

Coronary Artery Variation Phenotypes and Associated Clinical Characteristics in a Libyan Adult Cohort: A Multicentre Imaging Analysis

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Abstract—

Background: Coronary artery variations encompass a heterogeneous group of developmental and morphological phenotypes whose clinical expression may differ according to subtype and patient characteristics. Population-specific data from North Africa remain limited.

Methods: This multicentre retrospective cross-sectional study analysed 200 Libyan adults aged 26–85 years who underwent coronary assessment at three referral centres. Coronary artery variation status and phenotype were abstracted from coronary imaging reports together with demographic, anthropometric, cardiovascular risk, and symptom data. Descriptive statistics, chi-square tests, Monte Carlo procedures for sparse contingency tables, Cramér's V, and one-way analysis of variance were used as appropriate.

Results: Coronary artery variations were identified in 87/200 participants (43.5%). Among variation-positive cases, anomalous origin/ostial variants were most frequent (33/87, 37.9%), followed by other/unspecified patterns (17.2%), branching/length variants (14.9%), ectasia/aneurysm (13.8%), myocardial bridging (10.3%), and interarterial/intramural courses (5.7%). Phenotype distribution differed by sex (Monte Carlo $p=0.004$), whereas no significant association was observed with age band (Monte Carlo $p=0.243$). Palpitations occurred more frequently in participants with a coronary variation than in those without one (19.5% vs 8.8%; $\chi^2=4.811$, $p=0.028$; $V=0.155$), although the effect size was small. Mean body mass index did not differ across variation phenotypes ($F(5,81)=0.483$, $p=0.788$).

Conclusion: Coronary artery variation phenotypes were common in this clinically referred Libyan cohort and showed distinct sex-related patterns and a modest association with palpitations. Phenotype-level anatomical reporting may add clinically useful information beyond recording the presence or absence of a coronary variation.

Keywords— coronary artery variations; coronary anomalies; coronary anatomy; Libya; coronary imaging; myocardial bridging; palpitations.

I. INTRODUCTION

Coronary artery variations and anomalies comprise deviations in coronary origin, ostial position, course, branching, length, termination, or vessel morphology, and are commonly classified according to anatomical subtype to aid clinical and imaging interpretation [1,2]. Many are incidental, but selected phenotypes can influence myocardial perfusion, complicate catheter

engagement or surgery, and alter procedural planning. Contemporary guidelines therefore emphasize accurate anatomical definition when a clinically relevant anomalous origin or course is suspected [3,4].

Reported prevalence varies markedly according to the population studied, imaging modality, and—critically—the definition used. Large angiographic and CT-based series restricted to congenital anomalies of origin and course generally report prevalence in the low single digits [5,6], whereas broader frameworks that include myocardial bridging, ectasia, branching patterns, and other coronary variants yield substantially higher estimates [7–10]. This definitional heterogeneity makes direct comparison between populations difficult and supports reporting individual phenotypes rather than a single pooled anomaly rate.

Coronary CT angiography (CCTA) provides three-dimensional assessment of coronary origin and course and is particularly useful for defining relationships with the aorta and pulmonary artery. Invasive coronary angiography remains central to the assessment and treatment of obstructive coronary disease but may be less informative for some three-dimensional anatomical relationships [3,4,11]. The increasing use of coronary imaging has consequently expanded recognition of anatomical phenotypes that were previously under-reported.

Evidence describing coronary variation phenotypes in North African populations is limited [12]. The present analysis was designed to characterise the phenotype distribution of coronary artery variations in a multicentre Libyan adult cohort and to examine selected demographic and clinical correlates. To maintain a distinct clinical-anatomical focus, the primary analyses address phenotype, sex, age, body mass index (BMI), and palpitations rather than comparative diagnostic performance between imaging modalities or multivariable prediction of coronary artery disease.

II. METHODOLOGY

This was a multicentre retrospective cross-sectional analysis of routinely collected coronary imaging and clinical data from three Libyan referral centres—Tripoli Medical Center, Benghazi Medical Center, and Tajoura Heart Center—reported in accordance with the STROBE guidelines for observational studies [13]. The analytical cohort comprised 200 adults aged 26–85 years who underwent coronary assessment. Duplicate records and paediatric cases were removed during data cleaning. Records with insufficient information for the required variables and patients whose native coronary anatomy could not be reliably classified were excluded.

Data were abstracted using a structured collection instrument. Variables included age, sex, BMI, cardiovascular history and risk indicators, presenting symptoms, imaging modality, presence of a coronary artery variation, and anatomical phenotype. Coronary phenotypes were grouped as: anomalous origin/ostial variants; branching/length variants; ectasia/aneurysm; interarterial/intramural course; myocardial bridging; and other/unspecified variations. These groups were selected to preserve clinically meaningful anatomical distinctions while allowing statistical comparison.

Imaging modalities included coronary CT angiography (CCTA) and invasive coronary angiography (ICA). Imaging reports were abstracted by trained research personnel under the supervision of a cardiologist, with discrepancies resolved by consensus. Phenotypes were classified according to a standardised classification system based on the original imaging reports.

Age was grouped as 26–39, 40–49, 50–59, 60–69, and ≥ 70 years for phenotype summaries. BMI was analysed as a continuous measure when comparing variation phenotypes. Palpitations were treated as a binary clinical symptom. Statistical analyses were performed using IBM SPSS Statistics version 27, with the Monte Carlo procedures conducted in SciPy 1.17. Categorical variables are reported as frequencies and percentages. Pearson's chi-square test assessed associations between categorical variables, with Cramér's V used to quantify association strength where expected cell counts were adequate. One-way analysis of variance assessed mean BMI across phenotype groups. Because of sparse expected cell counts in the sex-by-phenotype and age-band-by-phenotype contingency tables, statistical significance for both comparisons was assessed using a Monte Carlo procedure based on 100,000 simulated tables with fixed row and column margins (Patefield's algorithm; fixed random seed for reproducibility). The Pearson chi-square statistic is reported for each comparison, while the Monte Carlo estimate was used for inference. Two-sided $p < 0.05$ was considered statistically significant. Missing data were handled using complete case analysis, as the proportion of missing data was low.

The "other/unspecified" phenotype category was a residual classification retained for imaging-reported coronary variations that could not be confidently assigned to one of the five explicitly defined subtypes (anomalous origin/ostial, branching/length, ectasia/aneurysm, interarterial/intramural course, or myocardial bridging) at the level of anatomical detail documented in the original imaging reports. This category is acknowledged as a limitation of the underlying source data (see Discussion).

All data used for analysis were anonymised. Ethical approval was granted by the responsible institutional research ethics committee (Approval No. LUC-REC/2024/078; 20 May 2024). Administrative permissions were obtained from Tripoli Medical Center, Benghazi Medical Center, and Tajoura Heart Center. Only anonymised retrospective clinical and imaging data were analysed, and patient confidentiality was maintained throughout the study.

AI-assisted tools were used during manuscript preparation for language editing, structural refinement, and reference formatting. ChatGPT (OpenAI; GPT-5.6 Sol) was used for these purposes. All scientific content, statistical results, citations, and interpretations were reviewed and verified by the authors, who take full responsibility for the final manuscript.

III. RESULTS

The final cohort included 200 adults. Men represented 84.5% (n=169) and women 15.5% (n=31). Mean BMI was 27.03±2.31 kg/m². Cardiovascular risk indicators were frequent: hypertension was documented in 83.0%, diabetes mellitus in 43.0%, hyperlipidaemia in 89.0%, and sedentary activity in 78.5%. Chest pain was reported in 95.5%, shortness of breath in 74.5%, and palpitations in 13.5%.

TABLE 1
BASELINE CLINICAL CHARACTERISTICS OF THE STUDY COHORT (N=200)

Characteristic	n	%
Male sex	169	84.5
Female sex	31	15.5
Hypertension	166	83
Diabetes mellitus	86	43
Hyperlipidaemia	178	89
Sedentary activity	157	78.5
Current smoking	64	32
Former smoking	47	23.5
Family history of CAD (1st/2nd degree)	104	52
Chest pain	191	95.5
Shortness of breath	149	74.5
Palpitations	27	13.5

Coronary artery variations were present in 87 participants (43.5%). Among variation-positive cases, anomalous origin/ostial variants constituted the largest group (37.9%). The remaining distribution is shown in Table 2.

TABLE 2
DISTRIBUTION OF CORONARY ARTERY VARIATION PHENOTYPES AMONG VARIATION-POSITIVE CASES (N=87)

Phenotype	n	% of variation-positive cases
Anomalous origin/ostial variants	33	37.9
Other/unspecified	15	17.2
Branching/length variants	13	14.9
Ectasia/aneurysm	12	13.8
Myocardial bridging	9	10.3
Interarterial/intramural course	5	5.7

Phenotype distribution differed significantly by sex (Pearson $\chi^2=16.833$, df=5; Monte Carlo p=0.004). Because 6 of 12 cells (50.0%) had expected counts <5 (minimum ≈1.38), inference was based on the Monte Carlo procedure rather than the asymptotic Pearson p-value. Myocardial bridging was observed only among men in this dataset (9/63 male variation-positive cases, 14.3%, versus 0/24 female variation-positive cases, 0.0%), whereas the other/unspecified category represented a larger

proportion of variation-positive women (10/24, 41.7%) than men (5/63, 7.9%), as shown in Table 3. Because several phenotype-by-sex cells were small, these findings should be interpreted as descriptive and hypothesis-generating.

TABLE 3
CORONARY ARTERY VARIATION PHENOTYPE BY SEX AMONG VARIATION-POSITIVE CASES (N=87)

Phenotype	Female, n (%)	Male, n (%)
Anomalous origin/ostial variants	6 (25.0)	27 (42.9)
Branching/length variants	3 (12.5)	10 (15.9)
Ectasia/aneurysm	4 (16.7)	8 (12.7)
Interarterial/intramural course	1 (4.2)	4 (6.3)
Myocardial bridging	0 (0.0)	9 (14.3)
Other/unspecified	10 (41.7)	5 (7.9)
Total variation-positive cases	24	63

Note: Cells are small; interpretation should be cautious. The "other/unspecified" category is a residual classification for variations that could not be confidently assigned to a specific phenotype based on the available imaging reports.

Coronary artery variation phenotype was not significantly associated with age band (Pearson $\chi^2=23.857$, $df=20$; Monte Carlo $p=0.243$). Because 26 of 30 cells (86.7%) had expected counts <5 , inference was based on the Monte Carlo procedure rather than the asymptotic Pearson p-value. Anomalous origin/ostial variants remained prominent in the older age bands, while myocardial bridging was concentrated in the 40–69-year groups; however, small subgroup counts limit inference regarding age-specific patterns.

TABLE 4
CORONARY ARTERY VARIATION PHENOTYPE BY AGE BAND AMONG VARIATION-POSITIVE CASES (N=87)

Phenotype	26–39	40–49	50–59	60–69	≥ 70
Anomalous origin/ostial	2	1	10	13	7
Branching/length	0	1	6	5	1
Ectasia/aneurysm	1	2	1	4	4
Interarterial/intramural	0	1	2	2	0
Myocardial bridging	0	4	2	3	0
Other/unspecified	0	4	6	3	2

Note: Cells are small; interpretation should be cautious.

Palpitations were reported by 17 of 87 participants with a coronary variation (19.5%) compared with 10 of 113 participants without a variation (8.8%). This association was statistically significant but small in magnitude ($\chi^2=4.811$, $df=1$, $p=0.028$; Cramér's $V=0.155$). In contrast, BMI did not differ significantly across variation phenotypes ($F(5,81)=0.483$, $p=0.788$), suggesting that overall adiposity did not distinguish anatomical phenotype within the variation-positive subgroup.

TABLE 5
ASSOCIATION BETWEEN CORONARY ARTERY VARIATION STATUS AND PALPITATIONS (N=200)

Variation status	Palpitations absent	Palpitations present	Total
Absent	103	10	113
Present	70	17	87
Total	173	27	200

IV. DISCUSSION

This multicentre analysis demonstrates substantial anatomical heterogeneity among Libyan adults referred for coronary assessment. The broad variation prevalence of 43.5% should not be interpreted as the prevalence of rare congenital coronary anomalies in the general population. Rather, it reflects a clinically referred cohort and an intentionally broad phenotype definition that includes ostial/origin patterns, branching and length variants, ectasia/aneurysm, myocardial bridging, interarterial/intramural courses, and other reported variations. Published prevalence estimates vary considerably when broader

anatomical variants are included, reinforcing the importance of transparent definitions [7–10]. Contemporary regional and international imaging series have reported widely varying prevalence estimates depending on the population studied, imaging modality, and anatomical definitions applied [14–17].

Anomalous origin/ostial variants formed the largest phenotype group in the present cohort. These findings are clinically relevant because ostial configuration, proximal course, and relationships to the great vessels may affect ischaemic risk and procedural strategy, particularly for anomalies with an interarterial course or other high-risk anatomic features that have previously been linked to exertional symptoms and, rarely, sudden cardiac death [18,19]. Current adult congenital heart disease guidance recommends anatomical confirmation with CCTA or magnetic resonance angiography when anomalous coronary origin is suspected, with CCTA generally favoured for spatial definition [3,4].

The observed sex-related difference in phenotype distribution is noteworthy but requires cautious interpretation. Myocardial bridging occurred only among men in this dataset, while women were relatively over-represented in the residual other/unspecified category. Previous imaging studies have shown substantial variability in the frequency of myocardial bridging and other coronary variants according to population and ascertainment method [7–10,22]. Sex-related differences in the frequency and pattern of coronary artery anomalies have been reported elsewhere, though the direction of the effect varies across series and imaging modalities [20,21]. The small number of women and sparse subtype cells in our cohort preclude a firm biological conclusion; larger sex-balanced datasets are needed. Additionally, the disproportionate representation of women in the "other/unspecified" category may reflect differences in imaging modality, image quality, or reporting practices rather than true biological differences. This should be considered when interpreting the sex-related findings.

Age-band analysis did not demonstrate a significant overall association with phenotype. This is plausible because many coronary variations are developmental anatomical traits rather than acquired abnormalities. Nevertheless, their clinical expression may change with age as atherosclerotic burden, myocardial demand, and comorbid disease accumulate. The absence of a statistically significant age association in the present cohort should therefore not be interpreted as evidence that age is irrelevant to clinical risk.

Palpitations were approximately twice as frequent among participants with a coronary variation as among those without one. The effect size was small, and the cross-sectional design does not establish causality. Still, selected phenotypes—particularly myocardial bridging, ectatic segments, and haemodynamically important anomalous courses—can be associated with transient ischaemia or arrhythmic symptoms in susceptible patients [23–25]. This finding supports careful symptom correlation when a coronary variation is identified rather than treating every anatomical observation as an incidental imaging label. However, palpitations may also be influenced by other factors such as anxiety, arrhythmias, or medication effects, which were not systematically assessed in this study.

Comparison with data from other North African and Middle Eastern populations is limited by the lack of published studies using comparable phenotype definitions. A Tunisian study of coronary anomalies reported prevalence estimates restricted to congenital anomalies of origin and course [12], which are not directly comparable to the broader phenotype framework used in this study. Larger, prospective studies using standardised definitions are needed to establish population-specific prevalence estimates across the region.

4.1 Limitations

Several limitations should be acknowledged:

- 1) **Retrospective hospital-based cohort:** This was a retrospective hospital-based cohort enriched for patients undergoing coronary assessment and therefore cannot provide population prevalence.
- 2) **Male predominance:** Men predominated (84.5%), limiting sex-specific inference. The disproportionate representation of women in the "other/unspecified" category further complicates the interpretation of sex-related findings.
- 3) **Imaging protocol variation:** Imaging was performed in routine clinical pathways rather than under a single prospective imaging protocol, and the distribution of imaging modalities was not uniform across centres.
- 4) **Broad phenotype framework:** The broad phenotype framework increases anatomical capture but complicates comparison with studies restricted to congenital anomalies of origin and course.

- 5) **Symptom ascertainment:** Symptom associations may be influenced by referral patterns and coexisting coronary disease. Palpitations were not systematically characterised in terms of frequency, duration, or triggers.
- 6) **Residual category:** The "other/unspecified" category is a residual classification that may mask important anatomical distinctions and affect the interpretation of sex-related findings.
- 7) **Missing data:** Missing data were handled using complete case analysis; the potential impact of missingness on the findings cannot be fully excluded.
- 8) **Cross-sectional design:** The cross-sectional design evaluates associations at a single time point and cannot establish causality.

The strength of the study is its multicentre design and phenotype-level reporting in a population for which published coronary anatomical data remain scarce. External validation in independent cohorts with standardised imaging protocols and more balanced sex distribution is needed to confirm these findings.

V. CONCLUSION

Coronary artery variations were frequently documented in this clinically referred Libyan adult cohort, with anomalous origin/ostial patterns forming the largest phenotype group. Variation phenotype differed by sex but not significantly by age band, and palpitations were more common among participants with a documented variation. These findings support phenotype-level reporting of coronary anatomy and careful integration of anatomical findings with the patient's clinical presentation.

Larger prospective, sex-balanced studies using standardised coronary variation definitions are needed to establish population-specific prevalence and clinical risk. Future research should also address the limitations identified in this study, particularly the need for standardised imaging protocols, complete anatomical characterisation, and systematic symptom assessment.

DECLARATIONS

Ethical approval: Ethical approval was granted by the responsible institutional research ethics committee (Approval No. LUC-REC/2024/078; 20 May 2024). Administrative permissions were obtained from Tripoli Medical Center, Benghazi Medical Center, and Tajoura Heart Center.

Informed consent: The study used retrospective, de-identified records, and the requirement for written informed consent was waived.

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Conflict of interest: The authors declare no conflict of interest.

Data availability: De-identified data supporting the findings are held within the doctoral research dataset and may be made available on reasonable request, subject to institutional and ethical restrictions.

Author contributions: Yaseen Ahmad Muhammad Wafi: Conceptualization, Methodology, Data curation, Formal analysis, Writing – original draft. Emad M.N. Abdelwahab, Lubna Shirin, and Mohammed S. Kabir: Supervision, Validation, Writing – review & editing. All authors reviewed and approved the final manuscript.

AI use disclosure: AI-assisted tools were used during manuscript preparation for language editing, structural refinement, and reference formatting. ChatGPT (OpenAI; GPT-5.6 Sol) was used for these purposes. All scientific content, statistical results, citations, and interpretations were reviewed and verified by the authors, who take full responsibility for the final manuscript.

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