The Cost-Effectiveness of Chest Radiography as a Screening Test for Chronic Obstructive Pulmonary Disease among the Bangkok Elderly†

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Abstract

Regular screening with chest radiography (CXR) in an annual physical check up of the elderly is most frequently practiced. This study aimed to identify the CXR indices and the cost-effectiveness of CXR as a screening test for Chronic Obstructive Pulmonary Disease (COPD) among the elderly in 124 urban communities of Bangkok around Siriraj Hospital. The gold standard for diagnosing COPD followed the guidelines of the Thoracic Society of Thailand.

There were 3,094 subjects who participated, completed spirometry and a CXR. The selected nine indices from PA and lateral CXR for diagnosing COPD were based on the presence of hyperinflation. The positive criteria of each index were reported.

The cut-off point of best average accuracy ie. Z score of the CXR was 0.07 with a sensitivity of 75.9 per cent (95% CI 70.2-81.6%), specificity of 72.4 per cent (95% CI 70.8-74.0%) and the best average accuracy of 74.1 per cent (95% CI 72.5-75.7%) whereas the cost-effective cut-off point of a Z score of CXR as a screening test for COPD was 0.04 at the lowest grand total cost. The cost to detect one case of COPD was 2,008 baht and needed to screen 17 elderly. It is suggested that CXR is probably

not a suitable screening test for COPD in the elderly due to the complicated derivation of the CXR indices. However, its efficacy may be of some value in in-office diagnosis of COPD.

Key word : COPD, Elderly, Cost-Effectiveness, Chest Radiography, Screening

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Chronic Obstructive Pulmonary Disease (COPD) is known to have a high prevalence and immense socio-economic impact in both industrialized and non-industrialized communities. Our first study demonstrated the high prevalence and incidence of COPD among the urban elderly of Bangkok[1]. Identification of patients with COPD related symptoms and spirometric abnormalities reflect a population at risk for morbidity and mortality from both respiratory and nonrespiratory causes. Our second study emphasized the cost-effectiveness of a simple questionnaire for the early detection of COPD among the elderly living in same communities[2].

However, chest radiography (CXR) has been routinely practiced annually in elderly people by most physicians. The study of the cost-effectiveness of CXR as a screening test for COPD in the elderly has never been conducted before. This field study was the third part of the 11^{th} project out of 16 projects under the megaproject of Faculty of Medicine Siriraj Hospital on the Integrated Health Research Program for the Thai Elderly (IHRE) and aimed firstly to explore the CXR indices and secondly its cost-effectiveness as a screening test among the elderly using gold standard diagnostic criteria based on the guidelines of the Thoracic Society of Thailand[3].

MATERIAL AND METHOD

This study was approved by the Ethics Committee on Human Rights involving Human Research of the Faculty of Medicine Siriraj Hospital. The design of the study was cross-sectional. The inclusion criteria of subjects were all 3,123 elderly people aged 60 years and over residing in 124 communities within a radius of 10 km around Siriraj Hospital in January 1998 who were ambulatory and agreed to participate throughout the study. The exclusion criterion was the presence of upper respiratory tract infection on the day of the study. Spirometry and CXR (postero-anterior (P-A) and lateral) were performed in the community. Only data of those who could complete the spirometry and CXR were analyzed.

The spirometer used was the electronic turbine, flow sensing pneumotachometer Pony Graphic 3.0, Cosmed Co. Ltd. Italy which meets the standards of the American Thoracic Society[4]. Volume and flow were recorded in BTPS. Spirometry was performed in a sitting position with a nose clip, guided by a group of experienced respiratory technicians. $FEV_{1.0}$ and FVC were the maximal values from three acceptable graphs and the $FEV_{1.0}$/FVC ratio was from the best test curve. Pre as well as post bronchodilator spirometry values were recorded using two puffs of

Salbutamol from a metered dose inhaler *via* a spacer. The gold standard for diagnosing COPD was a ratio of $FEV_{1.0}$/FVC of less than 70 per cent with a reversibility of less than 15 per cent increase of postbronchodilator $FEV_{1.0}$ in the absence of parenchymal lesions and cardiomegly on the chest radiography(3). The severity of COPD was defined as an $FEV_{1.0} \geq 70$ per cent, 50-69 per cent and less than 50 per cent of predicted value as mild, moderate and severe degree of airways obstruction respectively.

With regard to the PA and lateral chest radiographs, the nine CXR indices for diagnosing COPD were based on the presence of hyperinflation in terms of the level and shape and height of right diaphragm, the diameter of the trachea, and the width of the retrosternal space (Fig. 1A, Fig. 1B).

These CXR indices were as followed :

1. Postrib : The position of right posterior rib at the level of the dome of the right diagphragm in PA position(5).

2. Antrib : The position of right anterior rib at the level of the dome of the right diaphragm in PA position(6,7).

3. Patrac : The coronal width of the trachea 1 cm above the aortic arch in PA position(8,9).

4. Lattrac : The sagittal width of the trachea 1 cm above the aortic arch in the lateral position(8,9).

5. Patra/lattrac (tracheal index) : The ratio of the width of the trachea in the PA position to the width of the trachea in the lateral position(8,9).

6. Retro : The width of the retrosternal space measured horizontally from the posterior part of the sternum to the most anterior part of the ascending aorta in the lateral position(10).

7. Padi : The height of the right diaphragm in the PA position or length of a perpendicular line from the top of the dome of the right diaphragm to the line joining the right lateral costophrenic angle and the right cardiophrenic angle(11).

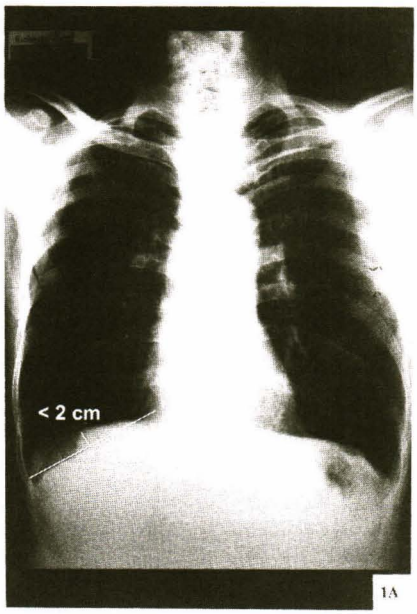
8. Ladi : The height of the right diaphragm in the lateral position or the length of a perpendicular line from the top of the dome of the right diaphragm to the line joining the anterior and posterior costophrenic angle(11).

9. Angle : A sterno-diaphragmatic angle ≥ 90 or < 90 degree in the lateral position(12).

Statistical analysis

The comparison between COPD and non-COPD subjects was performed using student's *t*-test. A p-value of < 0.05 indicates a statistically significant difference between the groups.

Each index was analyzed using univariate analysis and those with significant association underwent a Forward (LR) logistic regression. A receiver



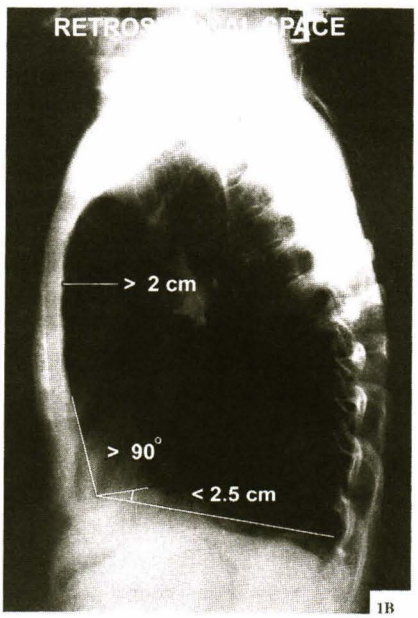


Fig. 1. CXR indices in A) for upright PA and in B) for lateral CXR.

operating characteristic (ROC) curve was used to analyze the sensitivity and specificity. The statistical analysis was performed using SPSS 9.05 for Windows.

The theoretical screening cut-off point of the indices is at the best average accuracy. The cost-effective screening cut-off point of the indices in the survey is at the lowest cost. Costs of spirometry and chest X-ray test were calculated from costs of equipment with depreciation, materials, personnel salaries and duration of the tests.

The screening program using CXR needed spirometry for confirmation and the derivation of the various costs were as follows :

$$\text{Cost for diagnosis} = [(T^+ + T^- + F^+ + F^-) \times 80.65] + [(T^+ + F^+) \times 92.4] \text{ baht}$$

One spirometry = 92.40 baht
Two views of chest radiography = 80.65 baht

As influenza infection is a significant cause of acute exacerbation of COPD (12th project of 16 project of IHRE). The false negative costs and the true positive costs were calculated as follows:-

F^-cost*** = (Number of F^- x cost for influenza treatment by severity in non-vaccinated group)
= (F^-_{mild} x 1682) + ($F^-_{moderate}$ x 5726)+ (F^-_{severe} x 7765) baht
T^+ cost = (Number of T^+ x cost of vaccine) + {Number of T^+ x (1-efficacy of vaccine) x average cost of influenza treatment for vaccinated group}
= (T^+ x 248.4) + (T^+ x 0.22 x 354) baht

*** refered to IHRE project No.12 i.e. the annual cost of influenza infection treatment for each case of mild, moderate and severe COPD were 1,682, 5,726 and 7,765 baht respectively[13].

RESULTS

Out of 3,094 (99.1% of total) elderly individuals who could complete spirometry and chest radiography, 220 cases had COPD according to the accepted definition. The characteristics of COPD and non-COPD cases are illustrated in Table 1. The COPD subjects were older, predominantly males and tobacco smokers with a higher number of pack- years than the non-COPD group.

Each CXR index underwent univariate analysis and calculated the area under the ROC curve, sensitivity, specificity, positive criteria and risk ratio (Table 2) that had a statistically significant association with COPD (except patrac).

CXR screening using these indices was obtained by score of one for the positive criteria of each index and zero score for the rest e.g. : padi $\leq$ 2.15 cm = 1, > 2.15 = 0, angle $\geq 90^\circ$ = 1, $< 90^\circ$ = 0 etc.

All the indices were analysed using multiple logistic regression and showed only seven indices in the Equation (1)

$$Z = 1/1+e^{-[-4.13 + (0.55\ padi) + (1.09\ ladi) - (0.65\ angle) + (0.92\ retro) + (0.5\ 1lattrac) + (0.63\ patrac/lattrac) + (0.91\ postrib)]} \ldots \text{Equation (1)}$$

Improvement Chi square = 10.43 (p-value 0.01), Model Chi square = 227.49 (p-value 0.000)

Table 1. Characteristics of COPD cases and non-COPD cases in the screening program.

	Population	COPD	Non-COPD	P-value*	Test
Number (cases)	3,094	220	2,874		
Age, mean ± SD (years)	67.9 ± 6.4	70.2 ± 6.7	67.7 ± 6.3	< 0.001	*t*-test
Sex (male : female)	0.6 : 1	2.6 : 1	0.6 : 1	< 0.002	χ^2
Smoker (%)	1,134 (36.6)	166 (75.5)	968 (33.7)	< 0.002	χ^2
Pack-year, mean ± SD	25.8 ± 24.4	32.8 ± 26.4	24.7 ± 23.8	< 0.001	*t*-test
Previous smoker (%)	449 (14.5)	64 (29.1)	385 (13.4)	< 0.002	χ^2
Current smoker (%)	685 (22.2)	102 (46.4)	583 (20.3)	< 0.002	χ^2
Non-smoker (%)**	1,959 (63.3)	54 (24.5)	1,905 (66.3)	< 0.002	χ^2

* COPD *vs* non-COPD, ** Tobacco smoking ≤ 0.5 pack-year

Table 2. Univariate analysis of CXR indices and positive criteria for diagnosing COPD*.

CXR index	Area	SE	P-value	95% CI	Sen	Spf	+ve criteria	RR	95% CI
1. Postrib	0.684	0.018	< 0.001	0.650-0.719	0.935	0.265	≥ 9th	4.50	3.11-6.51
2. Antrib	0.677	0.019	< 0.001	0.640-0.715	0.926	0.231	≥ 5th	4.88	3.03-7.86
3. Lattrac	0.575	0.021	< 0.001	0.533-0.617	0.565	0.604	≥ 1.95 cm	2.16	1.64-2.85
4. Patrac	0.513	0.022	0.522	0.470-0.557	0.943	0.059	≤ 2.05 cm	1.77	1.14-2.76
5. Patrac/lattrac	0.586	0.022	< 0.001	0.542-0.629	0.909	0.076	≤ 1.07	1.51	1.01-2.24
6. Retro	0.667	0.021	< 0.001	0.626-0.707	0.304	0.881	≥ 2.05 cm	3.64	2.66-4.97
7. Padi	0.617	0.020	< 0.001	0.578-0.656	0.737	0.448	≤ 2.15 cm	2.76	2.03-3.74
8. Ladi	0.743	0.017	< 0.001	0.710-0.777	0.710	0.679	≤ 2.65 cm	5.84	4.33-7.89
9. Angle					0.419	0.835	≥ 90°	4.10	3.07-5.46

* Area = area under ROC curve, CI = confidence interval, Spf = specificity, SE = standard error, Sen = sensitivity, RR = risk ratio

Table 3. Average accuracy at various cut-off points of CXR indices.

Z cut-off point	Sensitivity	Specificity	Average accuracy
0.50	0.5	100.0	50.2
0.20	33.2	94.3	63.7
0.10	60.5	82.9	71.7
0.07	75.9	72.4	74.1
0.04	84.1	60.3	72.2
0.02	94.1	33.9	64.0
0.01	100.0	3.9	51.9

Table 4. Severity of COPD subjects who gave a false negative score by CXR at various cut-off Z points.

Z cut-off point	Severity of COPD			Total
	Mild	Moderate	Severe	
0.50	140	54	25	219
0.20	95	39	13	147
0.10	62	20	5	87
0.07	37	13	3	53
0.04	25	9	1	35
0.02	8	4	1	13
0.01	0	0	0	0

The cut-off point for best average accuracy (Z score) of 74.1 per cent (95% CI 72.5-75.7) was 0.07 (Table 3) with a sensitivity of 75.9 per cent (95% CI 70.2-81.6) and a specificity of 72.4 per cent (95% CI 70.8-74.0), which implies that cases with a Z score from equation 1 of more than or equal to 0.07 are likely to have COPD.

From Table 4, at a Z cut-off point of 0.07, there were 53 missed COPD cases consisting of 37, 13, 3 cases of mild, moderate and severe COPD respectively.

For a cut-off point based on cost-effectiveness Z = 0.04 has been selected at the lowest grand total cost (Table 5).

To simplify Equation 1, the following Equation 2 is derived as follows :-

A = (0.55 x padi) + (1.09 x ladi) - (0.65 x angle) + (0.92 x retro) + (0.51 x lattrac) + (0.63 x patrac/lattrac) + (0.91 x postrib).....Equation (2)

It was found that :

"A" score $\geq$ 1.54 is the criterion for diagnosing COPD at a cut-off point at best average accuracy.

"A" score $\geq$ 0.95 is the criterion for diagnosing COPD by cost.

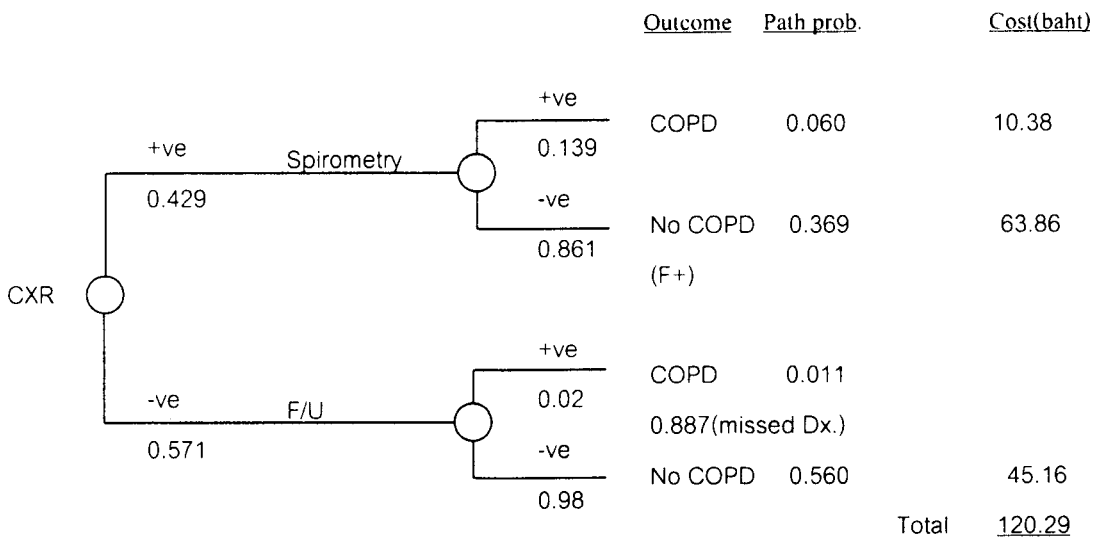


Diagram 1. The decision tree of the CXR screening test for COPD.

Using a CXR for screening one elderly for COPD by decision tree costs 120.29 baht (Diagram 1).

The details of cost-effectiveness of CXR screening program for COPD (Table 6) showed the cost to detect one case of COPD to be 2,008 baht and needed to screen 17 elderly individuals.

DISCUSSION

This study showed the efficacy of a CXR with two views as a screening test for diagnosing COPD using the gold standard diagnostic method of the Thoracic Society of Thailand and the simplified equation 2. However, there were seven indices to make this screening test possible with necessity of two

Table 5. Costs and outcome at various cut-off points (Z) of the CXR screening test.

Cut-off point Z	Sensitivity	Specificity	T+	T-	F+	F-	Cost for diagnosis (baht)	Cost for influenza infection treatment (baht)		Grand total cost (baht)
								F- cost	T+ cost	
0.50	0.5	100.0	1	2,873	1	219	249,716	738,809	326	988,851
0.20	33.2	94.3	8	2,711	163	147	271,338	484,049	23,818	779,205
0.10	60.5	76.2	133	2,382	492	87	307,281	335,279	43,395	685,955
0.08	74.5	72.4	164	2,119	755	56	334,447	165,013	53,510	552,970
0.07	75.9	66.2	167	2,082	792	53	338,143	159,967	54,489	552,599
0.05	81.4	60.3	179	1,818	1,056	41	363,645	121,568	58,404	543,617
0.04	84.1	42.9	185	1,732	1,142	35	372,146	101,349	60,362	533,857
0.02	94.1	33.9	207	975	1,899	13	444,126	44,125	67,540	555,791
0.01	100.0	3.9	220	113	2,761	0	524,976	0	71,782	596,758

Table 6. Cost-effectiveness of CXR screening test for COPD in Bangkok elderly.

No. of cases detected per subject screened	0.06	case
Missed diagnosis or false negative	1.1	%
False positive	36.9	%
No. of subjects screened to detect one COPD	16.7	subjects
Cost of screening one subject	120.29	baht
Cost to detect one case of COPD	2,008	baht

positions of PA and lateral views. The complexity of the method is noted.

Furthermore, the cost of two CXR in our study is 80.65 baht which included the technician's salary and did not include the cost of a doctor to interprete the result. In practice, the charge of a single CXR is at least 150 baht and two views will be 300 baht for each individual test (including a doctor to interprete the result), thus the real cost will be more expensive. From our study in order to detect one case of COPD using CXR as the screening method cost 2,008 baht. In comparison with the questionnaires, the CXR method was again more expensive.

It is apparently clear that CXR is probably not a useful screening method except to obtain additional data during the annual CXR check up for the elderly. Nevertheless, the Z score or A score for the efficacy of this CXR might be of some value to chest radiologists and chest specialists to help them diagnose COPD with confidence, i.e. it is useful as a diagnostic test rather than a screening test.

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ประสิทธิภาพของภาพรังสีทรวงอกในการตรวจคัดกรองโรคปอดอุดกั้นเรื้อรังในผู้สูงอายุของชุมชน กรุงเทพ ฯ†

เบญจมาศ ช่วยชู, พบ, นันทา มาระเนตร์, พด*, จริยา เลิศอรรฆยมณี, พบ**, ชนะ นฤมาน, วทม*, วันชัย เดชสมฤทธิ์ฤทัย, พบ*, ตรงธรรม ทองดี, พบ***, นิธิพัฒน์ เจียรกุล, พบ*, อรรถ นานา, พด*, วิษณุ ธรรมลิขิตกุล, พบ****, ทัศนียา สุธรรมสมัย, วทม*, สุธี แสงแก้ว, พยบ*, วิเชียร ศรีลำ, ป.วิทยาศาสตร์การแพทย์*, มนต์ชัย อักษรอินทร์, ป.ผู้ช่วยพยาบาล*, อมลวรรณ เดชผล, ศศบ*, ชัยรัตน์ เรืองแจ่ม, ป.ผู้ช่วยพยาบาล**

เนื่องจากผู้สูงอายุมักจะได้รับการตรวจติดตามสุขภาพด้วยภาพรังสีทรวงอกทุกปี ดังนั้นคณะผู้วิจัยจึงมีจุดประสงค์ที่จะศึกษาดัชนีทางเอกซเรย์ในการใช้ช่วยตรวจคัดกรองเพื่อวินิจฉัยโรคปอดอุดกั้นเรื้อรังในระยะเริ่มแรก ได้ทำการศึกษาผู้สูงอายุตั้งแต่ 60 ปีขึ้นไปใน 124 ชุมชนรอบโรงพยาบาลศิริราช เพื่อหาประสิทธิภาพของการตรวจด้วยภาพถ่ายรังสีทรวงอก ท่าหน้า-หลังและด้านข้าง ในการคัดกรองวินิจฉัยโรคปอดอุดกั้นเรื้อรังโดยอาศัยวิธีวินิจฉัยมาตรฐานของสมาคมอุรเวชช์แห่งประเทศไทย มีผู้สูงอายุ 3,094 ราย รับการตรวจครบทั้งภาพถ่ายรังสีทรวงอกและ spirometry

ผลการศึกษา พบว่า ดัชนีจากภาพถ่ายรังสีทรวงอกด้านหน้า-หลังและด้านข้างแสดง hyperinflation รวม 9 ดัชนี มีเพียง 7 ดัชนีที่ช่วยในการวินิจฉัย และได้เกณฑ์ค่าตัดสินของแต่ละดัชนีชัดเจน เมื่อนำมาหา Z score พบว่า Z score มากกว่าหรือเท่ากับ 0.07 ให้สงสัยเป็นโรคปอดอุดกั้นเรื้อรัง โดยจะมีความแม่นยำเฉลี่ยดีที่สุดคือ 74.1% (95% CI 72.5–75.7) ความไว 75.9%, (95% CI 70.2–81.6) ความจำเพาะ 72.4% (95% CI 70.8–74) ในการตรวจคัดกรองในชุมชนเพื่อให้เสียค่าใช้จ่ายน้อยที่สุด มีค่าดัชนีจากการตรวจภาพถ่ายรังสีทรวงอก Z score มากกว่าหรือเท่ากับ 0.04 ค่าใช้จ่ายเพื่อตรวจค้นได้โรคปอดอุดกั้นเรื้อรัง 1 ราย เป็นเงิน 2,008 บาท ต่อการตรวจกรองผู้สูงอายุ รวม 17 ราย คณะผู้วิจัยเชื่อว่า การตรวจคัดกรองโรคปอดอุดกั้นเรื้อรังในผู้สูงอายุด้วยภาพถ่ายรังสีทรวงอกอาจมีประโยชน์เพิ่มเติมจากการตรวจสุขภาพประจำปี

คำสำคัญ : โรคปอดอุดกั้นเรื้อรัง, ผู้สูงอายุ, ประสิทธิภาพ, เอกซเรย์ปอด, ตรวจคัดกรอง

เบญจมาศ ช่วยชู, นันทา มาระเนตร์, จริยา เลิศอรรฆยมณี, และคณะ
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