnostic specialists.[34] We hypothesized that using an EHR would provide new insights into the origin and prevention of diagnostic delays in lung cancer. Our objective was to evaluate characteristics and predictors of missed opportunities for earlier diagnosis of lung cancer in a health care system with an advanced integrated EHR.

METHODS

Setting

We used a retrospective cohort design to identify and evaluate all pathologically confirmed, newly diagnosed cases of primary lung cancer at two geographically dispersed Veterans Affairs (VA) medical centers. Our sample consisted of patients diagnosed between July 2005 and June 2007 at Site A and between July 2004 and June 2007 at Site B (a longer time period at the latter site allowed for more patients). Both sites are tertiary care referral centers with on-site multispecialty ambulatory care clinics and community-based satellite clinics that provide care to urban and rural populations. All patients are assigned a primary care provider, and most patients obtain their longitudinal care within these systems from academic and nonacademic providers and resident trainees. The study was approved by the local institutional review boards.

Table 1. Summary of Data Collection Instrument

Data Category	Description of Item(s)	Example
Patient characteristics	Age, race/ethnicity, sex, medical and psychological comorbidities, smoking	77-year-old white male with coronary artery disease
Type of clue (symptom or sign that should prompt further work-up)	Presence of at least one of the following: Blood in sputum/hemoptysis Hoarseness that lasts > 2 weeks Recurrent bronchitis or pneumonia Abnormal (ie, suggestive of possible neoplastic disorder) chest x-ray Abnormal chest CT Abnormal abdomen CT Serial abnormal imaging Abnormal sputum examination/sputum cytology Unexplained effusion Clubbing New onset Cushing's symptoms/syndrome New onset of hypercalcemia symptoms/syndrome New onset of syndrome of inappropriate antidiuretic hormone Superior vena cava obstruction Worsening persistent cough/bronchitis or new description of chronic cough lasting > 8 weeks Provider acknowledged unexplained weight loss or other unexplained weight loss > 10 lbs in addition to respiratory symptoms Chest pain or rib pain New onset/worsening pain in non-chest location	Abnormal chest x-ray showing nodule
Date clue first appeared on medical record review		June 5, 2005
Date next step was requested (ordered)		September 9, 2005
Date next step was completed		September 15, 2005
Presence of type 1 or type 2 missed opportunity?	Type 1: No evaluation (or work-up) for lung cancer was initiated within 7 days of appearance of a predefined clinical clue	Yes: Type 1
	Type 2: Failure to complete within 30 days a diagnostic procedure or consultation or the follow-up action requested in response to a predefined clue	No follow-up CT scan ordered to evaluate nodule by June 13, 2005
Contributory factors	Provider, system, and/or patient	Provider
Type of personnel involved	Codes for personnel adapted from Gandhi et al[11]	Staff physician
Setting of care	Codes for settings adapted from Gandhi et al[11]	Primary care
Date of lung cancer diagnosis by pathology		September 20, 2005

Abbreviation: CT, computed tomography.

Data Collection Procedures

We performed a detailed review of progress notes, consultations, laboratory and radiology reports, discharge summaries, and additional relevant data in the EHR to evaluate the diagnostic processes for missed opportunities. Two trained physician raters independently reviewed each case using a standardized data collection instrument adapted from our previous work in colorectal cancer diagnosis (Table 1).[35] Reviewers evaluated all relevant EHR data (in most patients as far back as 5 years) for the presence of predefined clinical clues that warrant a diagnostic work-up for lung cancer. Clues were derived from current literature[19,36-39] followed by team consensus (Table 1). To ensure reliable and consistent data collection, the study team supervised and trained the reviewers during pilot testing, and all discordant judgments of missed opportunities were discussed to obtain consensus. Data on patient outcomes (harm, stage of diagnosis) were not collected to reduce hindsight bias.[40]

After review of the EHR, we excluded patients who had a recurrence of lung cancer within the previous 5 years. Also excluded were patients whose pathologic diagnoses were made outside the VA setting, provided that they had not presented to the VA earlier with any potentially diagnostic clues for lung cancer.

No timeliness standards for diagnosis currently exist in the United States. However, the British Thoracic Society recommends that patients with suspected lung cancer should undergo an initial evaluation within 1 week of primary care referral and should receive diagnostic tests within 2 weeks of the decision to perform a biopsy.[41] Through team consensus and additional literature on test result follow-up,[42] we defined two types of missed opportunities that could result in diagnostic delays: (1) type I missed opportunities, defined as episodes of care in which there was failure to recognize a predefined clinical clue (ie, no required action or work-up was initiated within 7 days of clue appearance); appropriate decisions to watch and wait were not considered missed opportunities; and (2) type II missed opportunities, defined as episodes of care in which there was failure to complete within 30 days a diagnostic procedure, consultation, or other requested follow-up action in response to a predefined clue.

We defined the first appearance of a diagnostic clue as the earliest date that the clue could have been recognized by the care providers, regardless of when the patient first started experiencing symptoms. For instance, if a patient had hemoptysis since June 1, 2006, but did not report it to the care provider until December 1, 2006, the first appearance of a diagnostic clue was dated December 1, 2006. We applied rigorous criteria to define missed opportunities that could occur along the diagnostic pathway of lung cancer (Appendix Fig A1, online only). When information in the EHR was vague or inconsistent with expected practices, we used conservative guidelines to avoid overestimating missed opportunities. For example, reviewers were

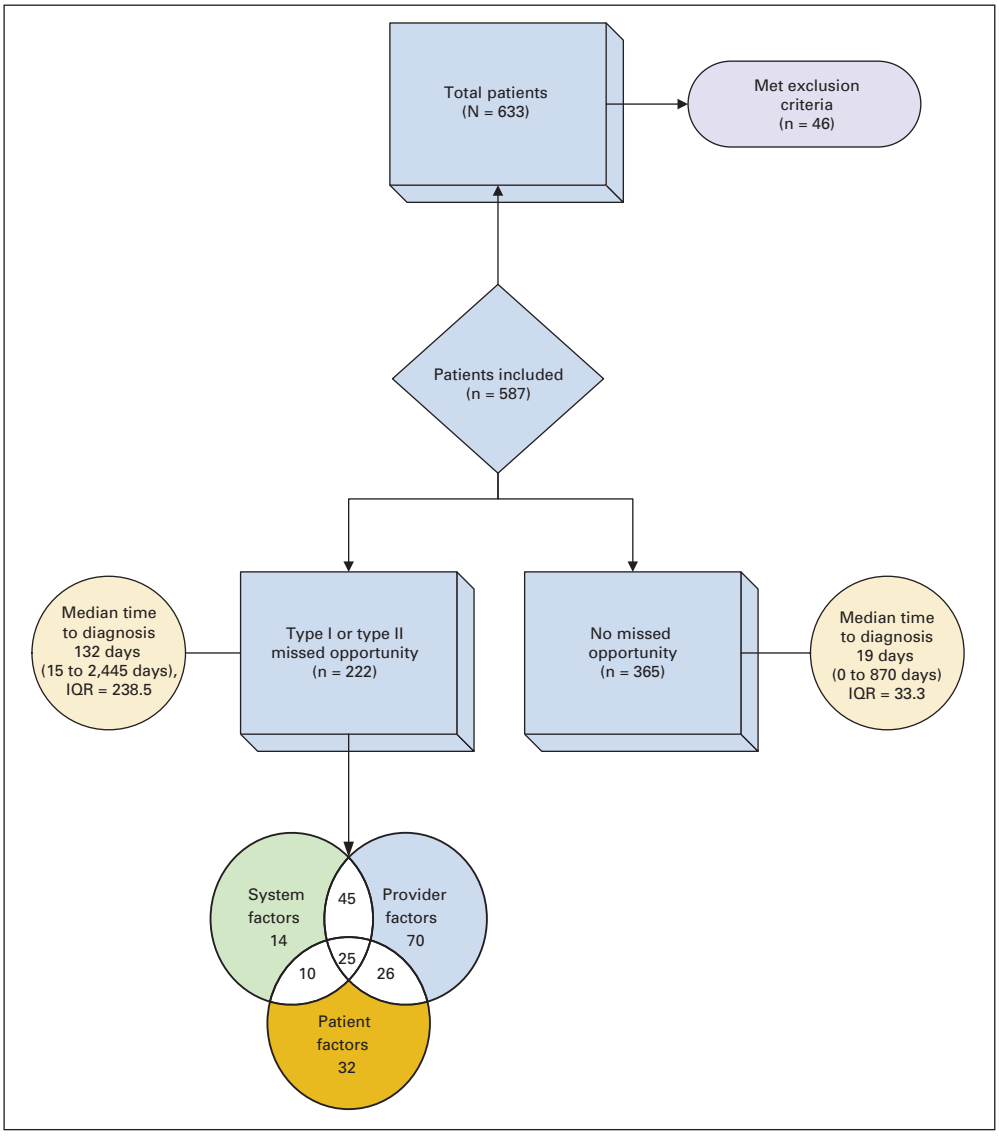

Fig 1. Study flowchart. IQR, interquartile range.

instructed not to record missed opportunities if there was insufficient supporting documentation in the EHR, or when documentation supported an informed decision not to work up a particular clue. No missed opportunity was recorded when delays occurred solely in response to appropriate diagnostic attempts, such as repeated negative bronchoscopies. For each case, we collected information on provider types and specialties, types of diagnostic procedures used, and patient characteristics. We also classified contributing factors in each case into one of three

Table 2. Baseline Characteristics of Patients With and Without Missed Opportunities

Characteristics	Patients With at Least One Missed Opportunity (n = 222)		Patients With No Missed Opportunities (n = 365)		*P*
	No.	%	No.	%	
Age, years*					
Median		67.9		67.8	
< 65	91	40.9	152	41.6	
65-74	66	29.7	107	29.3	
≥ 75	64	28.8	106	29.0	.99
Race*					
White	168	75.7	284	78.8	
Black	42	18.9	59	16.2	
Other	10	4.5	19	5.2	.66
Sex					
Male	221	99.6	360	98.6	
Female	1	0.45	5	1.4	.42
Year of diagnosis*					
2004	5	2.2	15	4.1	
2005	57	25.7	102	28.0	
2006	108	48.6	161	44.1	
2007	50	22.5	84	23.0	.51
Location					
Site A	158	71.2	240	65.8	
Site B	64	28.8	125	34.2	.17
Comorbid medical diseases†					
Congestive heart failure	19	8.6	32	8.8	.93
Coronary artery disease	70	31.5	107	29.3	.57
Hypertension	152	68.5	223	61.1	.07
Diabetes	50	22.5	70	19.2	.33
Chronic obstructive pulmonary disease	99	44.6	121	33.2	.006
Advanced cardiopulmonary disease with life expectancy < 1 year	2	0.9	5	1.4	.72
Severely disabled due to medical problem	13	5.9	19	5.2	.74
Cancer (prior to lung cancer)	58	26.1	76	20.8	.13
HIV	2	0.9	9	2.5	.22
Any of the above	199	89.6	314	86.0	.20
Comorbid psychiatric disorders					
Depression	42	18.9	53	14.5	.16
Anxiety	12	5.4	21	5.8	.86
Dementia	8	3.6	14	3.8	.89
Post-traumatic stress disorder	6	2.7	15	4.1	.37
Schizophrenia	3	1.4	3	0.82	.68
Bipolar disorder	0	0.0	4	1.1	.30
Alcohol dependence	30	13.5	52	14.2	.80
Antisocial personality disorder	3	1.4	0	0.0	.05
Severely disabled due to psychiatric problem	1	0.45	5	1.4	.42
Any of the above	78	35.1	121	33.2	.60
Smoking status‡					
Current smoker	127	57.2	218	59.7	
Prior smoker	88	39.6	130	35.6	
Nonsmoker	7	3.2	17	4.7	.47

*Percentages may not add up to 100% due to missing data.

†Medical record documentation was used to determine comorbid conditions. Advanced cardiopulmonary disease with life expectancy < 1 year determined by documentation of either advanced stage chronic obstructive pulmonary disease (eg, Stage IV), advanced heart failure (eg, Stage IV) or inoperable coronary artery disease combined with the mention of poor prognosis in the medical record.

‡Current smoker, patients who were actively smoking at the time of lung cancer diagnosis; prior smoker, patients who had smoked anytime in the past regardless of quantity and duration; nonsmoker, patients who had never smoked in the past.

categories (Table 1). "System factors" included scheduling delays, policies, and/or procedures that were judged to have contributed to a missed opportunity. "Provider factors" were attributed in situations when providers failed to recognize previously documented clues or did not follow standards of care or standard policies, resulting in a missed opportunity. Finally, we attributed missed opportunities to "patient factors" (eg, when patients did not adhere to medical advice or appointments).

Data Analysis

After evaluating reviewer agreement on the presence of missed opportunities and reaching consensus on discordant judgments, we identified two groups of patients: (1) those determined to have experienced at least one missed opportunity (of either type), and (2) those determined to have no missed opportunities. We compared these groups on demographic and clinical characteristics, location (Site A *v* Site B), and provider types and specialties. We then separately evaluated predictors for type I and type II missed opportunities. First, we compared the frequencies of diagnostic clues present in cases with type I missed opportunities and cases in the no missed opportunities group. We then similarly compared the frequencies of specific follow-up actions documented in cases with type II missed opportunities and cases in the no missed opportunities group. Finally, we calculated the median wait times associated with each type of diagnostic clue or follow-up action in type I and type II cases, respectively. We used Fisher's exact test for categoric variables when the assumptions for the χ^2 test were not met (two-tailed) and the nonparametric Wilcoxon rank sum test to compare median times to pathological diagnosis.

Finally, we fit three multivariable logistic regression models. The first model predicted the presence of any missed opportunity from provider type and specialty. The other models tested whether particular diagnostic clues or actions were associated with increased risk for type I and type II missed opportunities, respectively. Each model was adjusted for baseline patient characteristics that were distributed unequally between cases with and without missed opportunities. Predictors entered into the initial models included variables that were statistically significant at the 0.1 level in univariate analysis. The final models included only significant predictors. We used SAS version 9.2 (SAS Institute, Cary, NC) for all analyses.

RESULTS

Of 633 new patient cases of lung cancer identified over the study period, 587 met inclusion criteria (Fig 1), and 222 (37.8%) were judged to have missed opportunities after consensus agreements. Before consensus, both reviewers independently agreed on the presence of at least one missed opportunity in 184 patients and on the absence of any missed opportunities in 284 patients (overall $\kappa = 0.69$).[43] The median time elapsed from first appearance of a diagnostic clue to final pathologic diagnosis was 132.0 days (range, 15 to 2,445 days) in patients with at least one missed opportunity compared with 19.0 days (range, 0 to 870 days) in patients with no identified missed opportunities ($P < .001$). The outliers in the latter group included patients that required serial imaging and were appropriately followed up. The Venn diagram at the bottom of Fig 1 shows the distribution of provider-related, system-related, and patient-related factors in the 222 patients with at least one missed opportunity.

Type I missed opportunities were judged to occur in 148 (25.2%) of 587 included patients; among these, the median time to pathologic diagnosis was 168 days (range, 15 to 2,445 days; interquartile range, 290 days). Type II missed opportunities occurred in 121 patients (20.6%); in these patients, the median time to pathologic diagnosis was 141.5 days (range, 38 to 2,445 days; interquartile range, 224 days).

We compared baseline characteristics of patients with and without at least one missed opportunity for subsequent inclusion in adjusted predictor models. At the 0.10 level of significance, three comorbidities were more frequent in patients with missed opportunities: hypertension, chronic obstructive pulmonary disease (COPD), and antisocial personality disorder (Table 2). However, only COPD remained statistically significant in subsequent logistic regression models.

Provider characteristics (Table 3) were associated with patients with one or more missed opportunities. In the final adjusted multivariable

Table 3. Characteristics of Providers in Patients With and Without Any Missed Opportunities

Characteristics	Patients With Any Missed Opportunity (n = 222)		Patients With No Missed Opportunities (n = 365)		*P*
	No.	%	No.	%	
Type of provider*					
Staff physician	119	53.6	136	37.3	
Trainee	50	22.5	145	39.7	
Nurse practitioner	14	6.3	18	4.9	
Physician assistant	32	14.4	31	8.5	< .001
Specialty*					
Generalist/primary care	127	57.2	208	57.0	
Oncology	10	4.5	1	0.3	
Pulmonary	37	16.7	31	8.5	
Other medical subspecialty†	7	3.2	1.5	4.1	
Emergency medicine	17	7.7	53	14.5	
Surgery‡	15	6.8	20	5.5	
Other	0	0.0	1	0.3	< .001

NOTE. Adjustment variable, chronic obstructive pulmonary disease, was also significant (odds ratio, 1.56; 95% CI, 1.08 to 2.24).
*Percentages may not add up to 100% due to missing data.
†Other medical subspecialties include cardiology, nephrology, neurology, rheumatology/immunology, gastroenterology, dermatology, endocrinology, infectious disease, and intensive care.
‡Surgery includes general surgery, cardiothoracic surgery, orthopedic surgery, ophthalmology, otolaryngology, vascular surgery, neurosurgery, plastic surgery, and urology.

Table 4. Diagnostic Clues and Associated Median Time to Clue Recognition in Lung Cancer Patients With and Without Missed Opportunities

Clues	Patients With Type I Missed Opportunities (n = 148)					Patients Without Missed Opportunities* (n = 365)		
	Time to Clue Recognition in Type I Patients (days)							
	Median	Range	IQR	No.	%	No.	%	*P*
Blood in sputum/hemoptysis	128.5	98.0-159.0	61.0	2	1.4	33	9.0	.09
Recurrent bronchitis or pneumonia	109.0	22.0-293.0	136.0	5	3.4	7	1.9	.04
Abnormal chest x-ray	89.0	8.0-2,011.0	162.5	92	62.2	280	76.7	< .001
Abnormal chest CT	27.0	8.0-1,126.0	49.0	42	28.4	317	86.8	< .001
Abnormal abdomen CT	10.0	8.0-67.0	59.0	3	2.0	18	4.9	.0026
Hoarseness lasting > 2 weeks	109	109-109	0	1	0.7	10	2.7	.23
Unexplained effusion	51.0	12.0-56.0	44.0	3	2.0	10	2.7	.02
Worsening persistent cough/bronchitis or new description of chronic cough lasting > 8 weeks	51.0	8.0-177.0	138.0	11	7.4	64	17.5	< .001
Unexplained weight loss in addition to respiratory symptoms	49.0	12.0-556.0	455.0	7	4.7	74	2.3	< .001
Chest pain or rib pain	77.0	63.0-117.0	54.0	3	2.0	40	11.0	.01
New onset/worsening pain in non-chest location	35.5	12.0-222.0	37.5	8	5.4	28	7.7	< .001

NOTE. The following clues were not seen in any patients: clubbing, new onset Cushing's disease, or superior vena cava obstruction. The following clues were identified only in the no missed opportunities group: abnormal sputum examination/sputum cytology (3), new onset of hypercalcemia symptoms/syndrome (5), and syndrome of inappropriate [secretion of] antidiuretic hormone (2). Adjustment variable, chronic obstructive pulmonary disease, was significant (odds ratio, 1.83; 95% CI, 1.17 to 2.86).

Abbreviations: IQR, interquartile range; CT, computed tomography.

*All clues were recognized in ≤ 7 days.

model, trainees were less likely to be associated with patients with missed opportunities (odds ratio [OR], 0.41; 95% CI, 0.27 to 0.62; referent, staff physician). Whereas emergency medicine providers were relatively unlikely to be associated with missed opportunities (OR, 0.52; 95% CI, 0.28 to 0.96), oncology and pulmonary specialists were overrepresented in patients with missed opportunities (OR, 18.72; 95% CI, 2.30 to 152.46 and OR, 2.35; 95% CI, 1.36 to 4.08, respectively; referent, primary care). For both oncologists and pulmonologists, type I missed opportunities were more frequent. Patient factors were associated with more than half of missed opportunities associated with pulmonary (20 [54%] of 37), but were associated with only two (2 [20%] of 10) missed opportunities related to oncology. Sample sizes were insufficient to test whether these relationships differed between sites.

Table 4 shows χ^2 comparisons of diagnostic clues in patients with type I missed opportunities and no missed opportunities. Median times to clue recognition for missed clues is also listed. An abnormal chest x-ray was the most frequently missed clue, followed by abnormal chest computed tomography scan, and new or worsening persistent cough > 8 weeks. When we relaxed the criterion for recognition from 7 days to 14 days, the total number of patients with type I missed opportunities decreased from 148 to 127. Only recurrent bronchitis was associated with type I missed opportunities in unadjusted and adjusted logistic regression models (adjusted OR, 3.31; 95% CI, 1.20 to 9.10; referent, no recurrent bronchitis). We further assessed whether nonsmokers experienced longer delays from type I missed opportunities (data not shown). We found that of 19 outlier patients,[44] 11 were smokers, seven were past smokers, and one had never smoked. Smoking history was not associated with outlier status.

Table 5 compares the proportions of requested actions (procedures, consultations, or follow-up actions on clues) in patients with type II missed opportunities and no missed opportunities. For missed opportunities, median times to action completion are also listed. Patient factors were strongly associated with type II missed opportunities: completion of needle biopsies (15 [62.5%] of 24), completion of bronchoscopies (15 [100%] of 15), follow-up of abnormal chest x-rays (28 [38.9%] of 72), pulmonary consults (17 [65.4%] of 26), and follow-up of abnormal chest computed tomography scans (11 [61.1%] of 18). Follow-up of abnormal chest x-ray, completion of first needle biopsy, and follow-up of recurrent bronchitis were significant predictors of type II missed opportunities in the unadjusted logistic regression model. In the adjusted model, which controlled for the presence of COPD, only follow-up action on abnormal chest x-ray (OR, 2.07; 95% CI, 1.04 to 4.13; referent, no abnormal chest x-ray) and completion of first needle biopsy (OR, 3.02; 95% CI, 1.76 to 5.18; referent, no needle biopsy) were associated with type II missed opportunities. Appendix Table A1 summarizes logistic regression results for missed opportunities.

DISCUSSION

We used an advanced, integrated EHR to discover missed opportunities for an earlier lung cancer diagnosis and found evidence of missed opportunities in more than one-third (n = 222) of 587 patients diagnosed at two institutions. Missed opportunities led to significant delays in diagnosis. More than half of missed opportunities arose from failures to recognize diagnostic clues (in most patients, abnormal imaging results) already present in the EHR. Other missed opportunities resulted from failures to complete key diagnostic procedures or investigations in a timely manner; patient factors often contributed in these cases.

Previous studies of delayed lung cancer diagnosis have relied on interview and questionnaire data[20-22,27,45] or reviews of paper-based medical records.[12,21,27,46] However, recall bias and the large potential for missing information in paper-based records limit the utility of

Table 5. Requested Actions and Associated Median Time to Completion in Patients With and Without Missed Opportunities

Requested Follow-Up Actions, Procedures, or Consultations	Patients With Type II Missed Opportunities (n = 121)					Patients Without Missed Opportunities* (n = 365)		
	Time to Completion of Procedure or Consultation or Follow-Up Action Based on the Clue in Type II Patients (days)							
	Median	Range	IQR	No.	%	No.	%	*P*
Follow-up on blood in sputum	63.0	46-279	233.0	3	2.5	33	9.0	.01
Follow-up on recurrent bronchitis or pneumonia	1075	1,075.0-1,075.0	0	1	0.8	7	1.9	.30
Follow-up on hoarseness lasting > 2 weeks	58.0	48-68	20.0	2	1.6	10	2.7	.06
Follow-up on abnormal chest x-ray	48.0	32-548	23.0	72	59.5	279	76.4	< .001
Follow-up on abnormal chest CT	42.5	31.0-366.0	59.0	18	14.9	314	86.0	< .001
Follow-up on abnormal abdomen CT	39.0	39.0-39.0	0	1	0.8	18	4.9	.10
Follow-up on worsening bronchitis/cough	117.5	31.0-204.0	173.0	2	1.6	64	17.5	.03
Follow-up on unexplained weight loss	98.5	36.0-1,029.0	504.0	4	3.3	74	20.3	< .001
Follow-up on pain in non-chest location	45.0	40.0-72.0	32.0	3	2.5	28	7.7	.005
Pulmonary consult	50.0	33.0-588.0	26.0	26	21.5	283	77.5	< .001
First bronchoscopic biopsy	85.0	31-387	171.0	13	10.7	240	65.8	< .001
Second bronchoscopic biopsy	53	49.0-57.0	8.0	2	1.6	21	5.8	.12
First needle biopsy	50.0	32-253.0	52.0	24	19.8	72	19.7	< .001
Thoracic surgery consult	55.0	34-386.0	49.0	5	4.1	36	9.9	.02
Open lung biopsy	37.5	33-63.0	16.5	4	3.3	9	2.5	.08

NOTE. The following were not seen in any patients: clubbing, new onset Cushing's disease, or superior vena cava obstruction. The following clues/procedure/consultation were identified only in patients with no missed opportunities: chest pain (40), abnormal sputum examination (3), unexplained effusion (10), new onset of hypercalcemia symptoms/syndrome (5), new onset of syndrome of inappropriate [secretion of] antidiuretic hormone (2), third bronchoscopic biopsy (2), second needle biopsy (2), mediastinoscopy (8), thoracentesis (26), and positron emission tomography scan (15).

Abbreviations: IQR, interquartile range; CT, computed tomograhy.

*All actions were completed in ≤ 30 days.

these methods for studying opportunities to improve diagnostic care. Furthermore, previous work has involved a significant amount of subjective judgment[11,47,48] and yielded little insight about the frequency and origins of delayed cancer diagnoses.[10] Our study overcomes many of these limitations and, to the best of our knowledge, is the largest of its kind.

In the VA system, abnormal imaging results are transmitted to ordering providers through an automated notification system in the EHR.[49] Radiologists transmit the abnormal reports to an inbox where the clinician can access and act on the reports. Reports are always accessible to providers and are marked as abnormal to heighten awareness. However, for several reasons, clinicians may not always act on abnormal imaging results in a timely manner.[50] It is unlikely that this problem is unique to the VA.[13,45,51] Outcomes of imaging notification may actually be better within the VA system because of the integrated nature of its EHR, the presence of a state-of-the-art notification system, and clear policies and procedures for follow-up of diagnostic information.[49,52]

The origins of missed opportunities are multifactorial, and multidisciplinary strategies are needed to improve the timeliness of the diagnostic process. EHR-based strategies to reduce missed opportunities should target communication, recognition of abnormal imaging results, and monitoring of follow-up actions.[49,50] For example, programs in the EHR could identify high-risk patients with abnormal imaging and no evidence of follow-up; the program could then generate a trigger (ie, a signal to alert providers to review the medical record[53]) to a responsible clinician.[54] Second, strategies could be designed to improve recognition of clues that might otherwise stay buried in the wealth of the information available in the EHR. For instance, the documentation of "hemoptysis" or "blood in sputum" in a 60-year-old previous smoker could result in a trigger to initiate or continue the work-up of lung cancer through decision support and text-recognition rules.[55]

Third, patient transition among different settings of care[10] (eg, scheduling and completing procedures) is a high-risk area for preventable breakdowns in communication and coordination. The association of missed opportunities with oncology and pulmonary subspecialties highlights this issue. While trainees were less likely to be associated with missed opportunities, this might be because critical information (such as a test result) transmitted to trainees is also transmitted to their supervising physicians. Nevertheless, current EHR systems may not be able to support the sophisticated degree of tracking providers need to ensure fail-safe follow-up of high-risk patients. While such systems are being designed, the use of lung nodule clinical pathways[56] or other programs for patient navigation[57] appears promising. Additionally, the VA has recently initiated a national lung cancer collaborative program to improve the timeliness of lung cancer care. These approaches could be particularly beneficial for patients who miss appointments or procedures and are at risk of being lost to follow-up.

Our study findings may not be generalizable outside the VA setting. Moreover, our results may not generalize to other, similar investigations, because our model building was not exclusively based on theory and experience but included predictors on the basis of their chance covariation with the outcome. Studies of diagnostic breakdown traditionally suffer from methodologic limitation of low reliability,[58] which we addressed by using two independent reviewers followed by consensus agreements. We may have also missed clues or follow-up actions that were completed but either were not documented in the chart or were documented where the information was

hard to find among hundreds of other notes. However, in our previous work, we found that fewer than 2% of providers failed to document follow-up actions related to abnormal imaging results, so it is unlikely that we significantly overestimated missed opportunities because of lack of documentation.[50] Another limitation is the lack of comparison information from comparable health systems or from systems that use paper-based records. Hindsight bias[40] is of particular concern in studies such as ours, and we tried to minimize it by omitting data collection on outcomes, such as stage at diagnosis and patient harm. Finally, it is not clear whether reducing these delays would improve outcomes.[16] Nevertheless, timeliness is considered one of six aims for improving quality of health care.[59] Specific strengths of our study included a reliable data collection methodology and a rigorous definition of missed opportunities. Most important, an integrated EHR of a closed health system facilitated collection of data relevant to the entire diagnostic process.

In summary, delays in lung cancer diagnosis are not infrequent. Reducing delays will require strategies to address multiple contributing factors. Potential solutions include using the EHR to improve clinician recognition of abnormal imaging results and instituting programs to track patients with suspicious findings.

AUTHORS' DISCLOSURES OF POTENTIAL CONFLICTS OF INTEREST

The author(s) indicated no potential conflicts of interest.

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