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ORIGINAL SCIENTIFIC REPORT

Optimizing the Yield of Abnormal Preoperative Chest Radiographs in Elective Non-cardiothoracic Surgery: Development of a Risk Prediction Score and External Validation

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Abstract

Background Guideline recommendations for preoperative chest radiographs vary to the extent that individual patient benefit is unclear. We developed and validated a prediction score for abnormal preoperative chest radiographs in adult patients undergoing elective non-cardiothoracic surgery.

Methods Our prospective observational study recruited 703 adult patients who underwent elective non-cardiothoracic surgery at Ramathibodi Hospital. We developed a risk prediction score for abnormal preoperative chest radiographs with external validation using data from 411 patients recruited from Thammasat University Hospital. The discriminative performance was assessed by receiver operating curve analysis. In addition, we assessed the contribution of abnormal chest radiographs to perioperative management.

Results Abnormal preoperative chest radiographs were found in 19.5% of the 703 patients. Age, pulmonary disease, cardiac disease, and diabetes were significant factors. The model showed good performance with a C-statistics of 0.739 (95% CI, 0.691–0.786). We classified patients into four groups based on risk scores. The posttest probabilities in the intermediate-, intermediate-high-, and high-risk groups were 33.2%, 59.8%, and 75.7%, respectively. The model fitted well with the external validation data with a C statistic of 0.731 (95% CI, 0.674–0.789). One (0.4%) abnormal chest radiograph from the low-risk group and three (2.4%) abnormal chest radiographs from the intermediate-to-high-risk group had a major impact on perioperative management.

Conclusions Four predictors including age, pulmonary disease, cardiac disease, and diabetes were associated with abnormal preoperative chest radiographs. Our risk score demonstrated good performance and may help identify patients at higher risk of chest abnormalities.

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Introduction

Preoperative chest radiographs are commonly used to detect abnormalities requiring perioperative management, identify patients at higher risk of postoperative complications, aid in postoperative chest film interpretation, and screen tuberculosis in high-prevalence areas [1]. In addition, they help identify pulmonary masses or tumors that may impact surgical decisions [2]. Nonetheless, routine chest radiographs are no longer recommended due to risk of radiation-induced cancer, false-positive results, and increased costs [3]. Moreover, most abnormalities are chronic, with more than half detectable through history taking and physical examination [4]. Unexpected abnormalities rarely impact clinical management [5].

It is unclear which patients benefit from preoperative chest radiographs. Previous findings have been inconsistent [4, 6–10], perhaps because the studies were retrospective and interpretation was not standardized [3]. These studies also failed to consider associations between multiple predictors and their efficacy for predicting abnormal chest radiographs. The inconsistent findings have led to a change in guidelines [11–14] and different ordering practices among surgeons and hospitals [1, 15]. Therefore, this study aimed to develop and validate a risk prediction score for abnormal preoperative chest radiographs in adult patients undergoing elective non-cardiothoracic surgery. We further evaluated the impact of abnormal preoperative chest radiographs in perioperative management and the role of the predictive risk score in identifying abnormal chest radiographs.

Material and methods

Study design and population

Ethical approval was provided by the Human Research Ethics Committee of the Faculty of Medicine Ramathibodi Hospital and Thammasat University. A prospective observational study was conducted consisting of a development phase at Ramathibodi Hospital and a validation phase at Thammasat University Hospital (TUH). This study was conducted and reported according to Transparent Reporting of a Multivariable Prediction Model for Individual Prognosis Or Diagnosis (TRIPOD) and STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) [16, 17]. Study participants included consecutive adult patients aged 18 years or older, who had preoperative chest radiographs and underwent elective non-cardiothoracic operation and anesthesia. Exclusion criteria were pregnancy, cancelation due to administrative reasons, previous cardiothoracic surgery, re-surgery within the study period, chest or cardiac trauma, or unwillingness to participate in the study.

Study outcomes

The primary outcome of the study was preoperative chest radiographs classified as abnormal by a panel of anesthesiologists, radiologists, pulmonologists, and cardiologists. All chest radiographs were interpreted at a resolution of 6 million pixels. Interpretation was guided by comparison to previous radiographs with blinding to clinical information. Radiologists completed all reports at Ramathibodi Hospi-

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tal, and 15% were re-evaluated by W.S. for standardization. Chest radiographs at TUH were doubly interpreted by both radiologists and anesthesiologists (A.S., A.K., N.S.). Disagreement in reporting was resolved by A.K. The percentages of agreement and kappa values were reported. We also collected data at TUH on how abnormal chest radiographs were used for perioperative management by anesthesiologists or surgeons.

Study predictors

Nineteen potential predictors were selected by considering clinical importance and previous relevant studies.

- Patient characteristics:
  - age (years) categorized by distribution
  - sex
  - body mass index (BMI) (kg/m^2) categorized by the WHO definitions for Asians [18]
- Risk behaviors:
  - smoking (pack-years) categorized by the risk of postoperative pulmonary complications and positive likelihood ratio [19]
  - alcohol or drug use
  - presence of tuberculosis symptoms [20]
  - history of contact with tuberculosis patients [20]
- Comorbidities:
  - upper respiratory tract infection within two weeks
  - presence of tracheal tube
  - pulmonary diseases categorized into (1) no pulmonary disease, (2) stable airway disease including asthma, chronic obstructive pulmonary disease (COPD), and bronchiectasis, (3) stable non-airway diseases, which were pulmonary diseases affecting parenchyma, interstitium, blood vessels, or pleura, and (4) active pulmonary disorders with respiratory symptoms
  - cardiac diseases categorized into (1) no cardiac disease, (2) cardiac diseases with stable conditions, and (3) cardiac diseases with active conditions [21]
  - hypertension
  - cerebrovascular disease
  - acute kidney injury/chronic kidney disease (AKI/CKD) [22]
  - diabetes mellitus
  - thyroid mass/nodule
  - cancer
  - immunocompromised status
- Types of surgery were classified into low, intermediate, and high cardiac risk [23]

Data were collected from pre-anesthesia evaluation forms or the International Classification of Diseases, Tenth Revision (ICD-10) codes by anesthesiology residents blinded to the reports of chest radiographs.

Sample size estimation

Our sample size was estimated based on the 9% prevalence of abnormal preoperative chest radiographs in Thailand [6], providing 10 potential predictors in the final model, and 20 events per predictor [24]. The resulting estimated sample size was 2223 patients for the development phase. Assuming 10% incomplete data, our sample size target was 2446 patients for the development phase at Ramathibodi Hospital, with 1048 patients (30%) required for external validation at TUH.

Statistical analysis

Multiple imputation by chained equations was used to impute missing data with 20 replications [25]. For model development, a simple logistic regression was performed by fitting each predictor on abnormal preoperative chest radiographs. Predictors with $p < 0.10$ were considered in the multivariable logistic regression model. A forward selection was manually applied with only significant variables retained within the final model. Risk prediction scores were constructed based on the coefficients of the predictors and then trichotomized into four risk groups corresponding to the positive likelihood ratio. Calibration performance was assessed using the Hosmer–Lemeshow goodness of fit (HL-GOF) test and the ratio of observed and expected values (O/E ratio). The model discrimination was determined by the receiver operating characteristic (ROC) curve analysis and C-statistic estimated [26].

A bootstrap 5000-replication analysis was used for internal validation. The bootstrap-corrected calibration and discrimination coefficients were estimated to assess model performance. External validation was performed by applying the final developed model to data from TUH. Calibration and discrimination performance were also assessed as described above. Recalibration or model revision was undertaken when calibration performance was considered poor [27].

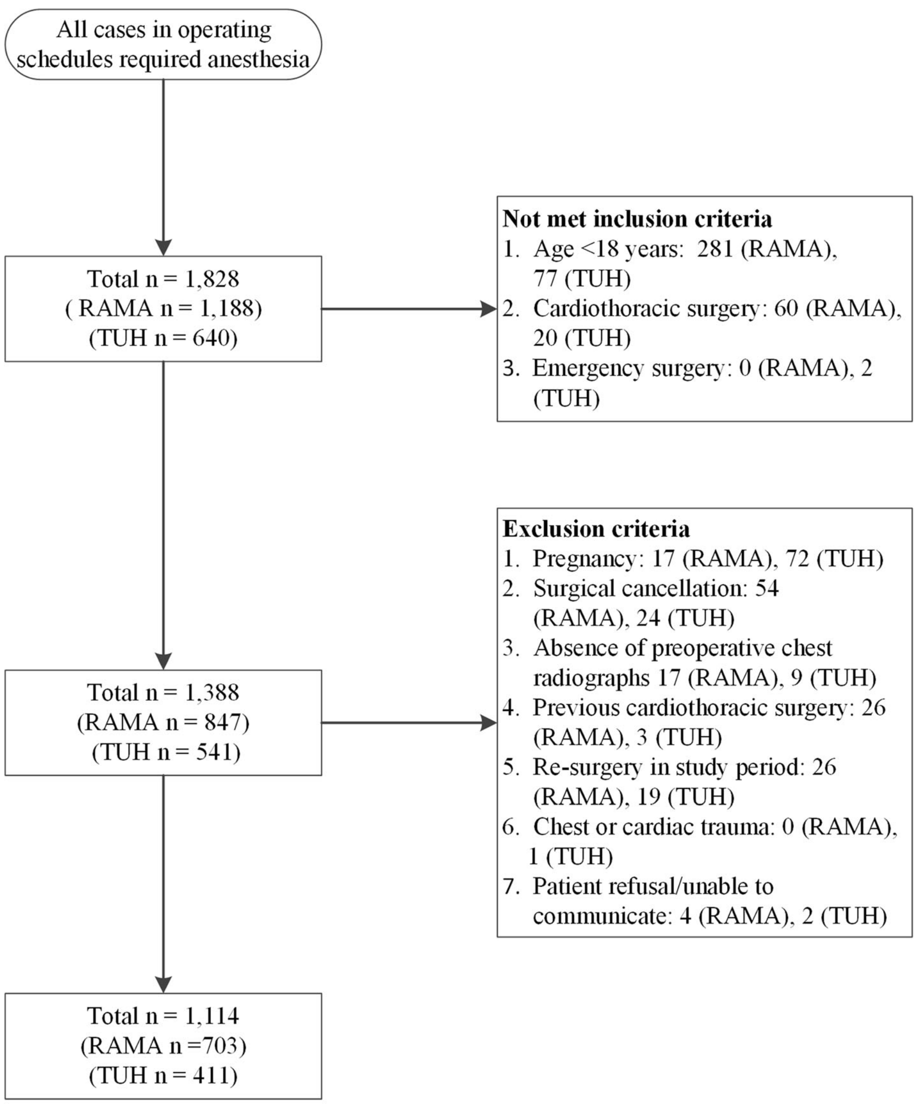
All statistical analyses were performed by STATA software version 16 (StataCorp LLC. 2019, College Station, Texas, USA). A value of $p < 0.05$ was considered statistically significant.

Results

The study was halted prematurely when all elective surgeries in both hospitals were postponed due to the COVID-19 pandemic. A total of 730 and 411 patients were scheduled for elective non-cardiothoracic surgery at Ramathibodi Hospital and TUH, respectively, throughout February and March 2020 (Fig. 1). Seventeen (2.0%) patients at Ramathibodi Hospital and nine (1.7%) patients at TUH were excluded because they did not have preoperative chest radiographs (Fig. 1). Characteristics of the patients included are presented in Table 1. At Ramathibodi Hospital 137 patients (19.5% with a 95% confidence interval [CI] of 16.6–22.6%) had abnormal preoperative chest radiographs. The reliability of radiograph interpretations was 97.4% with kappa statistic of 0.90.

Development phase

Imputation was performed on five predictors in 49 patients. Ten predictors including age, smoking, presence of tracheal tube, pulmonary disease, cardiac disease, diabetes, AKI/CKD, hypertension, cerebrovascular disease, and cancer were associated with abnormal preoperative chest radiographs from the univariate analysis and were simultaneously included in the multivariate model (Table 2).



RAMA Ramathibodi hospital, TUH Thammasat University Hospital.

Fig. 1 The flow of inclusion and exclusion criteria

Table 1 Characteristics of included subjects at Ramathibodi Hospital and Thammasat University Hospital

Patient characteristics	Ramathibodi Hospital	Thammasat University Hospital	*P*
Age (years)	58 [18–90]	57 [19–87]	0.873
Sex, male	280/703 (39.8)	184/411 (44.8)	0.107
Body mass index (kg/m^2)	24.4 ± 5.1	24.7 ± 4.9	0.298
Smoking (pack-years)	0 [0–50]	0 [0–30]	0.804
Alcohol or drug use	73/687 (10.6)	80/406 (19.7)	<0.001
Tuberculosis symptoms	6/674 (0.9)	4/396 (1.0)	1.000
Contact tuberculosis patient	4/675 (0.6)	4/398 (1.0)	0.478
Upper respiratory tract infection	2/703 (0.3%)	4/411 (1.0%)	0.201
Tracheal tube	5/703 (0.7)	7/411 (1.7)	0.122
Pulmonary disease			
Active lung	8/703 (1.1)	7/411 (1.7)	0.821
Stable non-airway	23/703 (3.3)	11/411 (2.7)	
Stable airway	22/703 (3.1)	13/411 (3.2)	
No	650/703 (92.5)	380/411 (92.5)	
Cardiac disease			
Active cardiac	6/703 (0.9)	5/411 (1.2)	0.136
Stable cardiac	78/703 (10.8)	31/411 (7.5)	
No	619/703 (88.3)	375/411 (91.2)	
Hypertension	281/703 (40.0)	183/411 (44.5)	0.137
Cerebrovascular disease	35/703 (5.0)	19/703 (4.6)	0.790
Kidney disease	124/703 (17.6)	60/411 (14.6)	0.187
Diabetes mellitus	139/703 (19.8)	83/703 (20.2)	0.865
Thyroid mass/nodule	56/703 (8.0)	18/703 (4.4)	0.032
Cancer	171/703 (24.3)	49/411 (11.9)	<0.001
Immunocompromised status	34/703 (4.8)	10/411 (2.4)	0.047
High-risk surgery	27/703 (3.8)	10/411 (2.4%)	0.203

Data are presented in number (percentage), mean ± standard deviation, or median [interquartile range]

Four predictors including age, pulmonary disease, cardiac disease, and diabetes were significantly associated with abnormal chest radiographs in the final model (Table 3). The risk of abnormal chest radiographs increased 2.4- and 4.0-times higher odds in ages ≥45 and ≥65 years, respectively. Patients with stable non-airway lung and active lung diseases had 6.5- and 26.9-times higher odds of abnormal radiographs compared to patients with stable airways and free from pulmonary diseases. In addition, patients with stable and active-cardiac diseases were approximately 2.2- and 16.9-times more likely to have abnormal radiograph than patients who did not have cardiac diseases. The prediction equation fitted well with the data (HL-GOF χ^2 = 2.53, p = 0.469); the O/E ratio was 0.986 (95% CI, 0.965–1.006). The final model showed good discriminative performance with a C statistic of 0.739 (95% CI, 0.691–0.786).

Four risk groups were generated at scores of −1.34, −0.56, and 0.33 (Table 4). Of the 703 patients, 403, 215, 61, and 24 patients were classified within the low, intermediate, intermediate-high, and high-risk groups. Posttest probabilities of having an abnormal preoperative chest radiograph in the intermediate-, intermediate-high-, and high-risk groups were 33.2%, 59.8%, and 75.7%, respectively. A simplified color-coded table classifying the patients' risk groups is shown in Table 5. The risk increased from low risk to at least intermediate risk in any patients aged 65 years or older. Patients with stable non-airway pulmonary diseases were classified as intermediate risk group when they were younger than 65 years and did not have cardiac disease or diabetes. Otherwise, they were classified as intermediate-high or high risk. All patients with active lung diseases were classified as high risk. Patients with cardiac diseases or diabetes were classified into the intermediate- to high-risk groups, except patients aged less than 45 years who had either diabetes or stable cardiac disease and were free from pulmonary diseases and were therefore classified as low risk.

Table 2 Univariate analyses of the summary characteristics at Ramathibodi Hospital by significant abnormal preoperative chest radiograph

	Original dataset		Imputed dataset		OR (95% CI)	*p*
	Abnormal radiograph		Abnormal radiograph			
	Yes	No	Yes	No		
Age (years)						
≥65	75/137 (54.7)	162/566 (28.6)			6.0 (3.2–11.1)	<0.001
45–64	49/137 (35.8)	237/566 (41.9)			2.7 (1.4–5.1)	0.001
<45	13/137 (9.5)	167/566 (29.5)			1	
Sex, male	60/137 (56.2)	220/566 (38.9)			1.2 (0.8–1.8)	0.292
BMI (kg m^{-2})						
≥27.5	27/136 (19.9)	147/566 (26.0)	27/137 (19.7)	147/566 (26.0)	0.6 (0.4–1.0)	0.051
23–27.4	39/136 (28.7)	190/566 (33.6)	39/137 (28.5)	190/566 (33.6)	0.7 (0.4–1.1)	0.086
<18.5	13/136 (9.6)	42/566 (7.4)	13/137 (9.5)	42/566 (7.4)	1.0 (0.5–2.0)	0.947
18.5–22.9	57/136 (41.9)	187/566 (33.0)	58/137 (42.3)	187/566 (33.0)	1	
Smoking (pack-years)						
≥20	18/132 (13.6)	35/560 (6.3)	20/137 (14.6)	38/566 (6.7)	2.4 (1.3–4.4)	0.004
10–19.9	8/132 (6.1)	27/560 (4.8)	7/137 (5.1)	28/566 (4.9)	1.5 (0.7–3.4)	0.308
<10	5/132 (3.8)	32/560 (5.7)	9/137 (6.6)	34/566 (6.0)	0.9 (0.4–2.3)	0.832
0	101/132 (76.5)	466/560 (83.2)	101/137 (73.7)	466/566 (82.3)	1	
Alcohol or drug use	15/130 (11.5)	58/557 (10.4)	16/137 (11.7)	59/566 (10.4)	1.1 (0.6–2.1)	0.672
Tuberculosis symptoms	1/129 (0.8)	5/545 (0.9)	1/137 (0.7))	6/566 (1.1)	0.9 (0.1–7.6)	0.929
Contact tuberculosis patient	0/131 (0.0)	4/544 (0.7)	1/137 (0.7)	5/566 (0.9)	1.0 (0.1–9.0)	0.972
Upper respiratory tract infection	0/137 (0.0)	2/566 (0.4)			0.8 (0.0–17.2)	0.899
Tracheal tube	3/137 (2.2)	2/566 (0.4)			6.3 (1.0–38.2)	0.045
Pulmonary disease						
Active lung	7/137 (5.1)	1/566 (0.2)			32.9 (4.0–270.1)	0.001
Stable non-airway	13/137 (9.5)	10/566 (1.8)			6.1 (2.6–14.3)	<0.001
Stable airway	3/137 (2.2)	19/566 (3.4)			0.7 (0.2–2.6)	0.636
No	114/137 (83.2)	536/566 (94.7)			1	
Cardiac disease						
Active cardiac	5/137 (3.6)	1/566 (0.2)			25.6 (3.0–221.8)	0.003
Stable cardiac	31/137 (22.6)	47/566 (8.3)			3.4 (2.1–5.6)	<0.001
No	101/137 (73.7)	518/566 (91.5)			1	
Hypertension	70/137 (51.1)	211/566 (37.3)			1.8 (1.2–2.6)	0.003
Cerebrovascular disease	14/137 (10.2)	21/566 (3.7)			3.0 (1.5–6.0)	0.003
Kidney disease	42/137 (30.7)	82/566 (14.5)			2.6 (1.7–4.0)	<0.001
Diabetes mellitus	48/137 (35.0)	91/566 (16.1)			2.8 (1.9–4.3)	<0.001
Thyroid mass/nodule	13/137 (9.5)	43/566 (7.6)			1.3 (0.7–2.4)	0.464
Cancer	41/137 (29.9)	130/566 (23.0)			1.4 (1.0–2.2)	0.090
Immunocompromised status	6/137 (4.4)	28/566 (4.9)			0.9 (0.4–2.1)	0.781
High-risk surgery	5/137 (3.6)	22/566 (3.9)			1.0 (0.4–2.5)	0.897

Values are number/total (%)

Table 3 A multivariate analysis of factors associated with significant abnormal preoperative chest radiographs at Ramathibodi Hospital

Study factors	Coefficient	SE	OR (95% CI)	*p*
Age (year)				
≥65	1.389	0.346	4.0 (2.0–7.9)	<0.001
45–64	0.855	0.340	2.4 (1.2–4.6)	0.012
<45	0		1 (Reference)	
Pulmonary disease				
Active lung	3.293	1.148	26.9 (2.8–255.2)	0.004
Stable non-airway	1.876	0.458	6.5 (2.7–16.0)	<0.001
Stable airway	-1.143	0.791	0.3 (0.1–1.5)	0.149
No	0		1 (Reference)	
Cardiac disease				
Active cardiac	2.829	1.304	16.9 (1.3–218.2)	0.03
Stable cardiac	0.787	0.289	2.20 (1.3–3.9)	0.006
No	0		1 (Reference)	
Diabetes mellitus				
Yes	0.614	0.238	1.85 (1.2–2.9)	0.01
No	0		1 (Reference)	

$$\ln\left[\frac{p}{1-p}\right] = -2.739 + 0.855(\text{age}45-64) + 1.389(\text{age} \geq 65) - 1.143(\text{stableairway}) + 1.876(\text{stablenon}-\text{airway}) + 3.293(\text{activelung}) + 0.787(\text{stablecardiac}) + 2.829(\text{activecardiac}) + 0.614(\text{DM})$$

Table 4 Diagnostic accuracy of derived model for prediction of significant abnormal preoperative chest radiograph

Risk groups	Score	Abnormal radiograph		%Sensitivity	%Specificity	%PPV	%NPV	LR^+	LR^-	%Post-test
		Yes	No	(95% CI)	(95% CI)	(95% CI)	(95% CI)	(95% CI)	(95% CI)	probability
Low	<−1.350	40	363							
Intermediate	≥−1.350	97	203	70.8 (62.4, 78.3)	64.1 (60.0, 68.1)	32.3 (27.1, 37.9)	90.1 (86.7, 92.8)	2.0 (1.7, 2.3)	0.5 (0.3, 0.6)	33.2
Intermediate-High	≥−0.563	50	35	36.5 (28.4, 45.2)	93.8 (91.5, 95.7)	58.8 (47.6, 69.4)	58.8 (47.6, 69.4)	5.9 (4, 8.7)	0.7 (0.6, 0.8)	59.8
High	≥0.336	18	6	13.14 (8.0, 20.0))	98.9 (97.7, 99.6)	75 (53.3, 90.2)	82.5 (79.4, 85.3)	12.4 (5.0, 30.6)	0.88 (0.8, 0.9)	75.7

PPV predictive positive value, *NPV* negative predictive value, *LR* likelihood ratio

Validation phase

The predictive score from bootstrap analysis performed well with a mean bootstrap-corrected calibration coefficient of 0.465 (95% CI, 0.463–0.466) relative to the original coefficient of 0.477. The bootstrap-corrected C statistic was 0.732 (95% CI, 0.732–0.733).

External validation was performed using data from patients at TUH. The majority of patient characteristics were similar to Ramathibodi Hospital except for rates of alcohol or drug use, cancer, thyroid mass/nodule, and being immunocompromised (Table 1). Of the 411 patients, 87 had abnormal preoperative chest radiographs, a prevalence of 21.2% (95% CI, 17.3–25.4%). The agreement in chest radiograph interpretation was 95.9% with kappa statistic of 0.87.

The model fitted well with the external validation data (HL-GOF χ^2 = 4.70, p = 0.195) with an O/E ratio of 0.987 (95% CI, 0.888–1.085). The C statistic was 0.731 (95% CI, 0.674–0.789). Risk prediction scores were calculated with 230 (60%) and 181 (40%) patients classified in the low- and intermediate-to-high-risk group with abnormal chest

Table 5 A simplified color-coded table for the prediction of significant abnormal preoperative chest radiograph

Age < 45 years	No cardiac disease		Stable cardiac disease		Active cardiac disease	
	Diabetes		Diabetes		Diabetes	
	No	Yes	No	Yes	No	Yes
No pulmonary disease	Low risk	Low risk	Low risk	Intermediate risk	Intermediate-high risk	High risk
Stable non-airway	Intermediate risk	Intermediate-high risk	Intermediate-high risk	High risk	High risk	High risk
Active lung	High risk	High risk	High risk	High risk	High risk	High risk

Age 45-64 years	No cardiac disease		Stable cardiac disease		Active cardiac disease	
	Diabetes		Diabetes		Diabetes	
	No	Yes	No	Yes	No	Yes
No pulmonary disease	Low risk	Intermediate risk	Intermediate risk	Intermediate-high risk	High risk	High risk
Stable non-airway	Intermediate risk	High risk	High risk	High risk	High risk	High risk
Active lung	High risk	High risk	High risk	High risk	High risk	High risk

Age ≥ 65 years	No cardiac disease		Stable cardiac disease		Active cardiac disease	
	Diabetes		Diabetes		Diabetes	
	No	Yes	No	Yes	No	Yes
No pulmonary disease	Intermediate risk	Intermediate risk	Intermediate-high risk	Intermediate-high risk	High risk	High risk
Stable non-airway	High risk	High risk	High risk	High risk	High risk	High risk
Active lung disease	High risk	High risk	High risk	High risk	High risk	High risk

Low risk; Intermediate risk; Intermediate -high risk; High risk

radiographs of 10.8% (95% CI, 7.7–14.6%) and 34.3% (95% CI, 21.4-41.7%), respectively.

Abnormal chest radiographs had a major impact on perioperative management in four patients. One patient (0.4%) in the low-risk group postponed surgery and was diagnosed with active tuberculosis. Three patients (2.3%) were in the intermediate-to-high-risk group, with two having surgery cancelled. They were diagnosed with non-tuberculosis mycobacterium and pulmonary metastasis. One patient scheduled for spinal surgery was newly diagnosed with lung cancer.

Discussion

We developed and validated a risk prediction score for abnormal preoperative chest radiographs. The model consisted of four predictors including age, pulmonary disease, cardiac disease, and diabetes. The risk of abnormality increased with age from low to at least intermediate in patients of 65 years and older. Higher rates of abnormality were reported in patients with active cardiopulmonary conditions compared to those with stable conditions. There was little value derived from preoperative chest radiographs in patients with stable airway diseases as the radiographs rarely indicate abnormalities that affect clinical management [28]. The finding that diabetes patients were more likely to have abnormal preoperative chest radiographs suggests increased cardiovascular risk in patients with longer disease duration or the presence of renal dysfunction or microalbuminuria [29]. However, our study did not reveal association with hypertension, AKI/CKD, or cerebrovascular disease.

Our study also investigated associations between abnormal preoperative chest radiographs and other reported predictors. Previous investigations associated with smoking status proved inconclusive [8, 30, 31]. Our univariate analysis revealed an association between smoking and abnormal preoperative chest radiographs. However, the subsequent multivariate analysis failed to demonstrate an association. Our results support previous reports that preoperative chest radiographs should not be recommended in patients with thyroid mass or undergoing high-risk surgery [10, 32]. Weibman [33] recommended performing preoperative chest radiographs in cancer patients based on a high incidence of new findings, but our results failed to demonstrate this association. Furthermore, computed tomography examination, not chest radiograph, is currently used for staging in cancer patients. We were also unable to demonstrate associations between tuberculosis symptoms, alcohol/drug use, or immunocompromised status with abnormal chest radiographs.

Our study supports the opinion of previous researchers that routinely performing preoperative chest radiographs may not be necessary because most abnormalities are chronic and do not affect clinical management [1, 3, 5]. Preoperative chest radiographs in the low-risk group provided less clinical impact compared to the other three groups. The benefit may not justify the risk of radiation-induced cancer, delayed operation, over-investigation, and costs [3]. Our risk prediction score may help practitioners identify patients at higher risk of abnormal chest radiographs. Furthermore, it can reduce medical expenses for patients and workload for healthcare professionals, especially in limited resource settings.

There were several strengths to our study. Firstly, we followed the STROBE and TRIPOD recommendations for conducting observational studies and developing prediction scores [34, 35]. Secondly, we simultaneously considered predictors identified from previous studies and validated the models with a good performance [27]. Thirdly, the small amount of missing data was appropriately imputed. Lastly, our scoring system is easy to use.

Our study had some limitations. Because of the COVID-19 pandemic, our study size was smaller than intended, but it was deemed sufficient. The prevalence was higher than anticipated, and the number of abnormal chest radiographs per parameter was 17.1, within the range of recommendation [24]. The estimated shrinkage was 0.92, higher than the recommendation [36].

The proportion of abnormal preoperative chest radiographs in our study was higher than the proportion in a previous meta-analysis [5]. This can be attributed to different definitions of abnormal radiographs and a variety of patient characteristics. Our study included only adult patients in Thai tertiary hospitals, where tuberculosis is prevalent, while the meta-analysis included only studies from European and North American countries [5]. Although our risk prediction score has not yet been tested in these countries, it may still prove clinically useful. Meanwhile, tuberculosis is endemic in many parts of the world and is becoming more prevalent in more developed countries through political and economic migration [37]. To generalize, further study is needed of the validity, clinical impact, and cost-effectiveness of our scoring system in other settings.

In conclusion, a prediction score with good performance for classifying risk associated with abnormal preoperative chest radiographs was developed. Advanced age, pulmonary disease, cardiac disease, and diabetes were associated with higher risk of abnormalities. Our risk prediction model may help identify patients at higher risk of chest abnormalities.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The study was approved by the Human Research Ethics Committee of the Faculty of Medicine Ramathibodi Hospital and Thammasat University No. 1.

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