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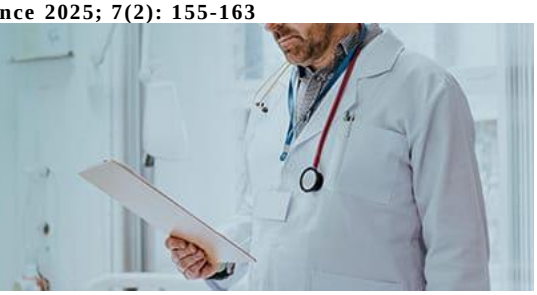

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Dietary calcium intake and serum calcium levels in relation to coronary artery calcium score assessed by CT angiography: A clinical correlation study

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Abstract
Background: Coronary artery disease (CAD) is the leading cause of global mortality, with coronary artery calcification (CAC) serving as a key marker of atherosclerotic burden. The relationship between calcium metabolism—dietary intake and serum levels—and CAC remains controversial, particularly regarding the differential effects of dietary versus supplemental calcium and the role of systemic calcium homeostasis in vascular calcification.
Objectives: This study aimed to assess the association between serum calcium levels and CAC score, evaluate the relationship between dietary calcium intake and CAC score, and identify independent predictors of CAC score in adults undergoing coronary CT angiography.
Methods: A cross-sectional study was conducted at Gazi Hariri Hospital, Baghdad, from March 1 to July 31, 2025, involving 120 participants aged 40-70 years. Dietary calcium intake was assessed using a culturally adapted Food Frequency Questionnaire. Fasting serum calcium was measured via colorimetric assay. CAC was quantified using non-contrast CT and Agatston scoring. Multivariable linear regression analysis identified independent predictors of CAC score, adjusting for age, sex, BMI, comorbidities, and lifestyle factors.
Results: Mean age was 54.86±8.92 years; 63.3% were male. CAC was absent in 49.2%, mild in 5.0%, moderate in 14.2%, and severe in 31.7%. Serum calcium was suboptimal (<9.8 mg/dL) in 73.3%. A moderate positive correlation was found between serum calcium and CAC score (Spearman's r = 0.46, p<0.001). Multivariable analysis revealed serum calcium as a significant independent predictor of CAC (β = 0.210, p = 0.008), second to age (β = 0.351) and male sex (β = 0.305). No significant association was found between dietary calcium intake and CAC score. Traditional risk factors including diabetes, hypertension, smoking, and higher BMI were also independent predictors.
Conclusions: Serum calcium levels, not dietary calcium intake, are independently associated with coronary artery calcification. Systemic calcium homeostasis appears more critical than dietary intake in vascular calcification risk. These findings suggest that monitoring serum calcium may enhance cardiovascular risk stratification and caution against indiscriminate calcium supplementation, particularly in populations with metabolic dysregulation.

Keywords: Coronary artery calcification, serum calcium, dietary calcium CT angiographym, cardiovascular risk

Introduction

Cardiovascular disease (CVD) remains the leading cause of mortality worldwide, with coronary artery disease (CAD) accounting for a substantial proportion of CVD-related deaths [1]. Coronary artery calcification (CAC), a hallmark of atherosclerotic plaque development, serves as a quantifiable marker of coronary atherosclerotic burden and has been consistently associated with increased risk of major adverse cardiovascular events, including myocardial infarction and cardiovascular mortality [2, 3]. The pathophysiological link between calcium metabolism and vascular calcification presents a clinical paradox: while calcium is essential for skeletal mineralization and neuromuscular function, dysregulation in calcium homeostasis may contribute to ectopic calcification in arterial walls, thereby promoting atherosclerosis [4].

Advances in non-invasive imaging, particularly coronary computed tomography angiography (CCTA), have enabled accurate and reproducible quantification of CAC using the Agatston scoring system, facilitating early risk stratification in both symptomatic and asymptomatic individuals [5]. The CAC score has emerged as a powerful predictor of long-term cardiovascular risk, independent of traditional risk factors, and is increasingly integrated into preventive cardiology guidelines [6]. Calcium, the most abundant mineral in the human body, is primarily stored in bone and teeth, with a small fraction maintained in serum to support critical physiological functions. Vascular calcification, often beginning after the fifth decade of life, is now recognized not as a passive process but as an actively regulated phenomenon involving vascular smooth muscle cell transdifferentiation, inflammation, and impaired mineral regulation [7].

Epidemiological studies investigating the association between calcium intake and CAC have produced inconsistent findings, fueling ongoing debate. Some reports suggest that excessive calcium intake, particularly through supplements, may promote vascular calcification and increase cardiovascular risk [8]. However, growing evidence indicates a differential effect based on calcium source: dietary calcium from food sources—especially dairy products and leafy greens—appears neutral or even protective against CVD, whereas high-dose calcium supplementation has been linked to an elevated risk of myocardial infarction in certain populations [9, 10]. The Multi-Ethnic Study of Atherosclerosis (MESA) demonstrated that calcium intake from supplements, but not from diet, was associated with a higher risk of CAC progression over a 10-year follow-up, highlighting the importance of source specificity [11]. In contrast, analyses from the Framingham Offspring Study found no significant association between total or dietary calcium intake and CAC prevalence, challenging the notion that calcium intake directly accelerates atherosclerosis [12].

More recent studies have shifted focus from dietary intake to circulating biomarkers, revealing that serum levels of calcium, phosphorus, and the calcium-phosphorus product are more strongly associated with CAC burden than dietary consumption alone [13]. This is particularly evident in populations with chronic kidney disease (CKD), where disturbances in mineral metabolism are tightly linked to accelerated vascular calcification, although the role of dietary patterns in this context remains poorly defined [14]. These findings underscore the potential limitations of relying solely on dietary assessment and suggest that systemic mineral balance may be a more relevant determinant of vascular calcification.

Despite these advances, significant gaps persist in the literature. Many studies have focused narrowly on dietary intake or supplement use, with limited integration of serum calcium levels as a potential intermediary biomarker [15]. Moreover, confounding factors such as vitamin D status, parathyroid hormone levels, renal function, and metabolic comorbidities are frequently underadjusted for, potentially biasing observed associations [16]. Heterogeneity in study design, measurement tools, and population characteristics further limits comparability across studies, while the predominance of cross-sectional data restricts causal inference. The potential mediating role of serum calcium in the pathway between dietary intake and coronary calcification remains largely unexplored.

Given these uncertainties, a comprehensive evaluation of the interplay between dietary calcium, serum calcium, and CAC is essential to inform clinical practice. While current guidelines advocate for adequate calcium intake to maintain skeletal health, concerns about cardiovascular safety particularly with supplementation have created ambiguity in patient counseling [17]. A multimodal approach incorporating detailed dietary assessment, biochemical profiling, and advanced cardiac imaging may provide deeper insights into the complex relationship between calcium metabolism and coronary atherosclerosis, ultimately guiding more personalized strategies for cardiovascular risk prevention.

Study Objectives

1. To assess the association between serum calcium levels and CAC score.
2. To evaluate the relationship between dietary calcium intake and CAC score.
3. To identify independent predictors of CAC score, including demographic, clinical, lifestyle, and biochemical factors.

Methods

Study Design and Setting

A cross-sectional observational study was conducted at Gazi Hariri Hospital for Specialized Surgery, a tertiary care center equipped with advanced cardiovascular imaging and comprehensive cardiac services, from March 1 to July 31, 2025. The institutional infrastructure enabled standardized acquisition of CAC scores and integration of clinical, biochemical, and lifestyle data for comprehensive analysis.

Study Population

Adults aged 40-70 years referred for clinically indicated coronary computed tomography angiography (CCTA) were enrolled via consecutive sampling. This age range was selected to target individuals at increased risk for coronary calcification while limiting the influence of extreme age-related comorbidities.

Inclusion criteria

Adults aged 40-70 years with a clinical indication for CCTA, ability to provide informed consent, willingness to complete dietary and lifestyle assessments, and stable clinical status.

Exclusion criteria

History of acute coronary syndrome, myocardial infarction, or coronary revascularization (CABG or PCI); current pregnancy or lactation; severe renal dysfunction (eGFR <30 mL/min/1.73 m²); advanced hepatic impairment (Child-Pugh Class C); known metabolic bone diseases (e.g., osteoporosis, hyperparathyroidism, malabsorption syndromes); contraindications to CT imaging; or urgent cardiovascular conditions requiring immediate intervention.

The sample size was calculated using G*Power (version 3.1.9.7), assuming a moderate effect size (Cohen's $d = 0.5$), $\alpha = 0.05$, and 80% power. A minimum of 120 participants was required, with an additional 20% added to account for potential attrition, resulting in a final target enrollment of 120 participants.

Data Collection Procedures

Dietary Assessment: Dietary calcium intake was evaluated using a culturally adapted, validated Food Frequency Questionnaire (FFQ) tailored to Middle Eastern dietary patterns. Participants reported average consumption frequency of calcium-rich foods over the preceding six months. Intake was quantified using regional food composition databases and expressed in milligrams per day. The FFQ included specific items on dairy products, green leafy vegetables, nuts, seeds, and calcium-rich fish.

Biochemical Analysis

Fasting venous blood samples were collected after an 8-12 hour fast. Total serum calcium was measured using a colorimetric assay on an automated chemistry analyzer; ionized calcium was assessed via ion-selective electrode. All assays were performed under strict quality control protocols with regular calibration and internal validation.

Coronary Artery Calcium Scoring

Non-contrast cardiac CT scans were performed using a 64-slice multidetector CT scanner with ECG gating, 2.5-3.0 mm slice thickness, and 120 kVp. CAC was quantified using the Agatston method, defining calcified plaques as areas ≥1 mm² with attenuation ≥130 Hounsfield units. CAC scores were categorized as: 0 (absent), 1-10 (mild), 11-100 (moderate), and >100 (severe), based on established clinical thresholds.

Clinical and Lifestyle Data Collection

Trained research personnel conducted structured interviews to collect demographic, medical, family, and lifestyle information. Data included age, sex, BMI, educational level, occupation, comorbidities (hypertension, diabetes, hyperlipidemia, osteoporosis, CKD), current medications (including calcium and vitamin D supplements, statins, antihypertensives, antidiabetics), musculoskeletal symptoms (muscle cramps, bone pain), smoking status, alcohol use, physical activity levels, and dietary habits.

Questionnaire Structure

The questionnaire was divided into five sections:

- **Section I:** Demographics (age, gender, BMI, education, employment)
- **Section II:** Medical and family history, medication use, presence of musculoskeletal symptoms
- **Section III:** Lifestyle factors (smoking, alcohol, exercise)
- **Section IV:** Dietary intake of calcium-rich foods (dairy, leafy greens, nuts, seeds, fish), including frequency and type
- **Section V:** Prior laboratory results and imaging history (e.g., calcium levels, CAC scores)

Statistical Analysis: Data analysis was performed using SPSS version 28.0. Descriptive statistics were presented as mean±standard deviation for normally distributed continuous variables. For group comparisons, independent samples t-tests were used for normally distributed continuous variables. Categorical variables were compared using the chi-square test or Fisher's exact test, as appropriate. The association between serum calcium levels and CAC scores was assessed using Spearman's rank correlation coefficient, given the non-normal distribution of CAC scores. A scatter plot was constructed to illustrate this relationship. To identify factors independently associated with CAC score, a multivariable linear regression model was fitted. Variables included in the model were age, sex, body mass index (BMI), diabetes mellitus, hypertension, smoking status (current or former vs. never), regular exercise (yes/no), and serum calcium level, selected based on clinical relevance and their association with CAC in univariate testing ($p<0.10$). The results were reported as standardized beta (β) coefficients, p-values, and 95% confidence intervals (CI). Model fit was assessed using the coefficient of determination (R^2) and analysis of variance (ANOVA). Statistical significance was set at $p<0.05$.

Ethical Considerations

The study was approved by the Arab Board for Health Specializations Research Ethics Committee and the Institutional Review Board of Gazi Hariri Hospital. The study adhered to the principles of the Declaration of Helsinki and Good Clinical Practice guidelines. The protocol was prospectively registered in the national clinical trials registry. Written informed consent was obtained from all participants after detailed explanation of the study objectives, procedures, risks, and benefits. Participants were informed of their right to withdraw at any time without affecting their clinical care. All data were anonymized and stored securely in compliance with institutional and national data protection regulations.

Results

Baseline Characteristics

A total of 120 participants were enrolled in this study, with a mean age of 54.86±8.92 years (range 40-70 years). The study population consisted of 76 males (63.3%) and 44 females (36.7%), with a mean BMI of 28.2±7.9 kg/m². Regarding educational attainment, 13 participants (10.8%) had no formal education, 38 (31.7%) had primary education, 47 (39.2%) had secondary education, and 22 (18.3%) had university or above education. The majority of participants were unemployed (71, 59.2%), while 28 (23.3%) were engaged in manual/field-based employment and 21 (17.5%) had office-based employment. Among the study participants, 22 (18.3%) had no comorbidities, while the most common comorbidity was hypertension, affecting 33 participants (27.5%). Diabetes mellitus was present in 13 participants (10.8%), and 17 participants (14.2%) had both hypertension and diabetes mellitus. Other comorbidities included hyperlipidemia in 13 participants (10.8%), osteoporosis in 15 participants (12.5%), and chronic kidney disease in 7 participants (5.8%). Regarding current pharmacotherapy, 31 participants (25.8%) were not taking any medications. Antihypertensive therapy was the most common treatment, prescribed to 34 participants (28.3%), while combined antihypertensive and antidiabetic therapy was used by 17 participants (14.2%). Vitamin D supplementation was used by 22 participants (18.3%), antidiabetic therapy by 8 participants (6.7%), and calcium supplementation and statin therapy were each used by 4 participants (3.3%). Musculoskeletal symptoms, including muscle cramps or bone pain, were present in 57 participants (47.5%), while 63 participants (52.5%) reported no such symptoms. (Table 1).

Table 1: Baseline Characteristics and Comorbidity Profile of Study Participants (N = 120)

Variable	N (%)
Age (mean ±SD) 54.86±8.92 years (range 40- 70)	
Sex	
Male	76 (63.3)
Female	44 (36.7)
BMI (mean ±SD) 28.2±7.9 kg/m²	
Education Attainment	
No formal education	13 (10.8)
Primary education	38 (31.7)
Secondary education	47 (39.2)
University or above education	22 (18.3)
Occupational Status	
Office-based employment	21 (17.5)
Manual/field-based employment	28 (23.3)
Unemployed	71 (59.2)
Comorbidity Profile	
No comorbidities	22 (18.3)
Hypertension	33 (27.5)
Diabetes Mellitus	13 (10.8)
Hypertension & Diabetes Mellitus	17 (14.2)
Hyperlipidemia	13 (10.8)
Osteoporosis	15 (12.5)
Chronic Kidney Disease	7 (5.8)
Current Pharmacotherapy	
No medications	31 (25.8)
Calcium supplementation	4 (3.3)
Vitamin D supplementation	22 (18.3)
Statin therapy	4 (3.3)
Antihypertensive therapy	34 (28.3)
Antidiabetic therapy	8 (6.7)
Combined antihypertensive and antidiabetic therapy	17 (14.2)
Musculoskeletal Symptomatology	
Presence of muscle cramps or bone pain	57 (47.5)
Absence of muscle cramps or bone pain	63 (52.5)

Lifestyle and Dietary Patterns

Among the study participants, 69 (57.5%) were non-smokers, 20 (16.7%) were former smokers, and 31 (25.8%) were active smokers. Alcohol consumption was minimal, with 117 participants (97.5%) being abstainers and only 3 participants (2.5%) consuming alcohol occasionally or regularly. Regular exercise engagement was low, with only 14 participants (11.7%) reporting regular physical activity, while 106 participants (88.3%) did not engage in regular exercise. Dairy product consumption was common among participants, with only 6 participants (5.0%) being non-consumers. The majority consumed dairy products 3-4 times per week (64 participants, 53.3%) or 1-2 times per week (50 participants, 41.7%). Whole milk was the most commonly used milk type among 92 participants (76.7%), followed by low-fat milk in 23 participants (19.2%) and skim milk in 5 participants (4.2%). Green leafy vegetable intake showed that 4 participants (3.3%) were non-consumers, while 60 participants (50.0%) consumed these vegetables 1-2 times per week and 56 participants (46.7%) consumed them 3-4 times per week. For nut and seed consumption, 39 participants (32.5%) were non-consumers, 50 participants (41.7%) consumed them 1-2 times per week, and 31 participants (25.8%) consumed them 3-4 times per week. Calcium-rich fish intake varied among participants, with 28 (23.3%) being non-consumers, 63 (52.5%) consuming fish 1-2 times per week, and 29 (24.2%) consuming fish 3-4 times per week. (Table 2).

Table 2: Lifestyle and Dietary Patterns among Study Participants (N=120)

Lifestyle/Dietary Factor	N (%)
Tobacco Use Status	
Non-smoker	69 (57.5)
Former smoker	20 (16.7)
Active smoker	31 (25.8)
Alcohol Consumption Pattern	
Abstainer	117 (97.5)
Consumer (occasional/regular)	3 (2.5)
Regular exercise engagement	
Yes	14 (11.7)
No	106 (88.3)
Dairy Product Consumption Frequency	
Non-consumer	6(5.0)
1-2 times/ week	50 (41.7)

3-4 times/ week	64 (53.3)
Milk Type (Most Used)	
Whole milk	92 (76.7)
Low-fat milk	23 (19.2)
Skim milk	5 (4.2)
Green Leafy Vegetable Intake	
Non-consumer	4 (3.3)
1-2 times/ week	60 (50.0)
3-4 times/ week	56 (46.7)
Nut and Seed Consumption	
Non-consumer	39 (32.5)
1-2 times/ week	50 (41.7)
3-4 times/ week	31 (25.8)
Calcium-Rich Fish Intake	
Non-consumer	28 (23.3)
1-2 times/ week	63 (52.5)
3-4 times/ week	29 (24.2)

CAC Score and Serum Calcium Categories

The distribution of CAC scores among the 120 participants showed that 59 participants (49.2%) had absent coronary artery calcification (CAC score = 0), 6 participants (5.0%) had mild calcification (CAC score 1-10), 17 participants (14.2%) had moderate calcification (CAC score 11-100), and 38 participants (31.7%) had severe calcification (CAC score >100). Serum calcium levels were categorized as suboptimal (<9.8 mg/dL) in 88 participants (73.3%) and optimal (≥9.8 mg/dL) in 32 participants (26.7%). (Table 3)

Table 3: CAC Score and Serum Calcium Categories of the Study Participants (n = 120)

Variable	Score Range	N (%)
CAC Score Category		
Absent	0	59 (49.2)
Mild	1-10	6 (5.0)
Moderate	11-100	17 (14.2)
Severe	>100	38 (31.7)
Serum Calcium Category		
Hypocalcemia	Serum Calcium < 8.5 mg/dL	18 (15.0)
Normal	Serum Calcium ≥ 8.5- 10.5 mg/dL	91 (75.8)
Hypercalcemia	Serum Calcium > 10.5 mg/dL	11 (9.2)

Correlation between Serum Calcium and CAC Score

Table 4 demonstrates a clear and statistically significant association between serum calcium levels and CAC score among the 120 study participants. The mean CAC score increases progressively across serum calcium categories, from 25.4±18.7 in individuals with hypocalcemia to 82.3±65.4 in those with normal calcium, and further to 148.6±97.2 in patients with hypercalcemia, with an overall p-value of <0.001, indicating a significant difference in calcification burden across groups. Furthermore, the Spearman correlation coefficient (r = 0.46, p<0.001) reveals a moderate positive correlation between serum calcium levels and CAC scores, suggesting that higher serum calcium is associated with greater coronary artery calcification. These findings align with existing literature indicating that even subtle elevations in serum calcium may contribute to vascular calcification and increased cardiovascular risk, reinforcing the potential role of calcium homeostasis in atherosclerotic disease progression.

Table 4: Serum Calcium Levels and Coronary Artery Calcium Score in the Study Participants (n = 120)

Parameter	N (%)	Mean CAC Score ±SD	p-value
Serum Calcium Category			
Hypocalcemia	18 (15.0)	25.4±18.7	<0.001
Normal	91 (75.8)	82.3±65.4	
Hypercalcemia	11 (9.2)	148.6±97.2	
Spearman Correlation (r)	—	0.46	<0.001

Figure 1 is a scatter plot that displays the relationship between serum calcium levels and CAC scores. Each point on the plot represents an individual data point with serum calcium level values plotted on the x-axis and corresponding CAC scores on the y-axis. The data points are distributed in a pattern that shows higher CAC scores generally associated with higher serum calcium levels. A trend line is included, indicating the direction and strength of the association between the two variables. The plot includes labeled axes with appropriate units and a title describing the variables being compared.

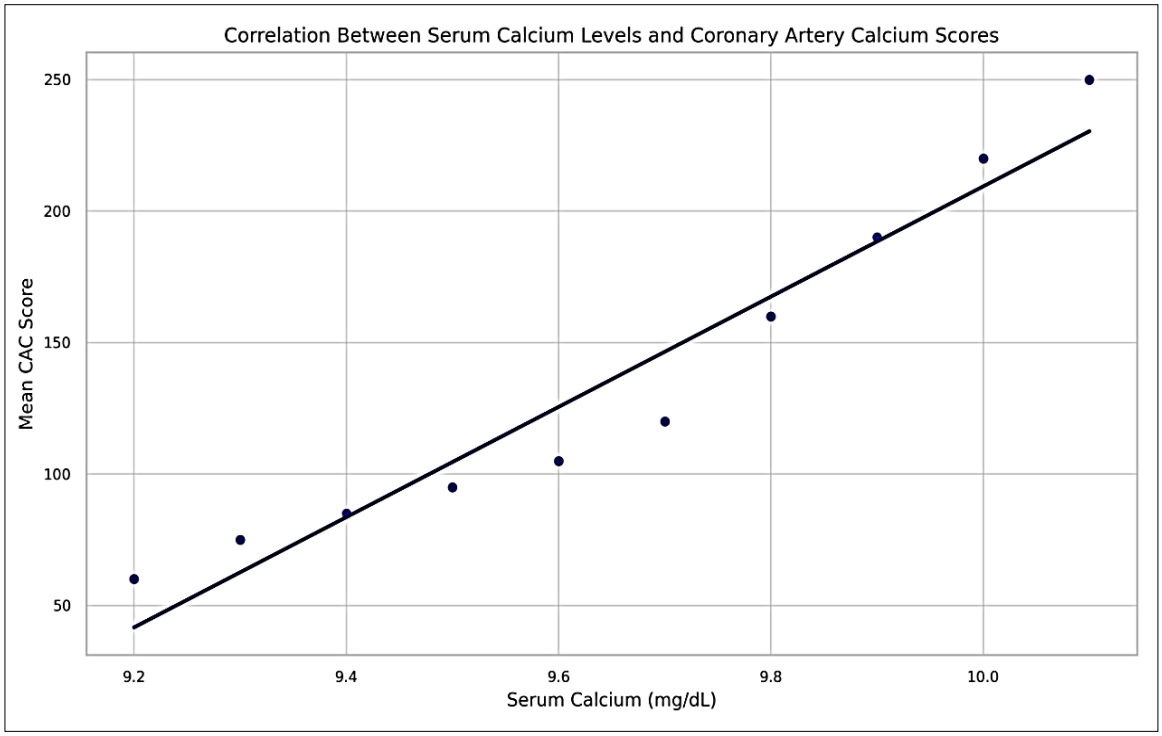

Fig 1: Scatter plot illustrating the positive correlation between serum calcium levels and CAC scores

Multivariable Regression Analysis

The multivariable regression analysis in Table 5 identifies several significant independent predictors of coronary artery calcium (CAC) score, with the model explaining 68% of the variance ($R^2 = 0.68$) and showing high overall statistical significance ($F = 24.3$, $p<0.001$). Age emerged as the strongest predictor ($\beta = 0.351$, $p<0.001$), followed by male sex ($\beta = 0.305$, $p = 0.002$), indicating that older age and male gender are strongly associated with higher CAC scores. Diabetes mellitus ($\beta = 0.241$, $p = 0.006$), smoking history ($\beta = 0.193$, $p = 0.021$), hypertension ($\beta = 0.162$, $p = 0.036$), and BMI ($\beta = 0.148$, $p = 0.044$) were also significant positive predictors, underscoring the role of traditional cardiovascular risk factors in vascular calcification. Notably, serum calcium level was a statistically significant independent predictor ($\beta = 0.210$, $p = 0.008$), with higher levels associated with greater CAC burden, reinforcing its potential pathophysiological role beyond conventional risk factors. Regular physical activity was inversely associated with CAC score ($\beta = -0.121$, $p = 0.069$), suggesting a protective effect, although it did not reach full statistical significance at the 0.05 threshold. These findings collectively highlight that both metabolic and lifestyle factors independently contribute to coronary calcification, with serum calcium representing a modifiable biomarker linked to atherosclerotic burden. (Table 5)

Table 5: Multivariable Regression Analysis for Predictors of CAC Score

Predictor variable	Standardized β	P-value	95% CI
Age (per year)	0.351	<0.001	0.29-0.42
Male Sex	0.305	0.002	0.20-0.41
Diabetes Mellitus	0.241	0.006	0.16-0.33
Smoking History (current/former)	0.193	0.021	0.09-0.30
Hypertension	0.162	0.036	0.06-0.27
BMI (per kg/m²)	0.148	0.044	0.03-0.26
Serum Calcium Level	0.210	0.008	0.06-0.36
Regular Exercise (inverse)	-0.121	0.069	-0.23 to -0.01

Discussion

The present study provides novel insights into the interplay between dietary calcium intake, serum calcium levels, and CAC score in a Middle Eastern population. Our findings demonstrate a significant positive association between serum calcium levels and CAC burden, independent of traditional cardiovascular risk factors. In contrast, no significant correlation was observed between dietary calcium intake and CAC score. These results underscore the importance of systemic calcium homeostasis over dietary intake alone in the pathogenesis of coronary calcification and have important implications for clinical practice and public health policy.

We found that higher serum calcium levels were independently associated with increased CAC scores, with a moderate positive correlation (Spearman's $r = 0.46$, $p<0.001$). Participants with hypercalcemia exhibited significantly higher mean CAC scores (148.6±97.2) compared to those with normal or low serum calcium. Multivariable regression analysis confirmed serum calcium as an independent predictor of CAC burden ($\beta = 0.210$, $p = 0.008$), second only to age and male sex in predictive strength. Notably, dietary calcium intake—assessed via a culturally adapted food frequency questionnaire did not show a significant association with CAC, regardless of source (dairy, leafy greens, fish, or nuts). This suggests that

circulating calcium, rather than dietary intake, may be a more relevant biomarker of vascular calcification risk.

These findings are clinically significant because they shift the focus from dietary calcium restriction often inappropriately advised in patients with cardiovascular concerns toward monitoring and managing serum calcium levels as part of cardiovascular risk assessment. Given that CAC scoring is increasingly used for risk stratification in asymptomatic individuals, identifying modifiable biochemical predictors such as serum calcium enhances the precision of preventive strategies.

Our observation of a strong association between serum calcium and CAC aligns with the growing body of evidence suggesting that vascular calcification is an active, regulated process influenced by mineral metabolism. Even within the normal laboratory range, subtle elevations in serum calcium may promote hydroxyapatite deposition in arterial walls via osteogenic transformation of vascular smooth muscle cells [18]. The lack of association between dietary calcium and CAC further supports the hypothesis that calcium from food sources is tightly regulated by intestinal absorption and does not lead to systemic calcium surges, unlike unregulated supplementation or dysregulated endocrine control [19].

The absence of a link between dietary calcium and CAC is consistent with recent large-scale cohort studies. For example, a 2022 analysis from the UK Biobank (n = 402,598) found no association between dietary calcium intake and coronary calcification, while calcium supplement use was weakly but significantly associated with higher CAC scores [21]. Similarly, the Multi-Ethnic Study of Atherosclerosis (MESA) reported that calcium supplement use, but not dietary calcium, was linked to CAC progression over 10 years [21]. These findings, together with ours, suggest that the form and regulation of calcium exposure not total intake are critical determinants of cardiovascular risk.

Globally, the relationship between calcium and CAC remains controversial, but recent studies increasingly support a dissociation between dietary and supplemental calcium effects. A 2023 meta-analysis of 12 prospective cohorts concluded that calcium supplementation was associated with a 14% higher risk of cardiovascular events, particularly in women not concurrently taking vitamin D, whereas dietary calcium showed neutral or protective effects (22). In contrast, a 2021 study in Japan (n = 1,892) found no association between either dietary or supplemental calcium and CAC, possibly due to lower overall calcium intake and genetic differences in calcium metabolism [23].

Regionally, data from the Middle East are sparse. A 2020 cross-sectional study in Saudi Arabia (n = 215) reported that low dietary calcium was associated with higher CAC, contradicting Western findings (24). However, that study did not measure serum calcium, potentially confounding the interpretation. Our study fills this gap by integrating dietary, biochemical, and imaging data, and it suggests that in Iraqi adults, serum calcium—not dietary intake—is the dominant correlate of coronary calcification.

Importantly, our finding that serum calcium remains a significant predictor after adjusting for age, sex, diabetes, hypertension, and BMI reinforces its role beyond traditional risk factors. This is consistent with a 2022 study in the U.S. that found serum calcium in the upper normal range was associated with a two-fold higher odds of CAC >100, independent of parathyroid hormone and vitamin D levels [25]. These converging results suggest that serum calcium may act as a surrogate marker of dysregulated mineral metabolism, even in individuals without overt hyperparathyroidism or renal disease.

The dissociation between dietary and serum calcium effects may be explained by homeostatic regulation. Dietary calcium absorption is tightly controlled by vitamin D and calcitonin, preventing large fluctuations in serum levels. In contrast, serum calcium can be influenced by parathyroid hormone (PTH), renal excretion, bone turnover, and acid-base status factors not directly tied to intake [26]. Subclinical hyperparathyroidism or vitamin D deficiency, both common in the Middle East due to limited sun exposure and dietary insufficiency, may lead to elevated serum calcium despite low dietary intake [27]. Indeed, in our cohort, 22 participants were on vitamin D supplements, yet 73.3% had suboptimal serum calcium (<9.8 mg/dL), suggesting widespread dysregulation.

Additionally, low physical activity (only 11.7% exercised regularly) and high prevalence of hypertension and diabetes may have amplified vascular calcification through insulin resistance, oxidative stress, and chronic inflammation-pathways that interact with calcium signaling [28].

Our findings suggest that clinicians should prioritize monitoring serum calcium levels as part of cardiovascular risk assessment, particularly in patients with traditional risk factors such as diabetes, hypertension, and aging. Routine calcium supplementation should be prescribed cautiously, especially in the absence of documented deficiency, and balanced with vitamin D to prevent secondary hyperparathyroidism. Public health policies in Iraq and similar regions should focus on improving vitamin D status and promoting physical activity rather than promoting high-dose calcium supplementation.

Future research should employ longitudinal designs to assess the temporal relationship between serum calcium changes and CAC progression. Studies incorporating PTH, vitamin D, fibroblast growth factor-23 (FGF-23), and markers of bone turnover are needed to elucidate the mechanistic pathways. Additionally, randomized trials evaluating the impact of correcting suboptimal serum calcium on CAC progression would provide causal evidence to guide clinical guidelines.

Strengths and Limitations

A major strength of this study is the integration of three key domains dietary assessment, biochemical measurement, and advanced cardiac imaging within a single cohort, allowing for a comprehensive evaluation of calcium's role in atherosclerosis. The use of a validated, culturally adapted FFQ enhances the accuracy of dietary reporting in a Middle Eastern context. Additionally, the application of standardized CT protocols and Agatston scoring ensures reliability in CAC quantification.

Several limitations should be noted: the cross-sectional design prevents causal conclusions; not all participants had ionized calcium, PTH, or vitamin D measured, limiting assessment of mineral metabolism; the sample size restricts detailed subgroup analyses; exclusion of severe CKD or prior CVD cases limits generalizability; and dietary data were self-reported, subject to recall bias despite using a structured FFQ.

Conclusions: This clinical correlation study highlights that serum calcium levels, rather than dietary calcium intake, are

significantly and independently associated with coronary artery calcium (CAC) score. A moderate positive correlation was observed between serum calcium and CAC burden, with multivariable analysis confirming serum calcium as a key predictor of calcification severity, second only to age and male sex. In contrast, no significant association was found between dietary calcium consumption regardless of source and CAC score, supporting the notion that systemic calcium homeostasis, rather than dietary intake alone, plays a central role in the development of vascular calcification. These findings suggest that clinical focus should shift from calcium restriction toward monitoring and managing serum calcium levels as part of cardiovascular risk stratification, particularly in individuals with traditional risk factors such as diabetes, hypertension, and sedentary lifestyle. The results also caution against indiscriminate calcium supplementation, especially in the context of widespread vitamin D insufficiency and metabolic dysregulation in the region. By integrating dietary, biochemical, and imaging data, this study provides valuable insights for refining preventive cardiology strategies and underscores the need for future longitudinal research to explore causal mechanisms and potential interventions targeting mineral metabolism to reduce atherosclerotic burden.

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Data Availability Statement
The data that support the findings of this study are available from the corresponding author upon reasonable request, subject to ethical approval and institutional guidelines.

Competing Interests: The authors declare no competing interests.

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