Application of Artificial Intelligence for Osteoporosis Screening Using Chest Radiographs

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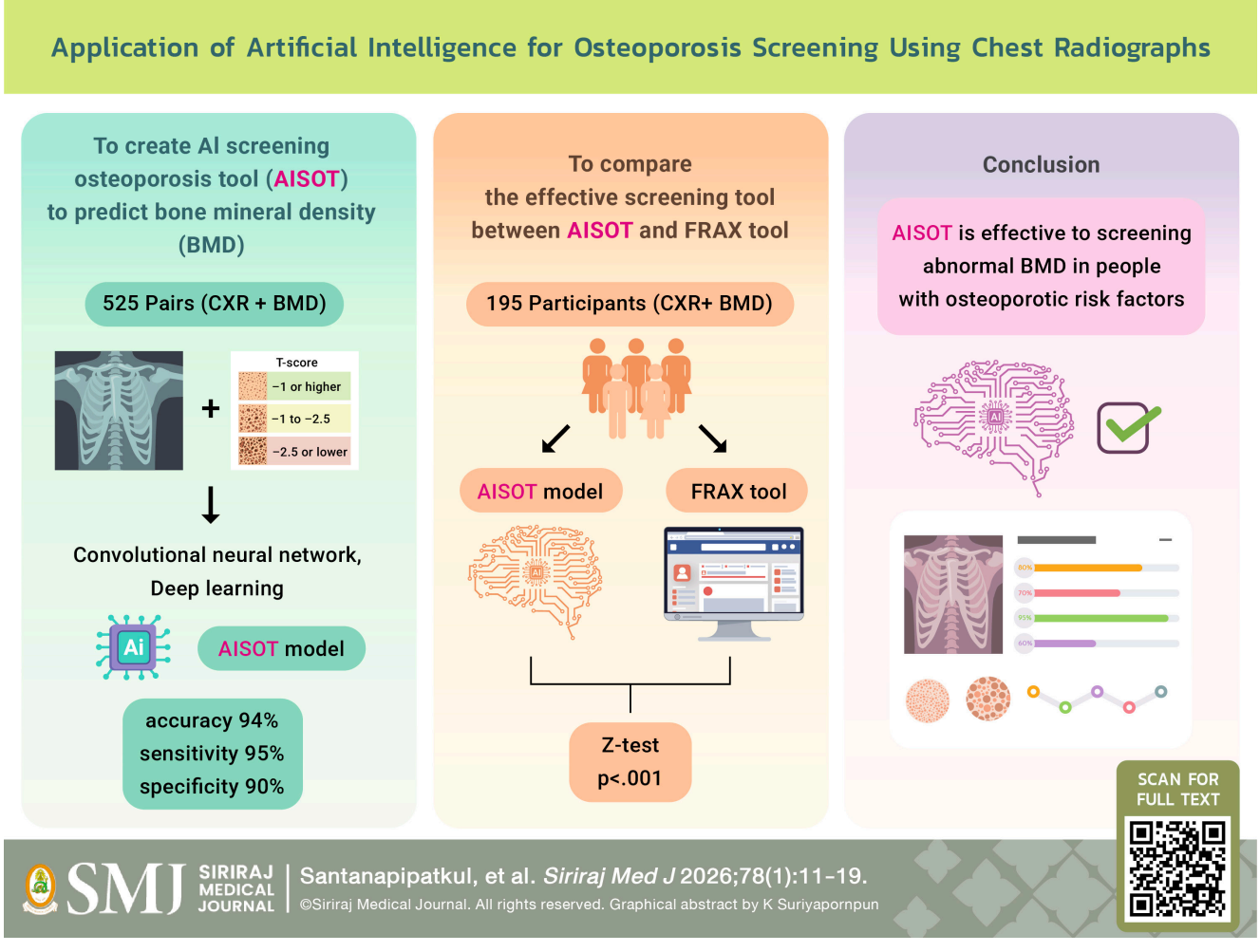

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ABSTRACT

Objective: To create the artificial intelligence screening osteoporosis tool (AISOT) to predict bone mineral density (BMD) using chest radiographs and to describe statistics characterizing the tool's effectiveness and satisfaction of the tool usage.

Materials and Methods: All 525 BMD examinations individually paired with chest radiographs during the years2022–2023. The AISOT was developed based on deep learning concept on chest radiograph images to predict BMD value. Both BMD observed and predicted values were classified osteoporosis condition by using T-scores of preclinical guidelines. The AISOT demonstrated the accuracy, sensitivity, specificity at 94% (95% CI: 84 -99%), 95% (95% CI: 83-99%) and 90% (95% CI: 56- 99%) respectively. The AISOT model was tested with 195 participants. The research instrument was a questionnaire developed by the researcher including personal health history, observed and predicted BMD values, FRAX tool osteoporosis evaluation and AISOT satisfaction. Z-test was utilized to compare statistics characterized the tool effectiveness.

Results: The AISOT vs the FRAX tool comprised accuracy at 74% (95% CI: 67- 80%) vs 51% (95% CI: 44 -58%) ($p < .001$); sensitivity at 61% (95% CI: 52-70%) vs 24 % (95% CI: 17-33%) ($p = .012$); specificity at 93% (95% CI: 85-98%) vs 92% (95% CI: 84-97%) ($p > .05$); PPV at 94% vs 83% ($p = .015$); NPV at 61% vs 44% ($p = .016$). AISOT satisfaction was at very satisfied level (mean = 4.81, SD.= 0.434).

Conclusions: AISOT is effective for screening abnormal BMD in people with osteoporotic risk factors. Future study of various settings will enhance its credibility.

Keywords: AI; BMD; osteoporosis; screening; chest radiograph (Siriraj Med J 2026;78(1):11-19)

INTRODUCTION

Osteoporosis is caused by decreasing systemic development of bone mineral density (BMD).[1] Osteoporosis typically remains as asymptomatic bone disease causing lack of concern to diagnose until bone fracture.[2] Elderly or lack of hormone balancing is more likely to stimulate the weakening process of the bone structure more rapidly.[2] Incidence of Osteoporosis in Thailand is around 20% in women and 10% in men, the age-adjusted incidence of hip fracture increased by 2% per year is rising from about 192.9 (males: 110.8; females: 272.1) to about 253.[3] (males: 135.9; females: 367.9) per 100,000 person-year.[3] In some cases even small accident could affect hip fracture that may cause a death around 12%.[4]

To detect osteoporosis, dual energy x-ray absorptiometry is the gold standard for examine BMD.[5] Lower BMD means higher chance to categorize as osteopenia to osteoporosis indicated higher severity.[5,6] There is a limitation of BMD examination due to high cost and limited availability. Even in Samutsakhon hospital, dual energy x-ray absorptiometry locates so far from the main hospital making it difficult to perform BMD.

To gain service reimbursement coverage from the government, criteria stated by Osteoporosis Institute of Thailand (OIT) must be met strictly.[7,8] For example, in male group the age must be older than 70 years. On the other hand, in female group the age must be older than 65 years old based on hormone deficiency condition. As stated by OIT, women at age less than 65 years who often eat meat without routinely exercise are likely to expose to osteoporosis incidence at 80-90%.[7] This implies that there are some people who do not meet the criteria but can still have abnormal bone mineral density.

According to the study done by Sachin Sharma, artificial intelligence (AI) was immersed to medical area to distinguish infected lung by Corona virus from others. Based on the same pattern, chest radiography (comprised several chest bones) could be used along with AI software to predict BMD referring to osteoporosis classification.[9] Therefore, the artificial intelligence screening osteoporosis tool (AISOT) was the main topic to serve research question in this study as can AISOT predict BMD accurately?

Fracture Risk Assessment Tool (FRAX) was developed by John A. Kanis, represented Sheffield University. The FRAX tool was widely used around 69 nationalities 34 languages availability to screen risk to have bone fracture.[10] The result from the FRAX tool was reported into 2 statements as in 10 year forward 1) the percentage of chance to have hip fracture (> 20 % must start osteoporosis treatment) 2) the percentage of chance to have other important bone fracture such as spine etc. (> 3 % must start osteoporosis treatment). To be evaluated by this tool did not need to input BMD value from the examination along with 12-item questionnaire related to fracture risk factors.

Effective and convenience osteoporosis screening tool could help determine the risk group to early detect abnormal BMD. Therefore, to compare differences of the characteristic statistics represent effective screening tool between the AISOT and FRAX tool (as its standard) would be useful.

Objectives

1. To create the AISOT to predict BMD.
2. To compare differences of the characteristic statistics represent effective screening tool between AISOT and FRAX tool.
3. To study satisfaction about AISOT utilization.

Research questions

1. Can AISOT predict BMD accurately?
2. Are there any significant differences between the characteristic statistics signifying effective screening tool of AISOT and FRAX tool?
3. How were samples satisfied by AISOT utilization?

Characteristic statistics of effective screening tool include sensitivity, specificity, accuracy, positive predictive value (PPV) and negative predictive value (NPV).

MATERIALS AND METHODS

A total of 525 BMD examinations during year from 2022 to 2023 personal-match paired with chest radiographs (within the interval of 1-year before and after period of the BMD examination date) were randomized through computer system. Eighty percent (423) out of the total chest radiographs were randomized and were employed as train set. Each 51 (10%) of the rest chest radiographs was used as valid set and test set to complete the model illustration to become osteoporosis screening tool.

The process of AI software program creation first taking place at each chest radiograph was transformed to pixel 8 bit pattern follow by value range 0-255, 128 x128 pixels. Then normalized value range was sent to convolutional neural network, then paired with BMD observe resulted from BMD examination and was turned to be algorithm coding.

According to BMD examination result, there were 3-group classification of osteoporosis condition as normal, osteopenia and osteoporosis. Based on the two by two table of screening test design, the osteoporosis must be categorized into 2 groups. Therefore, two models were generated based on criteria as follows:

Model 1:	BMD ≤ -1 (Osteopenia + Osteoporosis)	VS	BMD > -1 (Normal)
Model 2:	BMD ≤ -2.5 (Osteoporosis)	VS	BMD > -2.5 (Osteopenia + Normal)

The Model 1 characterized as normal vs osteopenia and osteoporosis indicated accuracy at 94% with the best benefit of sensitivity at 95% and specificity at 90% based on receiver operating characteristic (ROC) curve. Predicted BMD values were calculated.

To achieve deeper understanding regarding comparing effective screening tool performance between AISOT and FRAX tool, a total of 195 volunteers were recruited for the study. Inclusion and exclusion criteria were illustrated base on academic considerations to reduce bias in the study.

Inclusion criteria

1. Age 50 years or older who have had chest radiograph within 1 year. In case of age less than 50 years old, needed at least one of the following requirements.

1.1 Female had surgery to remove both of the ovaries or was diagnosed with low estrogen hormone condition at prior stage of menopause or taking aromatase inhibitor drug.

1.2 Male reported on androgen deprivation therapy.

1.3 Individuals who met at least one of the following criteria:

- Had a fragility fracture from a minor accident.
- Taking a glucocorticoid drug at a dose equivalent to 5 mg. of prednisolone daily for longer than 3 months.
- Reported at least one parent experienced a hip fracture though was a small accident.
- Maintained BMI < 20 kg/m^2
- Had a height lost of at least 4 cm or a loss of 2 cm per year compared to previous height
- Chest radiograph showed radiographic osteopenia or vertebral fracture

2. Held medical health benefit reimbursement for BMD examination.
3. Willing to participate in the study.

Exclusion criteria

1. Chest area operation history.
2. Diagnosed with bone cancer or cancer in any other organs with bone metastasis.
3. Diagnosed abnormal chest bones.

Both BMD (observed and predicted values) results have been classified to osteoporosis condition based on T-scores of preclinical guidelines (recommended by World Health Organization). Also, osteoporosis condition of each volunteer was classified by using FRAX tool. The comparison of the characteristic statistics represent effective screening tool between the AISOT and FRAX tool was done by using Z-test.

Research instruments

1. The AISOT developed by the researcher based on deep learning, convolutional neural network and transferring learning theory. The AISOT characterized the accuracy at 94% with sensitivity at 0.95 and specificity at 0.90 based on ROC curve (Table 3).

2. Questionnaires created by the researcher including

Part 1: Demographic data and 14 closed questions of osteoporosis risk factors

Part 2: Satisfaction questionnaire with 5 point Likert scale including 7 items

Data collection

After approval by ethical committee (SKH REC 153/2567/V.1), related divisions were approached to collaborate. Consent forms were completed by samples after agreement to participate in this research study. Questionnaire (part 1) was done by each participant. The researcher determined osteoporosis condition for each participant (face-to-face) by applying chest radiograph to AISOT. The results were kept in the system of each participant account with blinding concern to contaminate other research process. The information regarding BMD examination including appointment date, place and time were delivered to the participant. Each participant finished BMD examination. On the day appointment, each participant was educated regarding the result of BMD examination compared to AISOT at outpatient department. Satisfaction questionnaire (part 2) was done by participant. Further treatment was provided to each participant if needed.

Statistical analyses

The data were analyzed by using descriptive statistics relevant to show effective tool and tool usage satisfaction. The Z-test (inferential statistics) was utilized to signify two proportions significant differences.[11]

RESULTS

A total of 195 volunteers were classified as 120 (61.5%) hospital staff and 75 (38.5%) local health care providers. The majority of cases were female 186 (95.4%) participants. The mean of age was 59.09 (S.D. = 7.54) years old with the majority (55.9%) at the range of 50-59 years, minimum at 40 and maximum at 85 years old. Most of them (61.5%) held BMI less than 25 (kg/m^2). Around 20% have reported experienced bone fracture with 6.2% having father who experienced bone fracture as same as mother side around 6.7%. Around 2.6% reported having Rheumatoid arthritis. Around 1% of all participants had fragile bone condition, malabsorption of intestine, chronic liver disease, on steroid drug daily. The majority of female (89.7%) were in menopause hormone stage (Table 1).

After using the AISOT model to predict BMD in the samples, the tool resulted accuracy at 74% (95% CI: 67- 80%); sensitivity and specificity, PPV, NPV were at 61% (95% CI: 52-70%), 93% (95% CI: 85-98), 94% (95% CI: 86-97%), and 61% (95% CI: 55-66%) in order. The Likelihood Ratios for positive and negative tests were at 9.32 (95% CI: 3.95- 22.02) and 0.41 (95% CI: 0.33- 0.52) (Table 3).

After using BMD observe value result of each participant along with other independent risk factor to predict the osteoporosis condition, the result showed that FRAX tool accuracy was at 51% (95% CI: 44- 58%). With the same order according to the AISOT, the results of FRAX tool were at 24% (95% CI: 17-33%), 92% (95% CI: 84-97%),83% (95% CI: 68-92%), 44% (95% CI: 41-47%), 3.09 (95% CI: 1.35- 7.08) and 0.82 (95% CI: 0.73- 0.93) for sensitivity, specificity, PPV, NPV, the likelihood ratios for positive and negative tests in sequence (Table 3).

The proportion comparisons between the results of these tools showed that accuracy was highly significantly different ($Z = 3.359$, $p < .001$) and sensitivity, PPV and NPV were significantly different ($Z = 5.290$, $p = .012$; $Z = 0.94$, $p = .015$; and $Z = 2.407$, $p = .016$). Specificity was not significantly different (Table 4). The Pre-test probability was at 0.61. Post-test probability was at 0.94 (Table 3). This means that The AISOT increased the likelihood to find osteoporosis cases improve from 61 to 94% (33% increased) meanwhile FRAX tool has been improved seeking cases around 21% (61% to 82%).

For tool satisfaction, participants responded very satisfied to the AISOT regarding reduce difficulty (mean = 4.82, SD. = .426), safe time to perform (mean = 4.83, SD. = .418), safe cost (mean = 4.81, SD. = .430), very convenient to use (mean = 4.80, SD. = .438), support treatment planning (mean = 4.80, SD. = .438), increase knowledge to help other people (mean = 4.81, SD. = .434), in general (mean = 4.81, SD. = .434).

DISCUSSION

The AISOT was established to predict BMD. The AISOT was promising screening tool due to low cost, ease of use, rapid assessment and reasonable precision (74%) result. Seeking osteoporosis as soon as possible for early treatment was the main goal in this study. The discussion of AISOT as effective screening tool will be discussed as follows:

Osteoporosis, mainly cause of bone fracture referring to severe morbidity or mortality in some cases.[7] This

TABLE 1. Demographic data of samples (N = 195).

Demographic data	Number	Percentage (%)
Status (Hospital staff/ Health care volunteers)	120/75	61.5/38.5
Gender (Male/Female)	9/186	4.6/95.4
Age		
40 - 49	9	4.6
50 - 59	109	55.9
60 - 69	55	28.2
70 - 79	18	9.2
80 and above	4	2.1
Mean = 59.09 (S.D. = 7.54) Minimum = 40 Maximum = 85		
BMI (kg/m^2)		
18.49 and less	10	5.1
18.50 - 22.99	71	36.4
23.00 - 24.99	39	20.0
25.00 – 29.99	58	29.7
30.00 and above	17	8.7
Bone fracture experience* (Yes/No)	38/155	19.7/80.3
Does father have hip fracture* (Yes/No)	12/181	6.2/93.8
Does mother have hip fracture* (Yes/No)	13/180	6.7/93.3
Rheumatoid arthritis* (Yes/No)	5/188	2.6/97.4
Type I Diabetes* (Yes/No)	2/191	1.0/99.0
Secondary osteoporosis* (Yes/No)	2/191	1.0/99.0
Hyperthyroidism* (Yes/No)	8/185	4.1/95.9
Hormone deficiency* (Yes/No)	6/187	3.1/96.9
Chronic malnutrition* (Yes/No)	0/193	0.0/100.0
Absorption disorder* (Yes/No)	2/191	1.0/99.0
Chronic liver disease* (Yes/No)	2/191	1.0/99.0
Steroid daily intake* (Yes/No)	3/190	1.6/98.4
Only female with menopause** (Yes/No)	165/19	89.7/10.3

*n = 193; **n=186

TABLE 2. Diagnosis of osteoporosis classified by BMD with AISOT result and FRAX result.

		BMD		
		Positive	Negative	Total
AISOT (FRAX)	Positive	73 (29)	5 (6)	78 (35)
	Negative	46 (90)	71 (70)	117 (160)
	Total	119	76	195

Abbreviations: BMD, bone mineral density; AISOT, artificial intellectual screening osteoporosis tool; FRAX, fracture risk assessment tool

TABLE 3. The statistics characterized screening tool effectiveness of osteoporosis classified by AISOT, FRAX and the original created AISOT.

Statistics	AISOT (95% CI) (n=195)	FRAX (95% CI)	Original (n=525)
Sensitivity	0.61 (0.52, 0.70)	0.24 (0.17, 0.33)	0.95 (0.83, 0.99)
Specificity	0.93 (0.85, 0.98)	0.92 (0.84, 0.97)	0.90 (0.56, 0.99)
Accuracy	0.74 (0.67, 0.80)	0.51 (0.44, 0.58)	0.94 (0.84, 0.99)
Positive predictive value (PPV)	0.94 (0.86, 0.97)	0.83 (0.68, 0.92)	0.97 (0.86, 0.99)
Negative predictive value (NPV)	0.61 (0.55, 0.66)	0.44 (0.41, 0.47)	0.82 (0.53, 0.95)
Likelihood Ratios for positive test	9.32 (3.95, 22.02)	3.09 (1.35, 7.08)	9.51 (1.48, 61.15)
Likelihood Ratios for negative test	0.41 (0.33, 0.52)	0.82 (0.73, 0.93)	0.05 (0.01, 0.21)
Prevalence or Pre-test probability	0.61 (0.54, 0.68)	0.80 (0.67, 0.90)	
Pre-test odds	1.56	1.56	
Post-test odds	14.58	4.83	
Post-test probability	0.94	0.82	

Abbreviations: BMD, bone mineral density; AISOT, artificial intelligence screening osteoporosis tool; FRAX, fracture risk assessment tool

TABLE 4. The statistics characterized screening tool effectiveness of osteoporosis classification using Z test for proportional comparison.

Statistics	AISOT	FRAX	Z	p
Sensitivity	0.61	0.24	5.290	.012
Specificity	0.93	0.92	.268	> .05
Accuracy	0.74	0.51	3.359	< .001
Positive predictive value (PPV)	0.94	0.83	.94	.015
Negative predictive value (NPV)	0.61	0.44	2.407	.016

Abbreviations: AISOT, artificial intelligence screening osteoporosis tool; FRAX, fracture risk assessment tool

AISOT was established and was expected to utilize in osteoporosis risk group, 50-year-old or older, to find actual osteoporosis cases. The finding of accuracy at 74% was congruent with some previous studies have held same concept of using AI working on chest radiographs in screening but difference settings. For example, from 31 prior studies the accuracy was ranged from 66.1% to 97.9% (this finding was 74%). Sensitivity and specificity was ranged from 67.4% to 100.0% (this finding was 61%), and 60.0% to 97.5% (this finding was 93%) respectively.[12] This indicates that AI has potential to classify chest radiographs detailed similarly. Deeper insight of AI utilization in technology (how AI works better) along with clinical screening (earlier detection) will be a challenge for further research study. The improvement of finding real cases with AISOT utilization compared to without the AISOT was 33% (61% to 94%).

As a part of health check-up procedures, chest radiography usually have done annually refer to higher chance to access. The AISOT working on the chest radiography to seek high risk cases of osteoporosis for further investigations. Even if chest radiography was not available, to do so it is affordable and accessible in most health care places.[13] As far as the AISOT was utilized, the benefits range from early detection to early treatment with very low side effect. However, the AISOT has some acknowledged limitations as follows:

Due to limited participants for the study, sample selection contained sampling bias because they were selected based on inclusion criteria then volunteers were involved with no effect of randomization process.[14] Lack of external validation in the study may cause less promise of same potentially model's performance reported in the research result. In prospective future research, having greater number of sample size with various datasets from multicenter and using randomized sampling technique will gain more credibility, validity and reliability to generalize the research application.

Recently, FRAX tool has been popular in many countries.[9] In this study the prevalence of osteoporosis was 61%. High prevalence of disease could affect the sensitivity value.[15] In this study, the FRAX tool held the sensitivity at 24% lower than that of the AISOT with statistically significant difference. (p = .012). Unlike the specificity between the AISOT and FRAX tools (0.93 VS 0.92) showed that there is no significant difference. The explanation could be less availability of the Dual energy x-ray absorptiometry as a result the cutoff point used to serve high rate of true negative cases. Also, the likelihood ratios for positive test (less affected by the prevalence rate compare to positive predictive value) between the AISOT and FRAX tools were at 9.32 VS 3.09. This means the AISOT was better classification of positive outcome. Contrasting likelihood ratios for negative test, the FRAX tool was at 0.82 better than the AISOT was at 0.41.

According to the Fagan's Nomogram,[16] the result showed pre-test probability was 0.61, pre-test odds at 1.56, post-test odds at 35.15, post-test probability at 0.97, this means the AISOT help to screen abnormal BMD 28% higher than without the tool (Fig 1).

In term of research utilization, there are many factors need to consider as follows:

1. Osteoporosis was not identified as life threatening disease based on the disease progression like cancer but it could cause death in some cases based on accident definition like unpredictable occurrence.

2. Similar to most diseases, the concept of early detection to access early treatment definitely gains advantages. Osteoporosis treatment before fracture occurs referring to operation or cervix cancer screening before metastasis stage are agreed to gain obvious advantages.

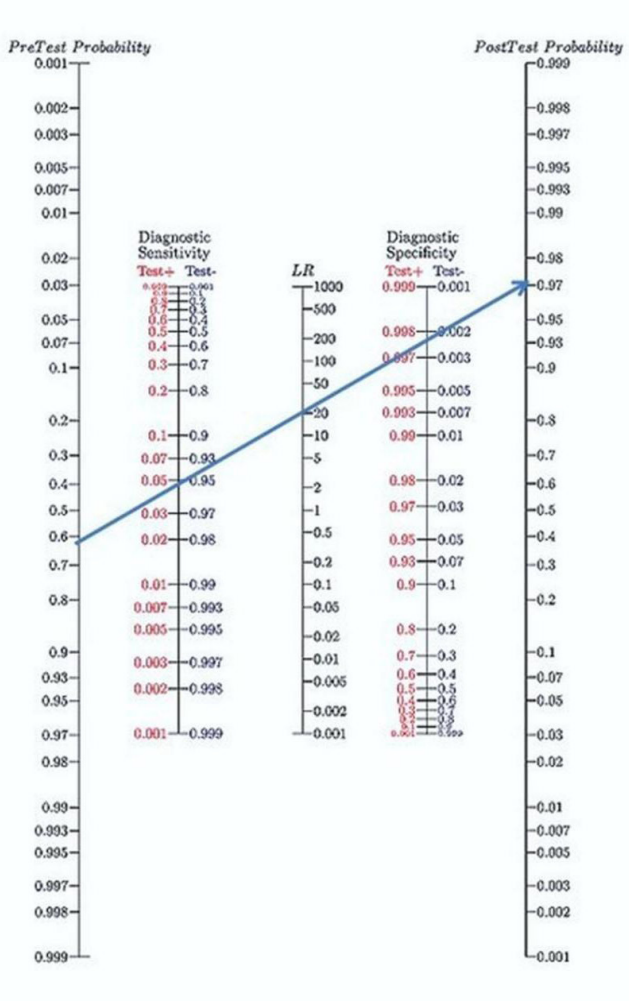

Fig 1. Fagan's Nomogram

3. To apply the AISOT in the high risk group as seniors will find the cases more than utilize in other group. However, national policy should be developed to serve the positive screening results to prevent negative health care service frustration.

4. National health care policy should be served the progression of the research finding such as health check-up yearly especially in non-high risk group with AISOT screening application and BMD examination regarding the positive result should be considered in the future.

CONCLUSION

The AISOT is a useful tool for screening abnormal BMD in people with osteoporosis risk factors due to no harm. Further prospective study with multicenter settings will help to perform sample selection with randomization. Lack of bias and error will obviously indicate better AISOT's performance to gain its credibility, validity and reliability to become popular clinical utilization.

Data Availability Statement

The data that support the findings of this study are not publicly available due to privacy and ethical restrictions related to the Personal Data Protection Act (PDPA) of Thailand. Data may be available from the corresponding author (Polasan Santanapipatkul) upon reasonable request and with permission from the Siriraj Institutional Review Board.

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Conflict of Interest

All the authors confirm that they have no personal or professional conflicts of interest to declare relating to any aspect of this research study.

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Author Contributions

Conceptualization and methodology, P.S, A.C., L.J. and N.W. ; Investigation, P.S., A.C. and L.J. ; Formal analysis, A.C. and L.J. ; Visualization and writing – original draft, P.S. ; Writing – review and editing, P.S., A.C. and L.J. ; Supervision, R.N. All authors have read and agreed to the final version of the manuscript.

Use of Artificial Intelligence

Artificial intelligence was not used in the preparation of the manuscript. All study concepts, analysis, interpretation, and writing were carried out by the authors.

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