Diagnostic Yield of Recommendations for Chest CT Examination Prompted by Outpatient Chest Radiographic Findings¹

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Purpose:

To evaluate the diagnostic yield of recommended chest computed tomography (CT) prompted by abnormalities detected on outpatient chest radiographic images.

Materials and Methods:

This HIPAA-compliant study had institutional review board approval; informed consent was waived. Reports of all outpatient chest radiographic examinations performed at a large academic center during 2008 ($n = 29138$) were queried to identify studies that included a recommendation for a chest CT imaging. The radiology information system was queried for these patients to determine if a chest CT examination was obtained within 1 year of the index radiographic examination that contained the recommendation. For chest CT examinations obtained within 1 year of the index chest radiographic examination and that met inclusion criteria, chest CT images were reviewed to determine if there was an abnormality that corresponded to the chest radiographic finding that prompted the recommendation. All corresponding abnormalities were categorized as clinically relevant or not clinically relevant, based on whether further work-up or treatment was warranted. Groups were compared by using t test and Fisher exact test with a Bonferroni correction applied for multiple comparisons.

Results:

There were 4.5% (1316 of 29138 [95% confidence interval {CI}: 4.3%, 4.8%]) of outpatient chest radiographic examinations that contained a recommendation for chest CT examination, and increasing patient age ($P < .001$) and positive smoking history ($P = .001$) were associated with increased likelihood of a recommendation for chest CT examination. Of patients within this subset who met inclusion criteria, 65.4% (691 of 1057 [95% CI: 62.4%, 68.2%]) underwent a chest CT examination within the year after the index chest radiographic examination. Clinically relevant corresponding abnormalities were present on chest CT images in 41.4% (286 of 691 [95% CI: 37.7%, 45.2%]) of cases, nonclinically relevant corresponding abnormalities in 20.6% (142 of 691 [95% CI: 17.6%, 23.8%]) of cases, and no corresponding abnormalities in 38.1% (263 of 691 [95% CI: 34.4%, 41.8%]) of cases. Newly diagnosed, biopsy-proven malignancies were detected in 8.1% (56 of 691 [95% CI: 6.2%, 10.4%]) of cases.

Conclusion:

A radiologist recommendation for chest CT to evaluate an abnormal finding on an outpatient chest radiographic examination has a high yield of clinically relevant findings.

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Rates of recommendations for additional imaging (RAIs) have increased by as much as 200% since 1995 (1). Critics implicated RAIs as a cause for increase in use of imaging and the associated costs, although the data to support this are mixed (2–4). Recommendation rates and costs in isolation are insufficient indicators of clinical value of RAIs. Value is more accurately defined by balancing clinical benefit and costs (5). Thus, a ratio of the clinical effect of RAIs to their incremental costs is a more appropriate metric by which utilization decisions should be evaluated. In the following study, we take the first steps to assessing the clinical effect of RAIs for a common clinical scenario.

Chest radiographic imaging is the most common outpatient diagnostic imaging study performed in the United States, and as many as half of all RAIs that arise from thoracic diagnostic studies are prompted by radiographic imaging of the chest (1). In a study of high-cost imaging derived from RAIs, Lee et al (6) demonstrated that chest radiographic and computed tomographic (CT)

imaging account for the highest recommended imaging examination pairs. Despite this high prevalence, the outcomes of recommended chest CT examinations based on radiographic examinations are not well understood. The purpose of our study was to evaluate the diagnostic yield of recommended chest CT examinations prompted by abnormalities detected at outpatient radiographic examinations of the chest.

Materials and Methods

This retrospective, Health Insurance Portability and Accountability Act–compliant study was approved by the institutional review board and included waivers of patient consent. The study was performed at a 907-bed tertiary care academic center (Massachusetts General Hospital, Boston, Mass) that serves a catchment area of Eastern Massachusetts with an outpatient population composed of 78% white, 5% black, 9% Latino, 4% Asian, and 4% other or unknown ethnicity. The radiology department receives imaging referrals from over 2500 hospital-based physicians and more than 1000 community-based physicians, composed of 16% primary care physicians and 84% specialists. Over 300 000 outpatient diagnostic imaging studies are performed and the images interpreted in the radiology department annually by over 100 staff radiologists, more than 85% of whom are subspecialists according to organ system.

Radiographic and CT Image Interpretation

Chest radiographic images and CT studies were reviewed on a dedicated picture archiving and communication system workstation (Impax, version 5.3.2; Agfa Diagnostic Software, Ridgefield Park, NJ). Images were primarily interpreted by board-certified thoracic radiologists

with 2–40 years of experience (mean, 19.5 years $\pm$ 14.2 [standard deviation]). Each radiographic image was interpreted by a single radiologist and no guidance or guidelines were provided regarding how to interpret the image or when a recommendation for chest CT examination should be made. Instead, consistent with typical clinical practice, decisions involving the interpretation of chest radiographic images and the use of recommendations were based on each radiologist's individual assessment of the radiographic findings in combination with any clinical context garnered from the study indication and/or clinical history available in the electronic medical record (EMR; Longitudinal Medical Record, Partners Healthcare, Boston, Mass). Computer-assisted detection software was not available or used at the time of image interpretation. Individual CT recommendation rates were calculated for the 11 thoracic radiologists who interpreted images.

Imaging Techniques

All posteroanterior and lateral chest radiographic examinations were performed

Advances in Knowledge

- There were 4.5% (1316 of 29 138 [95% confidence interval {CI}: 4.3%, 4.8%]) of outpatient chest radiographic reports that contained a recommendation for chest CT imaging.
- Of chest CT examinations performed within 1 year of the recommendation, 41.4% (286 of 691 [95% CI: 37.7%, 45.2%]) detected a corresponding abnormality that required treatment or further diagnostic work-up and 8.1% (56 of 691 [95% CI: 6.2%, 10.4%]) detected a corresponding abnormality that represented a newly diagnosed, biopsy-proven malignancy.
- Adenocarcinoma of the lung was the most common malignancy detected at radiologist-recommended chest CT examinations, and they represented 46.6% (27 of 58) of detected malignancies.

Implication for Patient Care

- Radiologist-recommended chest CT examinations to evaluate an abnormal finding on outpatient chest radiographic examinations result in a high yield of clinically relevant findings.

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Abbreviations:

CI = confidence interval

EMR = electronic medical record

RAI = recommendation for additional imaging

Author contributions:

Guarantors of integrity of entire study, H.B.H., T.K.A.; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; approval of final version of submitted manuscript, all authors; agrees to ensure any questions related to the work are appropriately resolved, all authors; literature research, H.B.H., M.D.G., C.C.W., M.S.C., J.O.S., T.K.A.; clinical studies, H.B.H., M.D.G., C.C.W., M.S.C., P.V.P., J.O.S., T.K.A.; statistical analysis, H.B.H., M.D.G., E.F.H., J.Z., P.V.P., J.O.S.; and manuscript editing, H.B.H., M.D.G., C.C.W., M.S.C., P.V.P., J.O.S., T.K.A.

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Conflicts of interest are listed at the end of this article.

on computed radiographic (Agfa Diagnostic Software) and digital radiographic (GE Healthcare, Waukesha, Wis) units, and chest CT examinations were performed on 16- and 64-row CT scanners (GE Healthcare; Siemens Medical Solutions, Malvern, Pa). Chest radiographic examinations were performed at an average of 1.5 mAs (posteroanterior) and 6 mAs (lateral) at 120 kV with a phototimer and a grid. The chest CT scans were performed with an average pitch of 1.375 and a typical section thickness of 2.5 mm at an average of 120 kV with tube current modulation (range, 120–350 mA) from the apices to the lung bases with or without contrast medium, according to standard departmental protocols that incorporate stated preferences of the ordering providers.

Patient Selection and Data Collection

Our department's radiology information system (Centricity; GE Healthcare) was queried for all outpatient diagnostic imaging examinations with chest radiographic examination codes performed and interpreted at our institution in 2008 (January 1, 2008, to December 31, 2008). Outpatient diagnostic imaging examinations included studies referred from hospital- and community-based general medicine and specialty clinics. Study duplication related to billing codes, addendums, or multiple accession numbers were avoided. The initial query returned 29138 unique outpatient chest radiographic examinations. To determine which examinations contained a recommendation, custom text searching (Ruby programming language; <http://www.ruby-lang.org>) was used to search the reports of these examinations for the character string "recommend" (ie, hits included recommend, recommendation, and recommending). This query returned a single row of data, including patient identification number, study accession number, examination code, examination date, examination indication, radiologist who interpreted the images, and the examination report. The data were recorded by using a spreadsheet (Microsoft Office Excel 2003; Microsoft Corporation, Redmond, Wash). A single radiologist

then reviewed the reports of every examination returned by the search to decide if a recommendation was actually made by the radiologist who interpreted the images and, if so, to determine the nature of the recommendation. Our study cohort was limited to outpatient chest radiographic examinations that contained a recommendation for follow-up chest CT examination.

Patients were excluded if they were younger than 18 years of age or if they had a chest CT examination within 5 years preceding the index chest radiograph, which resulted in 259 patients who were excluded. The latter exclusion criterion was intended to achieve a more focused clinical cohort by excluding patients with repeated thoracic CT imaging (ie, suggestive of a history of known pulmonary disease or malignancy) or patients in whom the follow-up chest CT examination instead may have been performed because of recommendations that stemmed from a previous chest CT examination rather than from the index radiographic examination.

Identification and Evaluation of Follow-up CT Examinations

For each patient in the study cohort, the radiology information system was queried to identify whether the patient received a chest CT examination at our institution within a 1-year period after the index chest radiographic examination. This query returned a single row of data, including patient identification number, study accession number, examination code, examination date, radiologist who interpreted the image, and the examination report. For each respective patient, the CT query data were linked to the chest radiographic examination query data by using the patient identification number. If multiple chest CT examinations were performed within the year, only the first chest CT examination was reviewed for purposes of the study. The range, mean (with standard error), and median time to performance of the follow-up chest CT examinations relative to the index chest radiographic examination that contained the recommendation were calculated.

Follow-up chest CT examinations were categorized based on two criteria. First, the reports for all follow-up chest CT examinations were compared with the reports for the index chest radiographic examinations to determine whether the CT examination contained an abnormality that corresponded to the finding on the index chest radiographic image that prompted the recommendation for chest CT examination. Only corresponding abnormalities that appeared on CT images were considered for this study. If correspondence could not be determined from the reports alone, the CT and radiographic images were reviewed on a picture archiving and communication system workstation by a single radiologist to make the determination; the same faculty-level, board-certified radiologist (T.K.A.) independently reviewed all of the cases. Second, if a corresponding abnormality was identified on the chest CT image, the same radiologist (T.K.A.) determined the etiologic cause of the abnormality that was most likely, and categorized the abnormality as clinically relevant or not clinically relevant based on whether the finding required treatment or a further diagnostic work-up. "Clinically relevant" was defined as an etiologic cause that required treatment or further diagnostic work-up, such as malignancy, infection, indeterminate pulmonary nodules, interstitial lung disease, and sarcoidosis. "Not clinically relevant" was defined as an etiologic cause that required no treatment or further work-up, such as benign parenchymal abnormalities (eg, subsegmental atelectasis or changes of prior granulomatous disease), benign musculoskeletal lesions (eg, healing fracture or osteophyte), or benign vascular variants. Whether or not the corresponding abnormality represented a clinically relevant etiologic cause was independently determined by the same radiologist (T.K.A.) based on the CT reports and, if necessary, the CT images.

For all corresponding abnormalities that were suspected to represent

malignancy on the CT report, the clinical notes and pathologic analysis reports in the EMR were independently reviewed by a single radiologist (H.B.H.) to determine if malignancy was confirmed and, if so, the histologic diagnosis and stage at diagnosis. For all cases of pathologic analysis–confirmed malignancy, the same radiologist (H.B.H.) searched the EMR to determine if the malignant lesion was known to the referring provider before the index radiographic image was obtained.

For all corresponding abnormalities described by the interpreting radiologist as an indeterminate pulmonary nodule that required imaging follow-up, a single radiologist (H.B.H.) independently reviewed the EMR of the patient (eg, diagnostic imaging results, cytology, surgical pathologic analysis and bronchoscopy results, and clinical notes) for 3 years after the date of the chest CT to determine the final nature or diagnosis of the nodule. The nodule was categorized as malignant, nonmalignant, or lost to follow-up. A nonmalignant nodule was defined by either 2 years of imaging stability for solid nodules or a benign histologic structure when biopsied. “Lost to follow-up” was defined as absence of documented 2-year stability and histologic diagnosis. The histologic diagnosis of malignant nodules was obtained from the EMR.

For the group of patients in whom the radiologist-recommended chest CT examination was not obtained ($n = 366$), a random sampling of 50 patients was obtained and the EMR of each of these patients was independently reviewed by a single radiologist (H.B.H.) with the intention of better understanding the reason for nonadherence to the chest CT recommendation. Patients were categorized as follows: no clinical follow-up at our institution after the index chest radiographic examination, no mention of the results from the chest radiographic examination in the clinical notes despite clinical follow-up, chest radiographic examination results mentioned in the clinical notes but the recommended chest CT

examination was not performed, clinical notes expressed intent to obtain the recommended chest CT images but chest CT examination was not performed, or documentation of follow-up chest CT examination at an outside institution.

Patient Demographics

To understand the demographic characteristics of the patient subgroups, we assessed age, sex, smoking history (ie, never smoked, current or former smoker, or unknown), and clinical indication of the patients. The limits of our database did not allow for automatic mining of this information, and therefore the medical records of these patients were independently reviewed by a single radiologist (H.B.H.) to obtain the demographic information. This demographic information was obtained for all patients who received a recommendation for chest CT examination based on the index radiographic examination, including patients who did and did not actually obtain the recommended CT examination, and for a random sample of 300 patients who did not receive a recommendation for chest CT

examination based on the index radiographic examination.

Statistical Analysis

Statistical analysis was performed with a software program (SAS 9.2; SAS Institute, Cary, NC). Groups were compared with t test and Fisher exact test, and linear regression analysis was used to test association between recommendation rates and years of clinical experience for the thoracic radiologists. A P value less than .05 indicated significance, except for the multiple comparisons of clinical indications where a Bonferroni correction was applied, with which a P value less than or equal to .003 indicated significance. Confidence intervals (CIs) were calculated where appropriate.

Results

Recommendation Rate

In 2008, there were 29 138 outpatient chest radiographic images interpreted in our department. The reports of 2996 (10.3% [95% CI: 9.9%, 10.6%]) of the chest radiographic examinations

Figure 1: Schematic representation of the patient selection process. *CXR* = chest radiographic examination.

matched the initial text-based screen for recommendations. Manual review of these reports found 1316 that contained a recommendation for chest CT examination, which represented a CT examination recommendation rate of 4.5% (1316 of 29 138 [95% CI: 4.3%, 4.8%]). Individual CT recommendation rates for the 11 interpreting thoracic radiologists ranged from 2.5% to 8.7% (mean, $4.7\% \pm 2.0$). There was a trend toward lower recommendation rates in thoracic radiologists with more years of experience, but this was not statistically significant ($P = .187$).

Recommendation Adherence

Approximately 80% (1057 of 1316) of patients with chest radiographic images that were interpreted to recommend a chest CT examination met the inclusion criteria for the study. Among the study group, 65.4% (691 of 1057 [95% CI: 62.4%, 68.2%]) underwent a chest CT examination at our institution within 1 year of the index radiographic examination that led to the recommendation. A schematic representation of this breakdown is presented in Figure 1. The range, mean $\pm$ standard error, and median time to performance of the obtained chest CT examinations were, respectively, 0–356 days, 26.1 days $\pm$ 1.9, and 7 days.

Results of Follow-up Imaging

The findings from the 691 chest CT examinations were classified according to whether the abnormality (or abnormalities) on the chest CT image corresponded to the index radiographic abnormality (or abnormalities) that prompted a recommendation for chest CT examination. Among these chest CT examinations, 38.1% (263 of 691 [95% CI: 34.4%, 41.8%]) had no corresponding abnormality, 20.6% (142 of 691 [95% CI: 17.6%, 23.8%]) had a nonclinically relevant corresponding abnormality (ie, no treatment or further work-up was required), and 41.4% (286 of 691 [95% CI: 37.7%, 45.2%]) had a clinically relevant corresponding abnormality (ie, treatment or further work-up was required). Figure 2 shows two examples of abnormality correlates on

CT images of radiographic abnormalities that prompted an RAI for chest CT examination. The clinically

relevant corresponding findings were subcategorized as malignancy (20.3%; 58 of 286 [95% CI: 15.8%, 25.4%]),

Figure 2: Examples of lesions seen on chest radiographic images that prompted a recommendation for chest CT examination and the corresponding abnormality on chest CT. (**a, b**) In the first example, a nodular opacity (arrow on **a**) is seen projecting over the right posterior ninth rib in the chest radiographic image of a 50-year-old woman who presented with cough; the recommended chest CT examination demonstrated this to be callus from a remote rib fracture (arrow on **b**). (**c, d**) In the second example, a nodular opacity (arrow on **c**) is seen projecting over the left anterior first rib on the chest radiographic image of a 53-year-old man who is a former smoker and presented with cough; the recommended chest CT examination demonstrated this to be a suspicious nodule in the apicoposterior segment of the left upper lobe (arrow in **d**). On resection, this was found to be well-differentiated adenocarcinoma of the lung.

Figure 3

Figure 3: Schematic representation of the results of follow-up chest CT examinations performed within 1 year of the index outpatient chest radiographic examinations that contained the RAI. *AVM* = arteriovenous malformation, *calc* = calcification, *COP* = cryptogenic organizing pneumonia, *CPAM* = congenital pulmonary airways malformation, *DIP* = desquamative interstitial pneumonia, *HTN* = hypertension, *MAI* = Mycobacterium avium intracellulare, *MSK* = musculoskeletal, *NSIP* = nonspecific interstitial pneumonia, *PCP* = Pneumocystis pneumonia, *UIP* = usual interstitial pneumonia.

indeterminate nodule (45.8%; 131 of 286 [95% CI: 39.9%, 51.8%]), parenchymal (16.1%; 46 of 286 [95% CI: 12.0%, 20.9%]), infection (11.2%; 32 of 286 [95% CI: 7.8%, 15.4%]), and other (6.6%; 19 of 286 [95% CI: 4.0%, 10.2%]). The corresponding findings that were not clinically relevant were subcategorized as parenchymal (51.4%; 73 of 142 [95% CI: 42.9%, 59.9%]), musculoskeletal (21.1%; 30 of 142 [95% CI: 14.7%, 28.8%]), vascular (4.9%; seven of 142 [95% CI: 2.0%, 9.9%]), and other (22.5%; 32 of 142 [95% CI: 16.0%, 30.3%]). More detailed results of follow-up imaging are summarized and listed in Figure 3.

Malignancies Discovered during Follow-up

Of the 691 follow-up chest CT examinations that were performed and met inclusion criteria, 8.4% (58 of 691 [95% CI: 6.4%, 10.7%]) demonstrated a biopsy-proven malignancy on the initial follow-up chest CT examination. The types of malignancy are listed in Table 1. Review of the EMRs for these patients demonstrated that 83% (48 of 58) of these malignant lesions were previously unknown to the medical team for each patient. Of the 29 nonsmall cell lung cancers discovered on the follow-up CT examinations and previously unknown to the patient's medical team, eight were stage I, two were stage II,

seven were stage IIIA, four were stage IIIB, and eight were stage IV.

Outcome of Indeterminate Nodules

Outcomes of the 131 indeterminate nodules demonstrated that 6.1% (eight of 131 [95% CI: 2.7%, 11.7%]) were malignant, 62.6% (82 of 131 [95% CI: 53.7%, 70.9%]) were nonmalignant, and 31.3% (41 of 131 [95% CI: 23.5%, 40.0%]) were lost to follow-up. Of the eight malignancies, five were primary lung malignancies (four adenocarcinomas and one large cell neuroendocrine carcinoma) and three were metastases (one breast, one pancreatic, and one ovarian). Review of the EMRs for these patients demonstrated that all

Table 1

Etiologies of Biopsy-proven Malignancies Detected on Chest CTs Performed within 1 Year of the Index Outpatient Chest Radiographic Image Containing the RAI

Type of Malignancy	No. of Malignancies
Primary lung malignancies	41
Adenocarcinoma	27
Squamous cell carcinoma	5
Nonsmall cell carcinoma unspecified	2
Small cell carcinoma	6
Mixed large and small cell carcinoma	1
Lung metastases	12
Sarcoma	4
Breast	3
Ovarian	2
Pancreas	1
Endometrial	1
Squamous cell carcinoma, unknown primary	1
Mediastinal lymphoma	3
Hodgkin lymphoma	2
Non-Hodgkin lymphoma	1
Thymic neoplasm (thymoma)	1
Bone metastases (prostate)	1
Total malignancies identified on CT	58

eight cases represented primary lung malignancy or pulmonary metastatic disease previously unknown to the medical team for each patient.

Reasons for Non-Adherence

The potential causes of referrer or patient nonadherence to the radiologist recommendation for chest CT examination are provided in Table 2. Of the four cases with a documented follow-up chest CT examination performed at an outside institution, one case showed a clinically relevant corresponding abnormality (bone metastases), two cases showed nonclinically relevant corresponding abnormalities (small focus of mucoid impaction and posttreatment changes), and one case showed no corresponding abnormality. Among the 14 patients in whom the results of chest radiographic examinations were mentioned in the

Table 2

EMR-based Explanations for Nonadherence to the Radiologist-recommended Chest CT for a Random Sample of Patients from the Nonadherent Group ($n = 50$)

Reasons for Lack of Adherence in a Sample of Patients Not Obtaining the Recommended Chest CT ($n = 50$)	No. of Patients
No clinical follow-up at our institution after the chest radiographic examination	2 (4)
No mention of chest radiographic examination results in the clinical notes despite clinical follow-up	26 (52)
Chest radiographic examination results mentioned in the clinical notes but the recommended chest CT was not performed	14 (28)
Clinical notes expressed an intention to obtain the recommended chest CT examination, but chest CT examination was not performed	4 (8)
Documentation of follow-up chest CT examination at an outside institution	4 (8)

Note.—Data in parentheses are percentages.

clinical notes but the recommended chest CT examination was not performed, explanations for not obtaining the CT examination were provided in eight of the cases: two patients had not yet undergone an operation for a known lung malignancy, two patients recently underwent outside-chest CT examination that obviated further work-up of the finding, three patients decided to pursue alternative treatment pathways (two patients chose follow-up by undergoing chest radiographic examination and one patient chose a trial of antibiotics), and one referring physician deemed the described abnormality to be scarring from prior granulomatous disease and felt that further CT evaluation was unnecessary. In one of the 28 patients in whom no mention was made of the results of the chest radiographic examination in the clinical notes, a chest CT examination performed nearly 3 years later showed that the abnormality originally described on the index radiographic examination

had grown. This prompted a biopsy that demonstrated the abnormality to be lung adenocarcinoma (mixed bronchioalveolar and mucinous).

Demographics of Study Population

A comparison of the age, sex, smoking history, and clinical indication for the index chest radiographic examination between the patients who did or patients who did not receive a recommendation for chest CT examination because of the index outpatient chest radiographic examination are provided in Table 3. The group of patients who received a recommendation for chest CT examination was, on average, older ($P < .001$) and more likely to be a current or former smoker ($P = .001$). The clinical indication of fever ($P = .003$) was significantly underrepresented in the group of patients who received a recommendation for chest CT examination. The groups were not significantly different ($P > .003$) with respect to the other clinical indications; specific P values are provided in Table 3.

A comparison of the age, sex, smoking history, and clinical indication for the index radiographic examination between the patient subgroups who received the recommended chest CT examination and did not receive the recommended chest CT examination are provided in Table 4. No statistically significant differences were observed between these patient groups with respect to age ($P = .79$), sex ($P = .75$), or smoking history ($P = .84$). The clinical indication of follow-up imaging ($P < .001$) and cough ($P = .001$) were significantly over-represented in the group of patients adherent to the recommendation for chest CT examination, and the clinical indication of preoperative imaging ($P < .001$) was significantly under-represented in the group of patients adherent to the recommendation for chest CT examination.

Discussion

Because the U.S. health care system is shifting from volume-driven to value-based payment models, it is increasingly important for the radiology community to validate the clinical effect of

Table 3

Comparison of Demographic Data, Random Sample versus All Patients Who Met Inclusion Criteria

Parameter	Without Recommendation for Chest CT	With Recommendation for Chest CT	P Value
Age			
Mean (y)	53.6	60.7	<.001
18–30 years	11.3 (34)	4.2 (44)	...
30–50 years	31.7 (95)	19.9 (210)	...
50–70 years	37.3 (112)	46.4 (490)	...
>70 years	19.7 (59)	29.6 (313)	...
Sex			
Men	48.0 (138)	49.5 (523)	...
Women	52.0 (162)	50.5 (534)	...
Smoking Status			
Never	54.7 (164)	41.0 (433)	...
Current or former	40.3 (121)	53.6 (567)	...
Unknown	5.0 (15)	5.4 (57)	...
Clinical indication for index chest radiographic examination			
Abdominal breath sound	3.7 (11)	5.1 (54)	.36
Chest pain	12.7 (38)	9.0 (95)	.06
Constitutional symptoms	4.3 (13)	5.4 (57)	.56
Cough	23.7 (71)	25.8 (273)	.50
Dyspnea	4.3 (13)	6.3 (67)	.21
Fever	3.3 (10)	0.9 (9)	.003
Follow-up imaging	4.3 (13)	6.7 (71)	.14
Hemoptysis	0 (0)	1.0 (11)	.14
History of malignancy	5.0 (15)	5.7 (60)	.78
History of sarcoid	0 (0)	0.7 (7)	.36
Lymphadenopathy	0.3 (1)	0.9 (10)	.47
Positive PPD	7.0 (21)	3.0 (32)	.004
Preoperative	16.0 (48)	19.7 (48)	.156
Other	15.3 (46)	9.7 (103)	.009

Note.—Unless otherwise indicated, data are percentages and data in parentheses are numbers. Data shows comparison between a random sample of the patients who met inclusion criteria and did not receive a recommendation for chest CT based on the index chest radiographic examination ($n = 300$) and all patients who met inclusion criteria and received a recommendation for chest CT based on the index chest radiographic examination ($n = 1057$). PPD = purified protein derivative skin test.

its work (5). Our study demonstrates that chest CT examinations obtained within 1 year of RAIs are associated with a high diagnostic yield of clinically relevant findings, and one in every 13 examinations yielded a previously unknown malignancy. These findings suggest that RAIs for chest CT examinations prompted by outpatient chest radiographic examinations represent a valuable contribution to patient care.

Radiologists who interpret outpatient chest radiographic images in our study made recommendations in 10.3% (2996 of 29138) of cases, with

recommendations for CT examination in 4.5% (1316 of 29138) of cases. The overall recommendation rate is comparable to rates previously reported for thoracic radiology and general radiography, which ranged from 7.7% to 10.9%, with notable differences in study design (1,3,7). We are unaware of another study that specifically reported chest CT recommendation rates from outpatient chest radiographic imaging. Older patients and current or former smokers were statistically more likely to receive recommendations for chest CT imaging, which may reflect a higher likelihood of radiographic

abnormalities and a lower threshold for radiologists to recommend a chest CT examination in these patients.

Recommendation rates for CT imaging among the 11 thoracic radiologists varied from 2.5% to 8.7%, which was comparable to previously published data (3). Although previous studies showed a decreased likelihood of RAI with increased radiologist experience (1), the number of radiologists involved in our study was insufficient for a meaningful comparison of radiologist experience and RAIs.

Our study found a high positive predictive value for chest CT images obtained within a year of the RAI, and 41.4% (286 of 691 [95% CI: 37.7%, 45.2%]) of the recommended chest CT images showed an abnormality that would change clinical management or require a further work-up. Moreover, 8.1% (56 of 691 [95% CI: 6.2%, 10.4%]) of the recommended chest CT images showed a newly diagnosed, pathologic analysis-proven malignancy. This adds critical context to the long-standing debate regarding the clinical value of radiologist-recommended chest CT examinations (8). For instance, recent studies (9–11) highlighted the potentially harmful effects of diagnostic radiation from CT examinations, which resulted in increased scrutiny of RAIs for CT imaging by referring providers. The high diagnostic yield demonstrated in this study suggests that the potential clinical benefits of radiologist-recommended chest CT examinations are likely to strongly outweigh the extremely low predicted risk of radiation-induced cancer associated with chest CT imaging (12).

Approximately 21% (142 of 691 [95% CI: 17.6%, 23.8%]) of follow-up CT examinations demonstrated a corresponding abnormality that did not require treatment or further diagnostic work-up, and 38% (263 of 691 [95% CI: 34.4%, 41.8%]) demonstrated no corresponding abnormality. Although these cases required no additional action, the information provided by the chest CT examination arguably provided important information for clinical management by alleviating immediate clinical concern and reducing the

Table 4

Comparison of Demographic Data at Our Institution within 1 Year of the Index Chest Radiographic Examination

Parameter	Chest CT Examination Obtained	Chest CT Examination Not Obtained	P Value
Age			
Mean age (y)	60.9	60.2	.49
18–30 years	3.3 (23)	5.7 (21)	...
30–50 years	19.1 (132)	21.3 (78)	...
50–70 years	48.5 (335)	42.3 (155)	...
>70 years	29.1 (201)	30.6 (112)	...
Sex			
Men	49.1 (339)	50.3 (184)	...
Women	50.9 (352)	49.7 (182)	...
Smoking Status			
Never	41.0 (283)	41.0 (150)	...
Current or former	54.1 (374)	52.7 (193)	...
Unknown	4.9 (34)	6.3 (23)	...
Clinical indication for index chest radiographic examination			
Abdominal breath sound	5.4 (37)	4.6 (17)	.66
Chest pain	9.3 (64)	8.5 (31)	.73
Constitutional symptoms	5.9 (41)	4.4 (16)	.32
Cough	29.1 (201)	19.7 (72)	.001
Dyspnea	6.9 (48)	5.2 (19)	.29
Fever	1.0 (7)	0.5 (2)	.73
Follow-up imaging	9.0 (62)	2.5 (9)	<.001
Hemoptysis	1.2 (8)	0.8 (3)	.76
History of malignancy	4.9 (34)	7.1 (26)	.16
History of sarcoid	0.3 (2)	1.4 (5)	.06
Lymphadenopathy	0.7 (50)	1.4 (5)	.33
Positive PPD	2.9 (20)	3.3 (12)	.71
Preoperative	14.9 (103)	28.7 (105)	<.001
Other	8.5 (59)	12.0 (44)	.08

Note.—Unless otherwise indicated, data are percentages and data in parentheses are numbers. Data show comparison (age, sex, smoking history, and clinical indication for index chest radiographic examination) between patients who obtained ($n = 691$) and those who did not obtain ($n = 366$) the radiologist-recommended chest CT examination. PPD = purified protein derivative skin test.

likelihood of unnecessary work-ups on subsequent imaging. The false-positive rates in our study are markedly lower than the false-positive rates found with routine screening chest radiography in asymptomatic patients (93.3%) (13).

An interesting subgroup of our study is the fraction of patients (34.6%; 366 of 1057) who did not undergo a follow-up chest CT examination within 1 year. The rate of nonadherence to RAIs in our study is comparable to the 45% nonadherence rates for radiologist-recommended chest CT examinations (14) and significantly better than the 60%

and 62% nonadherence rates associated with RAIs prompted by abdominal CTs and outpatient CT and MR examinations (15,16). Although there are myriad reasons for nonadherence to RAIs, Baumgarten and Nelson (15) found that the most common reason that referring clinicians did not obtain a radiologist-recommended examination was that they did not feel the recommended follow-up examination was clinically indicated. In our study, the reasons for noncompliance were often difficult to establish because in 50% of the cases there was no mention of the recommendation

for chest CT examination in the clinical notes. Regardless of the reason for non-adherence, the risk exists for missed or delayed diagnoses. For instance, if the same positive predictive value can be assumed for the CT examinations that were not obtained as for the CT examinations that were obtained, 30 cancers would have been potentially missed in the nonadherent group.

There are a number of limitations of our retrospective study. First, the study included a single academic medical center with a large specialist referral base, which could limit the generalizability of the results to nonreferral centers or private practices. Second, the study design did not capture follow-up imaging performed at outside institutions, which likely resulted in an underestimation of the recommendation adherence rate. Third, the group of patients who did not receive chest CT follow-up within 1 year of the RAI may have been deemed by referring physicians to not require follow-up imaging; therefore, this population may have a lower pretest probability of disease than the study population. Further prospective studies are needed to more precisely examine how a referring physician's clinical judgment about the likelihood of clinically relevant thoracic findings is related to the diagnostic yield of a radiologist-recommended chest CT examination.

In summary, our data suggest that chest CT examinations recommended to evaluate an abnormal finding on an outpatient chest radiographic image have a high yield of clinically relevant findings, including newly discovered malignancy. Future research may be considered to study which patients would benefit most from follow-up with chest CT examination.

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