การหาความแม่นยำของระบบการรายงานผลอัลตร้าซาวด์ American College of Radiology Thyroid Imaging, Reporting and Data System (ACR TI-RADS) เพื่อทำนายมะเร็งไทรอยด์ในประชากรไทย

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Abstract: The Diagnostic Accuracy of American College of Radiology Thyroid Imaging, Reporting and Data System (ACR TI-RADS) Ultrasound Classification for Diagnosing Thyroid Carcinoma in Thai Population

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Background: Thyroid carcinoma is the most common endocrine tumor. Both ultrasonography and Fine needle aspiration should be performed for accurate diagnosis and evaluation. The American College of Radiology Thyroid Imaging Reporting and Data System (ACR TI-RADS) is a risk stratification system for thyroid lesions, based on sonographic characteristics. Objective: The aim of this study was to determine the predictive value of ACR TI-RADS in prognostication of malignancy across the Thai population. Method: We conducted a retrospective, study in Queen Savang Vadhana Red Cross Memorial Hospital, Thailand between January 2020 and September 2021. Data from 125 patients with 201 thyroid nodules who underwent ultrasonography using TIRADS classification, FNA biopsy and histopathology report were collected. The sonographic features were described according to ACR TI-RADS. These results were analyzed for sensitivity, specificity, and predictive values using SPSS. Results: ACR TI-RADS had specificity of 73.6% and sensitivity of 70.5%. Positive predictive value and negative predictive value of 58.2%

and 82.7%, respectively. The accuracy of the ACR TI-RADS in our study was 71.6%. The prevalence of malignancy in TR1, TR2, TR3, TR4, and TR5 was 0%, 0%, 22%, 42%, and 92%, respectively. The echogenic foci has the highest area under the curve for detecting thyroid malignancy. Bethesda score 3 delivered as the cutoff for identifying malignant nodules in the TR4 and TR5 groups with sensitivity 86.7, and specificity 85.7. **Conclusion:** The ACR TI-RADS provides effective malignancy risk stratification for thyroid nodules. Thyroid nodules classified as TR4 or TR5 in our study are highly suspicious for malignancy and should be considered as indication for FNA.

Keywords: ACR TI-RADS, Thyroid carcinoma, Thyroid nodule, Malignancy risk

บทคัดย่อ

ภูมิหลัง: มะเร็งไทรอยด์เป็นมะเร็งต่อมไร้ท่อที่พบมากที่สุดชนิดหนึ่ง การอัลตร้าซาวด์เป็นการตรวจอย่างหนึ่งเพื่อช่วยในการวินิจฉัยมะเร็งไทรอยด์ โดย The American College of Radiology Thyroid Imaging Reporting and Data System (ACR TI-RADS) เป็นการจัดกลุ่มความเสี่ยงในการเป็นมะเร็งไทรอยด์โดยใช้ลักษณะก้อนที่ต่อมไทรอยด์จากผลอัลตร้าซาวด์ **วัตถุประสงค์:** ศึกษาการรายงานผลอัลตร้าซาวด์ไทรอยด์ ACR TI-RADS เพื่อพยากรณ์โรคมะเร็งไทรอยด์ ในประชากรไทย **วิธีการ:** การศึกษาย้อนหลังโดยเก็บข้อมูลผู้ป่วยก้อนที่ต่อมไทรอยด์ที่ได้รับการตรวจด้วยอัลตร้าซาวด์และการผ่าตัดตั้งแต่ เดือนมกราคม พ.ศ. 2563 ถึงกันยายน พ.ศ. 2564 จำนวน 201 ก้อนจากผู้ป่วย 125 คน โดยเก็บรวบรวมจากฐานข้อมูลของโรงพยาบาลสมเด็จพระบรมราชเทวี ณ ศรีราชา และวิเคราะห์ข้อมูลหาความแม่นยำโดยใช้โปรแกรม SPSS **ผล:** พบว่าการตรวจอัลตร้าซาวด์ ACR TI-RADS มีความจำเพาะ 73.6% ความไว 70.5% ค่าการทำนายเชิงบวก 58.2% ค่าการทำนายเชิงลบ 82.7% และค่าความแม่นยำ 71.6% โดยพบค่าความชุกการเกิดมะเร็งของ TR1, TR2, TR3, TR4, และ TR5 ที่ 0%, 0%, 22%, 42%, และ 92% ตามลำดับ นอกจากนี้ลักษณะทางอัลตร้าซาวด์ที่มีประสิทธิภาพในการทำนายการเกิดมะเร็งมากที่สุดได้แก่ echogenic foci และเมื่อพิจารณาก้อนที่ต่อมไทรอยด์กลุ่ม TR4 และ TR5 ร่วมกับผลการเจาะดูดเซลล์ พบกว่า Bethesda กลุ่ม 3 ขึ้นไปสัมพันธ์กับการเกิดมะเร็งที่ความจำเพาะ 86.7% และความไว 85.7% **สรุป:** ACR TI-RADS มีประสิทธิภาพในการทำนายความเสี่ยงการเกิดมะเร็งต่อมไทรอยด์ โดยพบโอกาสการเกิดมะเร็งมากในกลุ่ม TR4 ขึ้นไป โดยควรพิจารณาเจาะดูดเซลล์ในผู้ป่วยกลุ่มนี้

คำสำคัญ: อัลตร้าซาวด์ไทรอยด์, มะเร็งไทรอยด์, ก้อนที่ต่อมไทรอยด์, ความเสี่ยงในการเกิดมะเร็ง

Introduction

Thyroid cancer is the most common malignancy in the endocrine system. Thyroid cancer makes up 14.8%[1] of all detected thyroid nodules. Although the incidence of thyroid cancer is suspected to have been increasing in the recent years, the mortality rate does not share a similar trend. A possible explanation might be recent advancements facilitating more sensitive investigation and diagnostic modalities.[2-4] Small size thyroid cancer is detected and treated while it is rather slow progressed. Common thyroid nodule evaluation procedures make use of ultrasound, computer tomography scan, and fine needle aspiration. Ultrasound affords the most effective means of imaging as it is easy to use, supports the classification of nodule characteristics, and is cost effective.[5] Many classifications of thyroid nodule ultrasound have been created such as The American College of Radiology Thyroid Imaging Reporting, and Data System (ACR TI-RADS), the American Thyroid Association (ATA) Classification, the Korean Thyroid Imaging Reporting and Data System (K-TIRADS), the European Thyroid Association TIRADS (EU-TIRADS) and the Siriraj TI-RADS[6] to stratify each thyroid nodule, to indicate need for further biopsy and surgery, as follow-up. ACR TI-RADS offers the most effective criterion in reducing unnecessary biopsy with the highest relative diagnosis odds ratio among other classifications.[7, 8]

The ACR Thyroid Imaging Reporting and Data System is a point-based system introduced in 2017,[9, 10] whose aim is to create an uncomplicated classification, applicable to all ultrasounds. ACR TI-RADS can reduce unnecessary biopsies by 19.9-46.5% from their higher size threshold for biopsy. This, in turn, reduces the overdiagnosis.[11] The ACR TI-RADS classifies ultrasonographic findings via 5 characteristics. The total score from each ultrasound characteristic divides nodules into 5 groups, TR1, TR2, TR3, TR4, and TR5, in order of increasing risk of malignancy. Each TR group will have the cut-off size for follow-up, or fine needle aspiration.

There are two previous studies in Thailand which shows effective malignancy risk stratification in ACR TI-RADS.[12, 13] However, there are few participants, and the Bethesda system was not taken into account when analyzing the outcomes of fine needle aspiration.

Therefore, we want to investigate it more thoroughly.

The goal of this study is to evaluate the predictive values of ACR Thyroid Imaging Reporting, and Data System, and the associated ultrasound characteristics in the Thai population.

Materials and Methods

Selection of patients and nodules

This is a retrospective, study performed at Queen Savang Vadhana Memorial Hospital, Chonburi, Thailand. The study was approved by the medical ethics committee board, and informed consent was exempted. A retrospective search was done in the hospital database for patients with thyroid nodules who underwent thyroid surgery between January 2020 and September 2021. The sample size was estimated from infinite population proportion for the prevalence of 14.8% [1], a confidence level of 95%, a margin of error is .05 and a critical value is 1.96. the calculated sample size is 196.

The inclusion criteria were thyroid nodules of any size, with a complete ultrasonographic and a pathological report from thyroidectomy as a gold standard for thyroid cancer diagnosis. The exclusion criteria were any pathology with un-interpreted results. If the patient had more than one nodule, only nodule with a complete information was included. One hundred and twenty-five patients with a total of two hundred and one nodules were included in this study.

ACR TI-RADS

The TIRADS score was calculated in terms of five categories: 1. Composition (cystic, spongiform, mixed cystic and solid, solid); 2. Echogenicity (anechoic, hyperechoic or isoechoic, hypoechoic, very hypoechoic); 3. Shape (wider then tall, taller than wide); 4. Margin (smooth, Ill-defined, lobulated or irregular, extra-thyroidal extension); 5. Echogenic foci (none, or large comet-tail artifacts, macrocalcification, peripheral calcifications, punctate echogenic foci), size of each thyroid nodule, and evidence of abnormal cervical lymph nodes was noted. We categorized TR1, TR2, TR3 as a likely negative for malignancy group, and TR4, TR5 as a likely positive for malignancy group.

Examiner, reviewer

Ultrasonographic examinations were performed with a Canon Aplio i700, PLT-1005BT 10 MHz linear transducer probe, and a LOGIQ E9, ML6-15 linear transducer probe by a board-certified radiologist. If a patient had undergone multiple thyroid ultrasound examinations, the one with the closest date to the FNA or surgery was chosen. All results were reported according to ACR TI-RADS guideline 2017.

Fine needle aspirations

Fine needle aspiration was carried out by ultrasound-guided technique in non-palpable, and multiple nodules by certified radiologists, and with non-ultrasound guided technique in the single palpable nodule by otolaryngologists and surgeons. Results were reported in the Bethesda System for Reporting Thyroid Cytopathology[14]. The system comprises six categories, namely: non-diagnostic, benign, atypia of undetermined significance, follicular neoplasm, suspicious of malignancy, and malignant.

Data and statistical analysis

The prevalence of malignancy for each ACR TI-RADS category was calculated. A contingency table was created to analyze the sensitivity, specificity, positive predictive value, negative predictive value, and the area under the curve representing the ultrasound characteristics to support diagnosis. Data analyses were performed using SPSS statistics version 28. The Chi-square statistic was used in conjunction with P-value corresponding to independent t test. The diagnostic statistic was reported with sensitivity, specificity, positive predictive value, negative predictive value, and accuracy with cut-off by Youden's index. ROC analysis was used to find the area under the curve.

Results

Age and sex

Adult subjects age ranged from 21 to 80 years old; the mean age was 44.7 years, with a significant number of younger age patients being in the malignancy group. Among 125 subjects, there were 19 male (18%) and 106 female (81%). In terms of nodule and sex, 174 nodules were found in female patients while only 27 were found in male patients, a definite female preponderance [Table 1].

Data on nodules

201 nodules in 125 people were included in this study with 72 (35.8%) malignant nodules, and 129 (64.2%) benign nodules. Nodules' sizes varied: range 0.3 – 9.8 cm. The overall mean size was 2.68 cm (SD = 1.76). The mean

size in the malignancy group was 2.49 cm (SD = 1.55), and 2.78 cm (SD = 1.87) in benign group. All nodules underwent ultrasound examination and surgery, and their histopathologies were evaluated (100%), while fine needle aspiration was done in 83 nodules (41.3%).

ACR-TIRADS scores and Malignancy

In Table 1, ACR-TIRADS scores distribution were 5.5%, 7.5%, 41.8%, 31.3%, and 13.9% in TR1, TR2, TR3, TR4 and TR5 respectively; in addition, prevalence, or percentages of malignancy in relation to severity of ACR-TIRADS scores were 0%, 0%, 22.6%, 42.8% and 92.8% respectively. For sensitivity and specificity according to the primary outcomes, ACR TI-RADS had sensitivity of 73.6% and specificity of 70.5%. The accuracy was 76.1; and the negative predictive values was 82.7% [Table 2].

Table 1 : Baseline Characteristics and ACR TI-RADS According to Malignancy at Final Diagnosis

CHARACTERISTICS	Total (n = 201)	Malignant (n = 72)	Benign (n = 129)	p-value
Size (cm)	2.68 ± 1.76	2.49 ± 1.55	2.78 ± 1.87	.273
GENDER				.887
Male	27 (13.4%)	10 (13.9%)	17 (13.2%)	
Female	174 (86.6%)	62 (86.1%)	112 (86.8%)	
Age (YEAR)	44.7 ± 12.94	39.97 ± 12.25	47.33 ± 12.6	<.001*
TIRADS score (total)	4.01 ± 2.12	5.5 ± 2.35	3.18 ± 1.41	<.001*
TR 1	11	0 (0%)	11 (100%)	
TR 2	15	0 (0%)	15 (100%)	
TR 3	84	19 (22.6%)	65 (77.4%)	
TR 4	63	27 (42.8%)	36 (57.2%)	
TR 5	28	26 (92.8%)	2 (7.2%)	

*$p < .05$, ACR TI-RADS = American College of Radiology Thyroid Imaging, Reporting and Data system

Ultrasound Characteristics

Among ultrasound (US) characteristics and statistic results, echogenic foci showed the largest amount of area under the curve (AUC) of 0.702, followed by echogenicity of 0.672, and composition of 0.633 [Figure1]. Cut-offs were at 2, 2, 3, 3, 1 in composition, echogenicity, shape, margin, and echogenic foci, respectively. In the detection of malignancy, composition had the most sensitivity of 98.6%, and margin had the most specificity of 99.2% [Table 3].

Abnormal cervical lymph nodes were detected in 32 out of 201 patients (15.92%). The percentage of abnormal lymph nodes was higher in the malignancy group compared to the benign group. The abnormal nodes were found in 21 nodules out of 72 nodules (29.16%) with malignancy, and in 11 nodules out of 129 (8.52%) without malignancy. The sensitivity of the ultrasound test in detecting malignancy in cervical nodules was 29%, and the specificity was 91.4%.

Table 2 : Diagnostic accuracy of ACR TI-TADS

	Sensitivity	Specificity	PPV	NPV	Accuracy	P-value
TR ≥ 3	100.0%	20.2%	41.1%	100.0%	48.8%	<.001*
TR ≥ 4	73.6%	70.5%	58.2%	82.7%	71.6%	<.001*
TR = 5	36.1%	98.4%	92.9%	73.4%	76.1%	<.001*

* $p < .05$, PPV = Positive predictive value, NPV = Negative predictive value

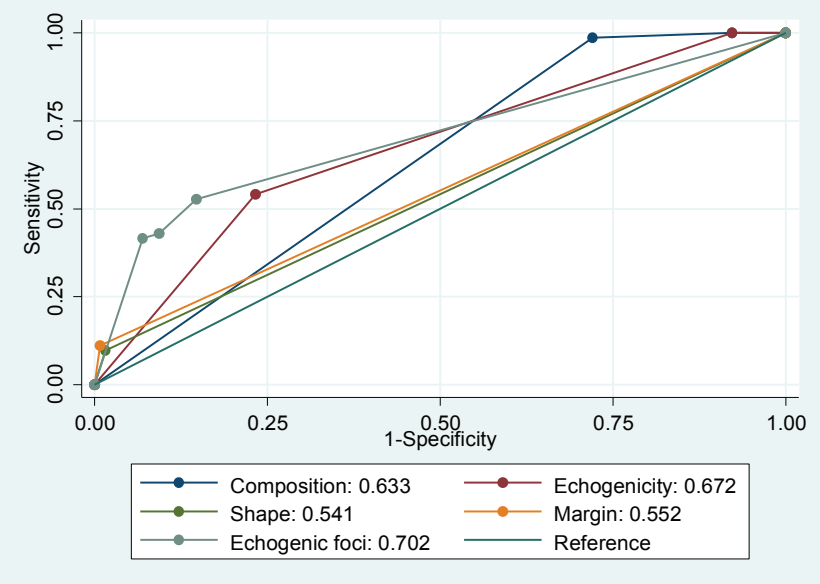

Figure 1 : The Receiver Operator Characteristic (ROC) curve of ACR TI-RADS Ultrasonographic Features

Table 3: Predictive value of ACR TI-RADS and Ultrasonographic Features in Prognostication of Thyroid Nodule Malignancy

Variables	Sensitivity	Specificity	PPV	NPV	Accuracy	*p*-value
Composition						
0	100.0%	0.0%	35.8%	N/A	35.8%	N/A
1	100.0%	7.8%	37.7%	100.0%	40.8%	.015*
2	98.6%	27.9%	43.3%	97.3%	53.2%	<.001*
Echogenicity						
0	100.0%	0.0%	35.8%	N/A	35.8%	N/A
1	100.0%	7.8%	37.7%	100.0%	40.8%	.015*
2	54.2%	76.7%	56.5%	75.0%	68.7%	<.001*
Shape						
0	100.0%	0.0%	35.8%	N/A	35.8%	N/A
3	9.7%	98.4%	77.8%	66.1%	66.7%	.007*
Margin						
0	100.0%	0.0%	35.8%	N/A	35.8%	N/A
3	11.1%	99.2%	88.9%	66.7%	67.7%	.001*
Echogenic foci						
0	100.0%	0.0%	35.8%	N/A	35.8%	N/A
1	52.8%	85.3%	66.7%	76.4%	73.6%	<.001*
2	43.1%	90.7%	72.1%	74.1%	73.6%	<.001*
3	41.7%	93.0%	76.9%	74.1%	74.6%	<.001*

* $p < .05$, PPV = Positive predictive value, NPV = Negative predictive value

Fine Needle Aspirations

Fine needle aspirations were performed in accordance with Bethesda categories in 83 nodules. Predictive values were found, based on 44 of 84 nodules in TR4 and TR5 groups which we classified as a likely positive for the malignancy group. [Table 4].

Table 4: Predictive value of ACR TI-RADS TR4, TR5 and Fine Needle Aspiration in Prognostication of Thyroid Nodule Malignancy (N = 44)

Bethesda CATEGORY ≥	Sensitivity	Specificity	PPV	NPV	Accuracy	*p*-value
I	100.0%	0.0%	68.2%	N/A	68.2%	N/A
II	93.3%	28.6%	73.7%	66.7%	72.7%	.049*
III	86.7%	85.7%	92.9%	75.0%	86.4%	<.001*
IV	66.7%	92.9%	95.2%	56.5%	75.0%	<.001*
V	50.0%	92.9%	93.8%	46.4%	63.6%	.006*
VI	20.0%	100.0%	100.0%	36.8%	45.5%	.072

*$p < .05$, PPV = Positive predictive value, NPV = Negative predictive value

Discussion

The ACR TI-RADS classification guideline has become one of the most used sonographic risk stratification systems.[15] Its key advantage is preventing unnecessary fine needle aspiration, and overdiagnosis. Recent meta-analysis shows the highest relative diagnosis odds ratio in ACR TI-RADS among ATA, Kwak TI-RADS, Korean TI-RADS and EU TI-RADS.[8] However, the efficacy of results from many previous studies vary, possibly due to the operator dependency in ultrasound imaging, and to differences in the study populations.[16] In this study we evaluate the predictive values of ACR TI-RADS in the Thai population, where there is no nuclear plant, or iodine insufficiency, the incidence of thyroid cancer and prevalence of the thyroid malignant nodules are less common than in population of the World.[2, 12, 13]

The results of this study show malignancy rates of 0%, 0%, 22.6 %, 42.8 %, and 92.8 % in TR1, TR2, TR3, TR4, and TR5, respectively. These are comparable to the finding in TR1, TR2 for a malignancy rate of less than 2%, but a higher rate of malignancy in TR3 to TR5 groups of <5%, 5%-20% and >20% respectively, as suggested in the White Paper of ACE TI-RADS in 2017.[9] This contrasts with a retrospective single study in 2020[17] and Middleton et al[18] multi-institutional study which reported a lower malignancy rate.

In this study, the sensitivity and specificity of the ACR TI-RADS classification system were 73.6%, and 70.5%, respectively. And there was a negative predictive value of 82.7%. An independent study by Ahmadi et al[19] reported a sensitivity of 78.4%, specificity of 73.2%, and NPV of 90% in a study of 323 nodules in 213 adults. In a meta-analysis study by Yang et al[8], sensitivity was 85% and a specificity of 68%. Recent research in Thailand also reported a sensitivity of 91.67%, and a specificity of 72.3%.[13] This study's findings - as in the case of many other studies - support ACR TI-RADS as a useful diagnostic tool. High specificity reflects the aim to minimize the nodule being subject to biopsy. In order to avoid missing malignancy in low-risk nodules, a follow-up option is currently available.

When compared to the Siriraj's TIRADS from the study at Siriraj Hospital, which has a sensitivity of 95% and a specificity of 64.8%, the ACR TI-RADS has a greater specificity but a lower sensitivity.[6] ACR TI-RADS is able to lessen overdiagnosis, despite Siriraj's TIRADS's ability to identify thyroid cancer more effectively. However, there's still limited data on Siriraj's TIRADS. A combined study of Siriraj's TIRADS and ACR TI-RADS could be helpful for the diagnosis of thyroid carcinoma in Thailand, but further study is required for this hypothesis.

Every ultrasonography feature in the ACR TI-RADS system is a significant finding in diagnosing malignant thyroid nodule [Table 2], especially in echogenic foci, echogenicity, and composition categories [Figure 1]. Previous studies[20, 21] agree with the significant finding in some ultrasound characteristics, and the retrospective

research in Thailand's Ayutthaya area[13] corroborated the high specificity, and negative predictive values of these features.

The Thyroid Bethesda System has cytologically equivocal results, thus the ultrasonography feature is being reconsidered as a requirement of further investigation of the nodule.[22, 23] We chose TR4 and TR5 groups to compare with the fine needle aspiration report and found that the Bethesda category ≥ 3 is an optimal value for thyroid cancer screening due to its high sensitivity, PPV, NPV and accuracy. Related to this study is that of Tan et al[24] which combined TI-RADS and Bethesda scores and found that the greatest diagnosis value was TR4 combined with Bethesda category 3. However, the sample size was small. This hypothesis should be the subject of further research.

This study has limitations. A single operator reviewed all ultrasonographic features. Also, thyroid nodules with benign ultrasound features and benign FNA result without thyroidectomy specimen evidence were excluded, the number of malignant nodules may have been overestimated. However, this is also a strong point of this study because it allowed for the interpretation of the TI-RADS ultrasonography in nodules with controversial FNA results.

Conclusions

The ACR TI-RADS provides effective malignancy risk stratification for thyroid nodules, as the classification system has both high sensitivity, and specificity. The classification can be used to lower permanent complications from thyroid surgery to lower treatment costs and the overdiagnosis of thyroid cancer among Thai people. Thyroid nodules with TR4 and TR5 in our study are strong indicators of malignancy and should be considered as indication for the appropriateness of FNA.

References

1. Frates MC, Benson CB, Doubilet PM, Kunreuther E, Contreras M, Cibas ES, et al. Prevalence and distribution of carcinoma in patients with solitary and multiple thyroid nodules on sonography. J Clin Endocrinol Metab 2006;91(9):3411-7.
2. Thyroid Cancer Fact Sheet [Internet]. 2020 [cited 2022 Mar 24]. Available from: https://gco.iarc.fr/today/data/factsheets/cancers/32-Thyroid-fact-sheet.pdf
3. The Surveillance E and ER (SEER) P. Thyroid Cancer — Cancer Stat Facts [Internet] 2022 [cited 2022 Apr 28]. Available from: https://seer.cancer.gov/statfacts/html/thyro.html
4. Chen AY, Jemal A, Ward EM. Increasing incidence of differentiated thyroid cancer in the United States, 1988-2005. Cancer 2009; 115(16):3801-7.
5. Radecki PD, Arger PH, Arenson RL, Jennings AS, Coleman BG, Mintz MC, et al. Thyroid imaging: comparison of high-resolution real-time ultrasound and computed tomography. Radiology 1984;153(1):145-7.
6. Songsaeng D, Soodchuen S, Korpraphong P, Suwanbundit A. Siriraj thyroid imaging reporting and data system and its efficacy. Siriraj Med J 2017;69(5):262-7.
7. Middleton WD, Teefey SA, Reading CC, Langer JE, Beland MD, Szabunio MM, et al. Comparison of performance characteristics of American college of radiology TI-RADS, Korean society of thyroid radiology TIRADS, and American thyroid association guidelines. AJR Am J Roentgenol 2018;210(5):1148-54.
8. Yang R, Zou X, Zeng H, Zhao Y, Ma X. Comparison of diagnostic performance of five different ultrasound TI-RADS classification guidelines for thyroid nodules. Front Oncol 2020;10:598225.
9. Tessler FN, Middleton WD, Grant EG, Hoang JK, Berland LL, Teefey SA, et al. ACR Thyroid Imaging, Reporting and data system (TI-RADS): white paper of the ACR TI-RADS committee. J Am Coll Radiol 2017;14(5):587-95.
10. Grant EG, Tessler FN, Hoang JK, Langer JE, Beland MD, Berland LL, et al. Thyroid ultrasound reporting lexicon: white paper of the ACR thyroid imaging, reporting and data system (TIRADS) committee. J Am Coll Radiol 2015;12(12 Pt A):1272-9.
11. Grani G, Lamartina L, Ascoli V, Bosco D, Biffoni M, Giacomelli L, et al. Reducing the number of unnecessary thyroid biopsies while improving diagnostic accuracy: toward the "Right" TIRADS. J Clin Endocrinol Metab 2019;104(1):95-102.
12. Suttawas A. ACR TI-RADS Classification in predicting thyroid malignancy at prachuapkhirikhan hospital. Reg 4-5 Med J 2019; 38(2):84–92.
13. Harmontree S. Accuracy of ACR-TIRADS in assessment and diagnosis of thyroid nodule in Sena Hospital, Ayutthaya province. J Med & Public Health, UBU. 2021;4(1):28-39.
14. Cibas ES, Ali SZ. The 2017 Bethesda system for reporting thyroid cytopathology. Thyroid 2017;27(11):1341-6.

15. Hoang JK, Middleton WD, Tessler FN. Update on ACR TI-RADS: successes, challenges, and future directions, from the AJR special series on radiology reporting and data systems. AJR Am J Roentgenol 2021;216(3):570-8.
16. Li W, Wang Y, Wen J, Zhang L, Sun Y. Diagnostic performance of American college of radiology TI-RADS: A Systematic review and meta-analysis. AJR Am J Roentgenol 2021;216(1):38-47.
17. Zheng Y, Xu S, Kang H, Zhan W. A Single-center retrospective validation study of the American college of radiology thyroid imaging reporting and data system. Ultrasound Q 2018;34(2): 77-83.
18. Middleton WD, Teefey SA, Reading CC, Langer JE, Beland MD, Szabunio MM, et al. Multiinstitutional analysis of thyroid nodule risk stratification using the American college of radiology thyroid imaging reporting and data system. AJR Am J Roentgenol 2017;208(6):1331-41.
19. Ahmadi S, Oyekunle T, Jiang X', Scheri R, Perkins J, Stang M, et al. A Direct comparison of the ATA and TI-RADS Ultrasound scoring systems. Endocr Pract 2019;25(5): 413-22.
20. Shayganfar A, Hashemi P, Esfahani MM, Ghanei AM, Moghadam NA, Ebrahimian S. Prediction of thyroid nodule malignancy using thyroid imaging reporting and data system (TIRADS) and nodule size. Clin Imaging 2020;60(2):222-7.
21. Al Dawish M, Alwin Robert A, Al Shehri K, Hawsawi S, Mujammami M, Al Basha IA, et al. Risk stratification of thyroid nodules with Bethesda III category: The experience of a territorial healthcare hospital. Cureus 2020;12(5):e8202.
22. Bongiovanni M, Spitale A, Faquin WC, Mazzucchelli L, Baloch ZW. The Bethesda system for reporting thyroid cytopathology: a meta-analysis. Acta Cytol 2012; 56(4):333-9.
23. Al Dawish M, Alwin Robert A, Al Shehri K, Hawsawi S, Mujammami M, Al Basha IA, et al. Risk stratification of thyroid nodules with Bethesda III category: The experience of a territorial healthcare hospital. Cureus 2020;12(5):e8202.
24. Tan H, Li Z, Li N, Qian J, Fan F, Zhong H, et al. Thyroid imaging reporting and data system combined with Bethesda classification in qualitative thyroid nodule diagnosis. Medicine (Baltimore) 2019;98(50):e18320.