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RESEARCH

Relationship Between Thyroid Gland Stiffness and Coronary Artery Calcium Score: A Shear Wave Elastography Study

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Abstract

Purpose This study aimed to investigate the relationship between thyroid tissue stiffness measured by shear wave elastography (SWE) and the coronary artery calcium score (CACS), particularly across different score groups, and to determine whether thyroid SWE can be utilized as a noninvasive method for cardiovascular risk assessment.

Methods This prospective cross-sectional observational study was conducted at our institution between March 2025 and August 2025. All participants underwent gray-scale ultrasonography and SWE. Participants were categorized based on their CACS. Comparisons among the CACS groups were performed using analysis of variance and the Kruskal–Wallis test. Correlations were analyzed using the Spearman correlation test, and statistical significance was set at $p < 0.05$.

Results A total of 113 participants were included. Thyroid gland volumes did not differ significantly among CACS groups. In contrast, thyroid tissue stiffness parameters showed a significant increase with higher CACS categories. Strong positive correlations were observed between CACS and thyroid stiffness ($p < 0.001$), indicating that higher calcium scores were associated with increased thyroid tissue stiffness.

Conclusion In our study, a strong positive correlation was observed between thyroid gland stiffness and CACS, with thyroid stiffness increasing proportionally with the CACS category. Thyroid tissue elasticity measured by SWE may serve as a complementary marker to CACS in predicting cardiovascular risk.

Keywords Elastography · Atherosclerosis · Thyroid gland · Cardiovascular disease

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1 Introduction

Cardiovascular disease is among the leading causes of mortality and morbidity worldwide, and endocrine factors, such as the thyroid gland, are known to play a role in its underlying pathophysiology [1–3]. Thyroid function influences lipid metabolism and endothelial function, and several studies have demonstrated an association between endothelial dysfunction, atherosclerosis, and thyroid abnormalities, even in euthyroid individuals [4–7]. Thyroid hormones, particularly triiodothyronine (T3), play a crucial role in cardiovascular physiology by regulating lipid metabolism and endothelial function. Reduced thyroid hormone activity has been associated with impaired nitric oxide–mediated vascular function, dyslipidemia, and accelerated atherosclerosis [1, 4, 8, 9]. In addition, autoimmune thyroid inflammation may contribute to vascular damage through chronic inflammation and oxidative stress; these mechanisms are also key components in the development of atherosclerosis and vascular calcification [5,

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8, 10]. Notably, even in euthyroid individuals, subtle variations in thyroid hormone levels and underlying subclinical inflammatory processes may influence cardiovascular risk and vascular remodeling. In this context, increased thyroid tissue stiffness may reflect low-grade inflammation and fibrosis, which are also key mechanisms in atherosclerosis and vascular calcification.

Coronary artery calcification measured by computed tomography (CT) serves as a prognostic indicator for the development of atherosclerosis and cardiovascular diseases, with the Agatston score widely used for risk stratification and clinical decision-making regarding primary preventive medications, such as statin [11, 12]. Shear wave elastography (SWE) is a noninvasive ultrasonographic (US) technique that quantitatively assesses the stiffness of soft tissues, including the thyroid, breast, liver, and musculoskeletal structures [13–15]. Thyroid tissue stiffness typically increases in conditions associated with inflammation and fibrosis [10, 16]. Given that inflammation and fibrosis of the thyroid gland share common pathophysiological mechanisms with atherosclerosis and vascular calcification, including chronic inflammation and oxidative stress, thyroid stiffness may serve as an indirect marker of coronary artery atherosclerosis and calcification [5, 8]. Previous studies have demonstrated an association between thyroid disorders, particularly autoimmune thyroiditis, and cardiovascular risk factors, such as elevated lipid levels and insulin resistance [17, 18]. However, to the best of our knowledge, no prior study has investigated the relationship between thyroid tissue stiffness measured by SWE and coronary artery calcium score (CACS).

Therefore, this study aimed to investigate the relationship between thyroid tissue stiffness measured by SWE and CACS across different calcium score categories and to evaluate whether thyroid SWE may serve as a noninvasive marker for cardiovascular risk assessment.

2 Material and Methods

2.1 Patients and Study Design

This prospective cross-sectional observational study was approved by the local ethics committee (approval no.2025/4/6) and conducted at our hospital between March 2025 and August 2025. Informed consent was obtained from all participants prior to inclusion. Thyroid elastography measurements were performed on the same day, immediately after cardiac CT examinations, without any significant time interval between the two procedures. A total of 113 participants aged between 22 and 84 years were included in this study.

The inclusion criteria were as follows: adult participants aged ≥ 18 years with available CACS measurements, a homogeneous thyroid parenchyma on gray-scale ultrasonography, and normal serum fT3, fT4, and TSH levels without a history of thyroid disease. The exclusion criteria included the presence of thyroid nodules, calcifications, or heterogeneous parenchyma on grayscale US; a history of thyroid surgery or thyroid medication; previous neck radiotherapy; poor-quality SWE measurements or artifacts; chronic liver, heart, or kidney failure; goiter or retrosternal extension affecting measurement reliability; and cases with significant artifacts preventing reliable CACS evaluation.

2.2 Ultrasound and Shear Wave Elastography Assessments

All participants were examined by an experienced radiologist (10 years of experience in the US and SWE) using a high-frequency (L5–14) linear array transducer with a Mindray Resona R9 ultrasound system (Shenzhen Mindray Bio-Medical Electronic Co., Ltd., Shenzhen, China). SWE was performed using a protocol consistent with previously reported SWE studies [10, 16]. To assess interobserver agreement, thyroid SWE measurements were independently performed by another radiologist in 20 patients.

During the examination, the participants were instructed to keep their heads slightly extended and to avoid speaking or swallowing. Each examination began with grayscale US. After evaluating the thyroid gland for nodules, calcifications, or parenchymal heterogeneity, the dimensions of both thyroid lobes (length [L] × width [W] × height [H]) were measured, and the volume was automatically calculated and recorded by the system. The total thyroid gland volume was obtained by summing the volumes of both lobes. Subsequently, SWE measurements were performed in the longitudinal plane with the patient remaining in the same position (Fig. 1). The measurement range was set to 0–75 kPa, and the patients were asked to hold their breath for 3–5s. When the image was stable, it was frozen, and a circular region of interest (ROI) of approximately 5–15 mm was placed on the elastogram to measure Young's modulus (kPa) from the right and left thyroid lobes, respectively. Measurements were taken only when the motion stability index (M-STB) was rated five stars and the image reliability index (RLB), indicating measurement consistency, exceeded 95%. Three measurements were obtained from the upper, middle, and lower portions of each lobe, and the mean of these measurements was recorded for statistical analysis. The radiologist performing the thyroid SWE measurements was blinded to the CACS results of all participants.

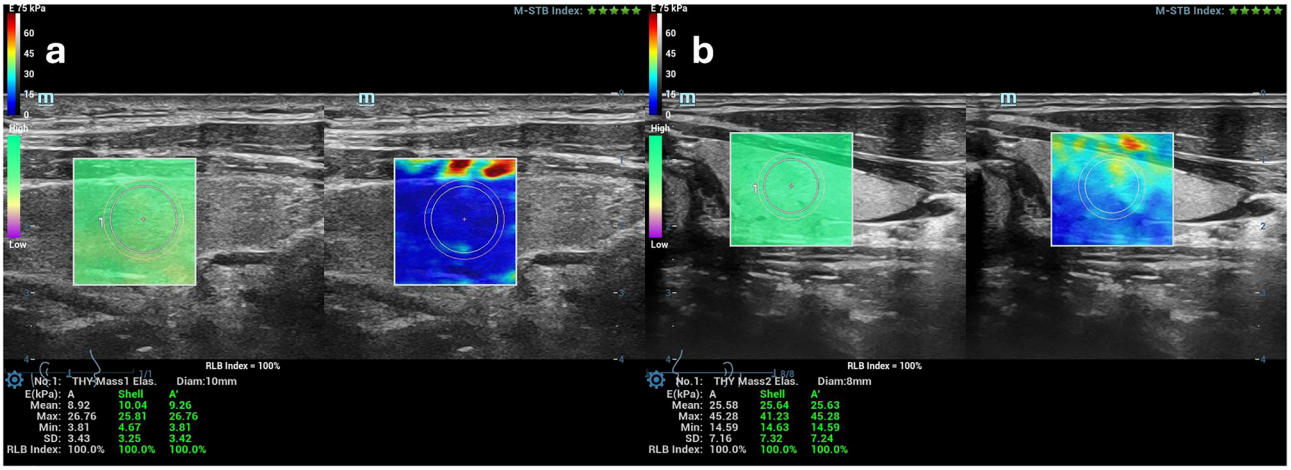


Fig. 1 Shear wave elastography (SWE) images of the thyroid gland in two male participants: **a** a 54-year-old male with a coronary artery calcium score (CACS) of 0 demonstrating a stiffness value of 8.92 kPa, and **b** a 55-year-old male with a CACS of 560 demonstrating a stiffness value of 25.58 kPa

2.3 Cardiac CT Protocol

All participants underwent cardiac CT examinations using a 64-slice CT scanner (Revolution EVO; GE Medical Systems, Milwaukee, WI, USA). Prior to the scan, intravenous beta-blockers were administered when the heart rate exceeded 65 beats per minute. An ECG-gated coronary calcium scan was performed before the coronary CT angiography examination.

Prospective ECG-triggered acquisition was used for the CACS scan with the following parameters: tube voltage of 120 kVp, automatic tube current modulation, rotation time of 0.35s, detector collimation of 64×0.625 mm, slice thickness and increment of 2.5 mm, and a matrix size of 512×512. The scan range extended from the level of the carina to the cardiac apex.

CACS assessments were performed on an advanced workstation (AW Server 3.2; GE Healthcare) using dedicated post-processing software (SmartScore). CACS assessments were performed by an experienced radiologist who was blinded to the thyroid SWE measurements. The CACS was automatically calculated for the left main, left anterior descending, left circumflex, and right coronary arteries using a predefined attenuation threshold of 130 Hounsfield units. The total calcium score was determined by summing all scores.

Participants were categorized according to CACS as follows: Group 1 had a score of 0 (no calcification), Group 2 had mild calcification (1–100), Group 3 had moderate calcification (101–400), and Group 4 had severe calcification (over 400) [19].

2.4 Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics software (version 27.0; IBM Corp., Armonk, NY, USA). Continuous variables are expressed as mean ± standard deviation (SD), and categorical variables are presented as numbers and percentages (%). Data distribution normality was assessed using the Shapiro–Wilk test.

Comparisons among the CACS groups were conducted using Welch's ANOVA test for normally distributed data with unequal variances and the Kruskal–Wallis test for non-normally distributed data. When a significant difference was identified, appropriate post hoc tests were applied.

Correlations between thyroid SWE parameters and CACS values were analyzed using the Spearman correlation test. The strength of correlations was interpreted as follows: $r < 0.20$, very weak; 0.20–0.39, weak; 0.40–0.59, moderate; 0.60–0.79, strong; and ≥ 0.80, very strong. Linear regression analysis was used to evaluate independent associations. Interobserver agreement was assessed using the intraclass correlation coefficient (ICC) method, and ICC results were interpreted as poor (< 0.50), fair (0.50–0.74), good (0.75–0.89), and excellent (≥ 0.90). Statistical significance was set at $p < 0.05$.

3 Results

3.1 Study Participants and Baseline Characteristics

A total of 113 participants were included, comprising 76 men (67.3%) and 37 women (32.7%). The mean age was

51.63 ± 11.16 years. The baseline demographic characteristics of the study population are presented in Table 1. The interobserver agreement for thyroid SWE measurements was excellent, with an ICC of 0.834 (95% CI, 0.794–0.913).

3.2 Comparisons Among Coronary Artery Calcium Score (CACS) Groups

Significant differences in thyroid tissue stiffness parameters were observed among the four groups classified according to CACS values: Group 1 (CACS = 0), Group 2 (1–100), Group 3 (101–400), and Group 4 (> 400) (Tables 2 and 3).

Welch's ANOVA test revealed that right thyroid lobe stiffness (RTLS) values differed significantly among the groups ($p < 0.001$). Post hoc Tamhane analysis revealed that Group 4 had significantly higher RTLS values than all other groups, whereas Group 1 showed significantly lower values than the others. Groups 2 and 3 demonstrated significantly higher RTLS values than Group 1 but significantly lower values than Group 4. No statistically significant difference was observed between Groups 2 and 3 ($p > 0.05$).

Total thyroid stiffness (TTS) values exhibited a similar pattern ($p < 0.001$). Group 4 showed significantly higher TTS values than all other groups, whereas Group 1 demonstrated the lowest values. Groups 2 and 3 had significantly higher TTS values than Group 1 but significantly lower than Group 4. There was no statistically significant difference between Groups 2 and 3 ($p > 0.05$).

Analysis of left thyroid lobe stiffness (LTLS) also showed significant differences among the groups ($p < 0.001$), with significantly higher LTLS values in the groups with elevated calcium scores.

Accordingly, as the CACS group increased, thyroid tissue stiffness showed a parallel increase across all measurement levels (RTLS, LTLS, and TTS). No statistically significant differences were found among the groups in terms of right thyroid lobe volume (RTV), left thyroid lobe volume (LTV), or total thyroid volume (TTV) ($p > 0.05$).

Table 1 Demographic characteristics of participants

Variable	Mean ± SD (min–max) or n (%)
Age (years)	51.63 ± 11.16 (22–84)
Height (cm)	168.72 ± 9.16 (150–192)
Weight (kg)	84.41 ± 15.92 (50–120)
BMI (kg/m^2)	29.59 ± 4.91 (20.81–47.61)
Sex (Male/Female)	76 (67.3%)/37 (32.7%)

Table 3 Kruskal–Wallis comparison of left thyroid lobe stiffness among CACS groups

CACS group	n	Mean rank
1	34	24.18
2	31	50.71
3	24	68.42
4	24	100.21
Total	113	–

Kruskal–Wallis H = 79.922
df = 3 $p < 0.001$

CACS, Coronary artery calcium score

Table 2 Post-hoc pairwise comparisons using Tamhane's T2 test for right thyroid lobe stiffness and total thyroid stiffness among CACS groups

Dependent Variable	Group (I)	Group (J)	Mean Difference (I–J)	Std. Error	p-value	95% Confidence Interval Lower–Upper
RTLS	4	1	19.76*	1.59	< 0.001	15.23–24.29
	4	2	15.20*	1.67	< 0.001	10.51–19.89
	4	3	14.02*	1.64	< 0.001	9.38–18.66
	1	2	−4.56*	0.77	< 0.001	−6.66–−2.46
	1	3	−5.74*	0.71	< 0.001	−7.70–−3.77
	2	3	−1.18	0.87	0.700	−3.55–1.20
TTS	4	1	20.84*	1.64	< 0.001	16.17–25.50
	4	2	16.62*	1.69	< 0.001	11.85–21.39
	4	3	14.74*	1.68	< 0.001	9.99–19.49
	1	2	−4.22*	0.68	< 0.001	−6.07–−2.37
	1	3	−6.10*	0.66	< 0.001	−7.91–−4.28
	2	3	−1.88	0.78	0.111	−4.01–0.25

*$p < 0.05$ indicates statistically significant difference

RTLS, Right Thyroid Lobe Stiffness; TTS, Total Thyroid Stiffness

3.3 Correlations between CACS and Thyroid Gland Parameters

The Spearman correlation analysis revealed strong positive correlations between CAC and thyroid tissue stiffness parameters (RTLS, r = 0.801; LTLS, r = 0.818; TTS, r = 0.829; all P < 0.001). These findings indicate that thyroid tissue stiffness markedly increases as CACS increases.

Body mass index (BMI) showed weak negative correlations with both CACS and thyroid stiffness parameters (CACS: r = −0.322; RTLS: r = −0.331; LTLS: r = −0.329; TTS: r = −0.344; p < 0.001), suggesting that higher BMI values were associated with slightly lower CACS and thyroid stiffness.

A weak but statistically significant positive correlation was found between age and CACS (r = 0.198, p = 0.018). Similarly, age showed weak positive correlations with RTLS, LTLS, and TTS values (r = 0.195, 0.184, and 0.196; p < 0.05).

No significant correlations were found between thyroid lobe volumes and CACS (p > 0.05). However, height, weight, and body mass index (BMI) were weakly to moderately positively correlated with thyroid lobe volumes (p < 0.05). All correlation analyses are presented in Table 4.

3.4 Multiple Linear Regression Analysis

Multiple linear regression analysis revealed that the model was statistically significant (F(4108) = 31.42, p < 0.001) and had a significant effect on total thyroid stiffness (TTS) (Table 5). The model demonstrated high explanatory power (R = 0.733, R^2 = 0.538, Adjusted R^2 = 0.521).

Among the independent variables, CACS was identified as the strongest and most significant predictor of TTS (β = 0.685, p < 0.001). A significant negative correlation was observed between BMI and TTS (β = –0.165, p = 0.016). In contrast, no significant associations were found between age (p = 0.970) or total thyroid volume (TTV) (p = 0.941) and TTS. Additionally, low VIF values (< 1.1) indicated the absence of multicollinearity within the model.

4 Discussion

In the present study, a significant increase in thyroid tissue stiffness was observed with higher CACS categories. Thyroid tissue stiffness was found to be significantly higher in the groups representing more advanced disease with elevated CACS values. This finding suggests a potential parallel relationship between CACS, recognized as an indicator of coronary artery disease and its severity, and thyroid tissue elasticity, possibly driven by shared pathophysiological mechanisms, such as chronic inflammation and fibrosis.

Several studies have examined the associations between thyroid hormone disorders and the incidence of coronary artery atherosclerosis, as well as related mortality and morbidity [6, 20–22]. In an observational study by Shen et al., a negative correlation was identified between FT3 levels and coronary artery calcification [21]. Similarly, several studies have reported negative correlations between FT3 levels and coronary artery disease, whereas no significant associations were found with FT4 or TSH levels [6, 20, 23]. In contrast, studies by Ling et al. and Kim et al. demonstrated a negative correlation between FT4 levels and the extent of coronary atherosclerosis [24, 25]. In another large-scale study involving 3722 patients, Lim et al. reported a significant correlation between TSH levels and coronary artery disease [26]. These repeated

Table 4 Spearman Correlation among Clinical and Elastography Parameters

Variables	Age	Height	Weight	BMI	CACS	RTLS	LTLS	TTS	RTV	LTV	TTV
Age	1.000	−0.239*	−0.202*	0.196*	0.198*	0.195*	0.184*	0.196*	−0.171*	−0.174*	−0.212*
Height	−0.239*	1.000	0.499***	−0.278**	−0.063	−0.041	−0.039	−0.045	0.278**	0.209**	0.273**
Weight	−0.202*	0.499***	1.000	0.821***	−0.202*	−0.196*	−0.191*	−0.204*	0.329***	0.207*	0.323***
BMI	0.196*	−0.278**	0.821***	1.000	−0.322**	−0.331***	−0.329***	−0.344***	0.256**	0.173*	0.265**
CACS	0.198*	−0.063	−0.202*	−0.322**	1.000	0.801***	0.818***	0.829***	−0.051	0.002	−0.050
RTLS	0.195*	−0.041	−0.196*	−0.331***	0.801***	1.000	0.956***	0.982***	−0.097	−0.045	−0.109
LTLS	0.184*	−0.039	−0.191*	−0.329***	0.818***	0.956***	1.000	0.986***	−0.079	−0.078	−0.113
TTS	0.196*	−0.045	−0.204*	−0.344***	0.829***	0.982***	0.986***	1.000	−0.082	−0.058	−0.106
RTV	−0.171*	0.278**	0.329***	0.256**	−0.051	−0.097	−0.079	−0.082	1.000	0.688***	0.935***
LTV	−0.174*	0.209**	0.207*	0.173*	0.002	−0.045	−0.078	−0.058	0.688***	1.000	0.812***
TTV	−0.212*	0.273**	0.323***	0.265**	−0.050	−0.109	−0.113	−0.106	0.935***	0.812***	1.000

Values represent Spearman's rho coefficients. ***p < 0.001, **p < 0.01, *p < 0.05

CACS, Coronary Artery Calcium Score, RTLS, right thyroid lobe stiffness; LTLS, left thyroid lobe stiffness; TTS, total thyroid stiffness; RTV, right thyroid lobe volume; LTV, left thyroid lobe volume; TTV, total thyroid volume; BMI, body mass index

Table 5 Multiple linear regression model for predictors of total thyroid stiffness

Model Summary											
Model	R	R^2	Adjusted R^2	Std. Error of Estimate							
1	0.733	0.538	0.521	6.042							
ANOVA											
Model	Sum of Squares	df	Mean Square	F	*p*-value						
Regression	4587.68	4	1146.92	31.42	< 0.001						
Residual	3942.87	108	36.51								
Total	8530.56	112									
Coefficients											
Variable	B	Std. Error	Beta	t	*p*-value	95% CI (Lower)	95% CI (Upper)	Zero-order	Partial	Part	Tolerance	VIF
(Constant)	23.321	4.715	–	4.946	< 0.001	13.975	32.667					
CACS	0.016	0.002	0.685	10.062	< 0.001	0.013	0.019	0.715	0.696	0.658	0.924	1.082
TTV (mL)	−0.010	0.136	−0.005	−0.074	0.941	−0.281	0.260	−0.072	−0.007	−0.005	0.947	1.056
Age (years)	0.002	0.053	0.003	0.038	0.970	−0.103	0.107	0.163	0.004	0.002	0.930	1.076
BMI (kg/m^2)	−0.293	0.120	−0.165	−2.451	0.016	−0.530	−0.056	−0.287	−0.230	−0.160	0.942	1.062

CACS, Coronary artery calcium score, TTS, total thyroid stiffness, BMI, body mass index

findings across studies support the regulatory effects of thyroid hormones on vascular smooth muscle cells and endothelial function. In a large cohort study by Zhang et al., serum FT4 and TSH levels within the normal range were found to be inversely associated with CACS and subclinical atherosclerosis. These results suggest that even subtle physiological variations in thyroid function may have significant effects on the cardiovascular system.

In our study, a significant positive correlation was observed between SWE-derived thyroid stiffness and CACS among participants with normal serum thyroid hormone levels. This finding may reflect similar pathophysiological mechanisms to those reported by Zhang et al., who observed increased coronary calcification despite normal thyroid hormone levels [22]. Both studies highlight that structural or functional alterations in the thyroid gland may be associated with atherosclerotic processes, even in individuals without clinically evident thyroid disease. However, while Zhang et al. [22] investigated this relationship using hormonal parameters, our study evaluated the biomechanical properties of thyroid tissue using SWE. Therefore, our findings support the potential utility of thyroid SWE not only in the assessment of thyroid disorders but also as a noninvasive biomarker of cardiovascular risk.

In a study conducted by AlQazzaz et al., an association was demonstrated between thyroid artery Doppler measurements and CACS burden [27]. To date, no study has directly investigated the relationship between thyroid parenchymal stiffness measured by SWE and CACS. In this regard, the present study is the first to demonstrate a potential link between thyroid tissue biomechanics and coronary calcification burden.

In our study, separate correlations were observed between age and thyroid stiffness, as well as between age and CACS. Multiple linear regression analysis performed to determine whether thyroid stiffness values were age-dependent revealed that CACS was the strongest and most significant independent variable affecting total thyroid stiffness. Increased thyroid stiffness in individuals without thyroid disease was found to correlate with higher CACS scores, independent of age.

This study has several strengths. First, it is, to the best of our knowledge, the first study to investigate the relationship between thyroid tissue stiffness measured by SWE and CACS. Second, the prospective design and standardized imaging protocol increase the reliability of the findings. Third, the use of blinded assessments and the demonstration of high interobserver agreement further strengthen the validity of the results.

Our study has several limitations. First, it was a single-center study with a relatively small sample size. Second, intra-observer agreement for thyroid SWE assessments was not evaluated. Third, thyroid autoantibody levels were not measured; however, cases with heterogeneous parenchymal structure on US were excluded to rule out thyroid disease. Nonetheless, early or subclinical thyroiditis could not be completely ruled out and might have influenced SWE measurements. Fourth, the participants included in this study were patients with an indication for CACS assessment, which may limit the generalizability of the findings. Finally,

alcohol and smoking habits, lipid levels, and thyroid hormone measurements were not evaluated because they were beyond the primary scope of this study. However, because these factors may influence both thyroid tissue elasticity and coronary artery calcification, potential confounding effects cannot be entirely excluded.

To validate the present findings, multicenter studies with larger sample sizes are needed. Including different CACS categories and incorporating participants undergoing non-contrast CT without a specific CACS indication may be beneficial. In addition, evaluating metabolic, hormonal, and lifestyle factors (such as alcohol use and smoking), as well as thyroid autoantibodies, may broaden the scope of the findings. Future longitudinal studies will help to better define the role of thyroid SWE in cardiovascular risk assessment.

5 Conclusions

In this study, we demonstrated a strong positive association between thyroid gland stiffness measured by SWE and CACS across different risk categories. Thyroid tissue stiffness increased significantly with higher CACS values, suggesting a potential link between thyroid tissue alterations and cardiovascular pathology. These findings indicate that the study objective was achieved and support the hypothesis that thyroid SWE may serve as a noninvasive marker for cardiovascular risk assessment.

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Author contribution Conceptualization: [Enes Gurun]; Methodology: [Enes Gurun]; Formal analysis and investigation: [Enes Gurun], [Gamze Nur Duman], [Gonca Genc], [Ismail Akdulum], [Mesut Ozturk], [Ismet Mirac Cakir], [Hasan Gundogdu]; Writing—original draft preparation: [Enes Gurun], [Ismail Akdulum]; Writing—review and editing: [Enes Gurun]; Resources: [Enes Gurun]; Supervision: [Enes Gurun]; Project administration: [Enes Gurun], [Mesut Ozturk], [Ismet Mirac Cakir], [Hasan Gundogdu].

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Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interest The authors declare no conflict of interest.

Ethical Approval The study was approved by the local ethics committee (2025/4/6). All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Verbal and written informed consent was obtained from the patients.

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