

Radial Artery Thrombosis and Associated Risk Factors in Patients Undergoing Radial Coronary Angiography

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Background: Radial access is considered the preferred method for coronary angiography (CAG) and percutaneous coronary intervention. Radial artery thrombosis (RAT) stands out as the primary complication associated with trans-radial access. Our objective was to explore the occurrence of RAT and its associated risk factors. **Method:** A study encompassing 150 patients who underwent coronary interventions via radial access was conducted. Colour Doppler ultrasonography was used to assess proximal and distal radial flow rates 4–6 hours post-procedure. Patients diagnosed with RAT constituted the study group, while those without RAT were designated as controls. **Results:** Among the 150 patients, 20 (13.3%) developed RAT, with partial occlusions observed in 2.7% and total occlusions in 10.7%. Univariate analysis identified potential correlations between RAT and variables such as female gender, hypertension (HT), history of coronary artery disease, use of anti-thrombocyte medications, duration of compression, indication for CAG, haematocrit levels, neutrophil count, creatinine levels and estimated glomerular filtration rate. However, only HT showed a statistically significant association. Multivariate analysis confirmed HT, anti-thrombocyte drug use, duration of compression, haematocrit levels and creatinine levels as independent predictors of RAT. **Conclusion:** HT, anti-thrombocyte drug use, duration of compression, haematocrit levels and creatinine levels are identified as independent predictors of RAT. Standard pulse examination may not adequately detect RAT.

Keywords

Coronary angiography, percutaneous coronary intervention, radial artery thrombosis (RAT), radial coronary angiography, risk factors, thrombosis, transradial access, vascular complications

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Cardiovascular diseases are the most common cause of mortality and morbidity in adults worldwide.¹ Coronary angiography (CAG) is the gold standard method for evaluating atherosclerotic coronary artery disease (CAD).² It is conventionally performed via the trans-femoral (TF) route. Recently, however, the trans-radial (TR) route has become the preferred way.³ The TR route offers better procedure comfort, shorter hospitalization duration and better physical and social functions after the procedure than the TF route.⁴ It has also been shown that TR interventions reduce bleeding complications and process costs compared with TF interventions.⁵

The importance of the route selected is increasing over time due to the increased demand for catheterization.³ The TR route is ideal for catheterization because mobilization is fast and major interference-site complications are minimal. However, the lower opening rates of vein grafts used in coronary artery bypass surgery (CABG) compared with those used in artery grafts have led to the search for new arterial grafts.⁶ Radial artery is the second most common artery graft of choice after the left internal mammary artery.¹ Therefore, the short- and long-term effects of radial artery thrombosis (RAT) following TR interventions are important, particularly in preserving future access to cardiac catheterization, with its potential use as a graft for CABG being another consideration.

Due to the asymptomatic course of RAT, there are limited data on its actual incidence. RAT was reported to be as high as 25–38% in patients who have undergone radial artery cannulation for perioperative blood pressure monitoring.⁷ While some studies found the rates of the RAT to be less than 10%, others reported rates more than 15%.^{8–11} It is showed that repetitive puncture, increased compression time and high compression pressures increase the frequency of RAT, while heparin usage decreases.^{12–14}

The incidence of RAT differs from centre to centre and from study to study. However, the associated risk factors were not yet thoroughly defined. In this article, we would like to investigate the RAT frequency and the associated risk factors after TR interventions in a tertiary university hospital.

Methods

Inclusion criteria

This prospective study included patients aged 18 years or older who either presented with acute coronary syndromes or required CAG for diagnostic evaluation. All procedures were conducted via the right proximal radial artery route.

Exclusion criteria

Patients were excluded from the study if they were unable to provide informed consent or had known contraindications to radial access. These contraindications included abnormal Allen's test results, known radial artery occlusion from previous procedures or the presence of arteriovenous fistulas in the target arm.

A total of 150 consecutive patients were included in this study.

This study was conducted in accordance with the Declaration of Helsinki and was approved by the Duzce University Institutional Review Board. Written informed consent was obtained from all participants prior to the study.

Coronary angiography

All the CAGs were performed by three interventional cardiologists with at least 2 years of experience in radial intervention each. A 2–3 mL dose of 2% lidocaine solution was applied for local anaesthesia prior to artery entry. The artery was accessed with a 20-gauge needle inserted from 1 to 2 cm proximal to the styloid process at an angle of 25–30° to the horizontal plane or from 2 to 3 cm proximal to the wrist line. The TR kit, which consists of an 11 cm-long 6F hydrophilic sheath and 0.021 inch-thick guide wire, was used. The guide wire was passed through the needle after observing the proper flow of blood from the needle, indicating successful entry into the artery. The hydrophilic sheath and the dilator were advanced through the wire. The dilator and wire were removed, and all patients received a spasmolytic cocktail consisting of 200 µg of nitroglycerin and 4,000 U of heparin. This mixture was diluted to a total volume of 20 cc with normal saline and administered through the side arm of the arterial sheath. Additional doses of heparin were administered intravenously to patients with acute coronary syndromes and ad-hoc percutaneous coronary interventions (PCIs). Radial angiography was performed with radiopac (Iopromide) and bidirectional catheter. 6F Judkins right and left, extra backup, amplatz left and amplatz right were used to treat the occluded arteries. The radial sheath was removed immediately after the procedure in all the patients. Radial band was used for haemostasis of the radial artery.

Data collection

RAT was assessed using colour Doppler ultrasound immediately after the removal of the radial band. Radial current velocity was recorded in the proximal and distal areas of the radial artery in the patients. The patient's height, weight, body mass index (BMI), cardiac risk factors, drugs used before the procedure, dose of heparin applied during the procedure and duration of the radial band were also recorded. CAG images of patients were evaluated. Complete blood count, kidney function tests, blood sugar level, thyroid function tests and lipid profile were studied before the interventions.

Colour Doppler ultrasonography

Colour Doppler examination shows the blood flow in the vessels, obtaining information about the direction and velocity of the flow. Pulse-wave Doppler signals and spectral analysis show the current velocity at key points within the vessel. The velocities vary from artery to artery, with being higher in arteries close to the heart. The normal ranges of systolic velocities of the subclavian and the axillary arteries, brachial arteries and radial and ulnar arteries are generally 70–120 cm/s, 50–100 cm/s and 40–90 cm/s, respectively. The flow rate of digital arteries is even lower. The normal upper-extremity Doppler flow forms are triphasic; however, temperature changes can significantly alter the characteristics of the waveforms in the hand and near the hand, especially with movements such as punching.¹⁵

Although thrombus filling of the artery can be observed through black-and-white examination, the colour or power Doppler examination is more useful to show whether the vessel is open and to determine the degree of vessel recanalization by thrombolysis.¹⁵ When a thrombus is detected in the artery, the transducer should be compressed against the artery. If the artery is filled with a thrombus, it will not collapse by compression. It is important to differentiate the artefacts from the thrombus. If there is collapse due to compression in the artery, it may indicate that the suspected image is due to artefacts.¹⁵

Statistical analysis

All continuous variables were expressed as mean ± standard deviation, while categorical variables were presented as numbers and percentages (n, %). The normality of continuous variables was assessed using the Kolmogorov–Smirnov test. Categorical variables and normally distributed continuous variables were analysed using the chi-squared test and independent-sample t-test, respectively. Continuous variables with skewed distributions were compared using the Mann–Whitney U test. Univariate logistic regression analyses were conducted to identify independent predictors of RAT. Variables demonstrating a significant p-value in the univariate analysis were included in the multivariate analysis. Results from both univariate and multivariate regression analyses were reported as odds ratios (OR) with 95% confidence intervals (CIs). A p-value of <0.05 (two-tailed) was considered statistically significant. Data analysis was performed using Statistical Package for Social Sciences software, version 18.0 (SPSS; IBM, Armonk, NY, USA).

Results

The baseline characteristics, admission physical examination findings and laboratory parameters of the patients are shown in *Table 1*.

A total of 150 consecutive patients were included in the study. Of them, 89 (59.3%) were male, while 61 (40.7%) were female. The mean age was 59.53 ± 11.01 years. Ninety-four (62.7%) patients had hypertension (HT), 49 (32.9%) had diabetes mellitus (DM), 40 (26.7%) were smokers, 36 (24.2%) had hyperlipidaemia (HL), 39 (26%) had CAD anamnesis, 19 (12.7%) had chronic kidney disease (CKD), 7 (4.7%) had cerebrovascular disease (CVD) and 11 (7.3%) had heart failure. The mean BMI was 28.9 ± 5.19 kg/m², and most of the patients (80.7%) were under anti-thrombocyte treatment (*Table 1*).

Most patients (86.7%) presented with suspicion or evidence of ischaemia at the outpatient clinic, while 13.3% presented with acute coronary syndromes. The mean radial band duration was 3.22 ± 1.29 hours. A total of 20 (13.3%) patients experienced RAT, of which 4 (2.7%) patients had

Table 1: Baseline characteristics of the patients

Demographics and risk factors	Patients (n=150)
Age, years	60.16 ± 14.01
Male sex, n (%)	89 (59.3)
HT, n (%)	94 (62.7)
DM, n (%)	49 (32.9)
HL, n (%)	36 (24.2)
Smoking, n (%)	40 (26.7)
Obesity, n (%)	77 (51.3)
BMI, kg/m ²	28.94 ± 5.19
CAD anamnesis, n (%)	39 (26)
CKD, n (%)	19 (12.7)
Stroke, n (%)	7 (4.7)
Heart failure, n (%)	11 (7.3)
Anti-thrombotic drug usage before CAG, n (%)	121 (80.7)
Partial radial artery occlusion, n (%)	4 (2.7)
Total radial artery occlusion, n (%)	16 (10.7)
Any radial occlusion, n (%)	20 (13.3)
Proximal flow rates, m/s	58.28 ± 25.94
Distal flow rates, m/s	49.61 ± 24.86
Compression time, h	3.22 ± 1.29
Heparin, U	5.01 ± 1.98
Elective CAG, n (%)	130 (86.7)
AMI presentation, n (%)	20 (13.3)
Haematocrit, %	38.91 ± 4.80
WBC, cells/μL	7.87 ± 2.07
Neutrophil, cells/μL	5.01 ± 2.97
Platelet, cells/μL	236.35 ± 55.76
BUN, mg/dL	17.07 ± 9.16
Creatinine, mg/dL	0.85 ± 0.55
e-GFR, mL/min/1.73 m ²	86.37 ± 19.86
Glucose, mg/dL	118.22 ± 49.92
ft3, pg/dL	3.18 ± 0.49
ft4, ng/mL	0.95 ± 0.38
TSH, mU/dL	1.51 ± 1.7
TG, mg/dL	210.89 ± 134.72
LDL, mg/dL	108.52 ± 37.35
HDL, mg/dL	39.48 ± 9.55
TC, mg/dL	188.72 ± 41.19

AMI = acute myocardial infarction; BMI = body mass index; BUN = blood urea nitrogen; CAD = coronary artery disease; CAG = coronary angiography; CKD = chronic kidney disease; DM = diabetes mellitus; e-GFR = estimated glomerular filtration rate; ft3 = free T3; ft4 = free T4; HDL = high-density lipoprotein; HL = hyperlipidaemia; HT = hypertension; LDL = low-density lipoprotein; TC = total cholesterol; TG = triglyceride; TSH = thyroid-stimulating factor; WBC = white blood cells.

a partial RAT. The mean proximal radial flow velocity was 58.28 ± 25.94 cm/s, and the distal radial flow velocity was 49.61 ± 24.86 cm/s (Table 1).

The laboratory parameters of the study are also presented in Table 1. The mean haematocrit value was 38.91 ± 4.80%, white blood cell count was 7.87 ± 2.07 (×10³/μL), neutrophil count was 5.01 ± 2.97 (×10³/μL) and platelet count was 236.35 ± 55.76 (×10³/μL). The mean blood urea nitrogen was 17.07 ± 9.16 mg/dL, creatinine was 0.85 ± 0.55 mg/dL, estimated glomerular filtration rate (e-GFR) was 86.37 ± 19.86 mL/min/1.73 m², thyroid-stimulating factor level was 1.51 ± 1.7 mIU/L, free T4 was 0.95 ± 0.38 ng/mL, free T3 was 3.18 ± 0.49 pg/mL, mean randomized blood

glucose was 118.22 ± 49.92 mg/dL, low-density lipoprotein cholesterol was 108.52 ± 37.35 mg/dL, high-density lipoprotein cholesterol was 39.48 ± 9.55 mg/dL, triglyceride was 210.89 ± 134.72 mg/dL and total cholesterol was 188.72 ± 41.19 mg/dL.

Comparison of the baseline characteristics, admission physical examination findings and laboratory parameters of the study group and controls are shown in Table 2.

There was no statistically significant difference with regard to age (p=0.834), HT (p=0.240), DM (p=0.432), HL (p=0.735), smoking (p=0.205), CKD (p=0.600), CVD (p=0.940) and BMI (p=0.893). Additionally, there was no statistically significant difference with regard to laboratory parameters, except for the neutrophil count (0.020), between the groups (Table 2).

The female gender was more susceptible to developing RAT than the male gender (19.6 versus 8.9%, p=0.059). The use of anti-thrombotic drugs before CAG provided protection against RAT (16.9 versus 35%, p=0.057). Patients with CAD showed lower RAT rates than patients without CAD (5.1 versus 16.2%, p=0.081).

There was a statistically significant difference with regard to proximal flow rates (15.09 ± 6.90 versus 64.92 ± 20.89, p=0.001), distal flow rates (4.38 ± 1.38 versus 56.56 ± 18.38, p=0.001) and compression time (3.72 ± 1.54 versus 3.14 ± 1.24, p=0.0649) between the groups, respectively (Table 2).

Table 3 represents the results of the univariable and multivariable analyses.

In the univariate analysis, several factors were identified as potential predictors of RAT. These included female gender (OR=2.48, 95% CI: 0.947–6.491, p=0.064), HT (OR=0.341, 95% CI: 0.130–0.896, p=0.029), history of CAD (OR=3.581, 95% CI: 0.791–16.204, p=0.098), anti-thrombocyte drug usage (OR=0.378, 95% CI: 0.135–1.056, p=0.064), compression time (OR=1.446, 95% CI: 0.309–6.769, p=0.069), indication for CAG (OR=3.581, 95% CI: 0.791–16.204, p=0.098), haematocrit levels (OR=0.916, 95% CI: 0.829–1.012, p=0.084), neutrophil count (OR=1.134, 95% CI: 0.979–1.314, p=0.093), creatinine levels (OR=0.061, 95% CI: 0.004–0.840, p=0.097) and e-GFR (OR=1.024, 95% CI: 0.996–1.054, p=0.094).

In the multivariable regression analysis, after adjusting these variables, HT (OR=0.224, 95% CI: 0.068–0.738, p=0.014), anti-thrombocyte drug usage (OR=0.278, 95% CI: 0.105–0.739, p=0.010), compression time (OR=2.280, 95% CI: 1.419–3.662, p=0.001), haematocrit levels (OR=0.881, 95% CI: 0.782–0.992, p=0.037) and creatinine levels (OR=0.030, 95% CI: 0.002–0.453, p=0.011) were identified as independent predictors of RAT.

Discussion

RAT was reported in 13.3% of patients in our study. HT, anti-thrombotic drug use, haematocrit, creatinine level and compression time were the independent predictors for the development of RAT.

RAT is the most common complication of TR interventions. Its rate varies from 10 to 15% from study to study.^{8,11,12} While our study found an RAT rate of 13.3%, it is important to note that RAT is often clinically silent. This is largely due to the dual blood supply to the hand from the radial and ulnar arteries, as well as the presence of the palmar arch. The ulnar artery can usually provide sufficient blood supply to the hand even if the radial artery is occluded. However, the significance of RAT lies primarily in

Table 2: Comparison of baseline characteristics and laboratory parameters of the study group and the controls

Demographics and risk factors		Study group (n = 20)	Controls (n = 130)	P
Age, years		59.05 ± 10.95	60.37 ± 14.41	0.694
Gender, n (%)	Female	12 (60)	49 (37.7)	0.059
	Male	8 (40)	81 (62.3)	
HT, n (%)		8 (40)	86 (66.2)	0.24
DM, n (%)		5 (25)	44 (33.8)	0.432
HL, n (%)		4 (21.1)	32 (24.6)	0.735
Smoking, n (%)		3 (15)	37 (28.5)	0.205
Obesity, n (%)		10 (50)	67 (51.5)	0.898
BMI, kg/m ²		28.92 ± 5.33	29.09 ± 4.26	0.83
CAD anamnesis, n (%)		2 (10)	37 (28.5)	0.081
CKD, n (%)		2 (10)	18 (13.9)	0.6
Stroke, n (%)		1 (5)	6 (4.6)	0.94
Heart failure, n (%)		0	11 (8.5)	0.361
Anti-thrombotic drug usage before CAG, n (%)		13 (65)	108 (83.1)	0.057
Proximal flow rates, ml/sec		15.09 ± 6.90	64.92 ± 20.89	0.001
Distal flow rates, ml/sec		4.38 ± 1.38	56.56 ± 18.38	0.001
Compression time, hour		3.72 ± 1.54	3.14 ± 1.24	0.064
Heparin, U		4.50 ± 1.57	5.09 ± 2.03	0.216
Presentation	Elective CAG, n (%)	18 (90)	112 (86.2)	0.638
	AMI presentation, n (%)	2 (10)	18 (13.8)	
Hematocrit, %		37 ± 4.73	39.18 ± 4.77	0.081
WBC, cells/μL		7.92 ± 2.59	7.87 ± 1.99	0.916
Neutrophil, cells/μL		6.45 ± 2.51	4.79 ± 1.66	0.02
Platelet, cells/μL		240.85 ± 49.05	235.66 ± 56.86	0.7
BUN, mg/dl		23.4 ± 3.1	20.8 ± 3.6	0.093
Creatinine, mg/dl		0.71 ± 0.21	0.88 ± 0.59	0.21
e-GFR, ml/min/1.73 m ²		93.35 ± 17.36	85.30 ± 20.07	0.092
Glucose, mg/dL		130.50 ± 73.96	116.33 ± 45.24	0.239
fT3, pg/dL		3.20 ± 0.59	3.18 ± 0.48	0.904
fT4, ng/mL		0.85 ± 0.14	0.96 ± 0.40	0.209
TSH, mIU/dL		1.33 ± 0.82	1.54 ± 0.91	0.621
TG, mg/dL		200.65 ± 95.97	212.46 ± 97.31	0.716
LDL, mg/dL		119.35 ± 28.31	106.86 ± 38.37	0.165
HDL, mg/dL		41.15 ± 7.15	39.22 ± 9.87	0.403
TC, mg/dL		201.95 ± 35.12	186.69 ± 46.33	0.161

Bold values are statistically significant (p<0.05).

AMI = acute myocardial infarction; BMI = body mass index; CAD = coronary artery disease; CAG = coronary angiography; CKD = chronic kidney disease; DM = diabetes mellitus; e-GFR = estimated glomerular filtration rate; fT3 = free T3; fT4 = free T4; HDL = high-density lipoprotein; HL = hyperlipidaemia; HT = hypertension; LDL = low-density lipoprotein; TG = triglyceride; TSH = thyroid-stimulating factor; WBC = white blood cells.

Table 3: Univariate analysis and multivariate model for radial artery thrombosis

Univariate analysis	p value	OR (95% CI)	Multivariate analysis	p value	OR (95% CI)
Age	0.691	0.992 (0.956–1.309)			
Female gender	0.064	2.48 (0.947–6.491)			
HT	0.029	0.341 (0.130–0.896)	HT	0.014	0.224 (0.068–0.738)
DM	0.435	0.652 (0.222–1.910)			
HL	0.735	1.224 (0.379–3.957)			
Smoking	0.215	2.254 (0.624–8.150)			
Obesity	0.898	1.063 (0.415–2.727)			
BMI	0.892	1.006 (0.918–1.103)			
CAD anamnesis	0.098	3.581 (0.791–16.204)			
CKD	0.639	0.691 (0.148–3.236)			
Stroke	0.940	1.088 (0.124–9.540)			
Heart failure	0.999	0.0 (0–0)			
Anti-thrombotic drug usage before CAG	0.064	0.378 (0.135–1.056)	Anti-thrombotic drug usage before CAG	0.010	0.278 (0.105–0.739)
Compression time	0.069	1.368 (0.976–1.916)	Compression time	0.001	2.280 (1.419–3.662)
Heparin	0.227	0.823 (0.600–1.129)			
Presentation (Elective CAG and AMI presentation)	0.639	1.446 (0.309–6.769)			
Haematocrit	0.084	0.916 (0.829–1.012)	Haematocrit	0.037	0.881 (0.782–0.992)
WBC	0.916	1.012 (0.808–1.268)			
Neutrophils	0.093	1.134 (0.979–1.314)			
Platelet	0.698	1.002 (0.993–1.010)			
BUN	0.272	0.949 (0.865–1.042)			
Creatinine	0.037	0.061 (0.004–0.840)	Creatinine	0.011	0.030 (0.002–0.453)
e-GFR	0.094	1.024 (0.996–1.054)			
Glucose	0.245	1.005 (0.997–1.013)			
ft3	0.903	1.061 (0.410–2.748)			
ft4	0.153	0.170 (0.015–1.933)			
TSH	0.620	0.917 (0.652–1.291)			
TG	0.714	0.999 (0.996–1003)			
LDL	0.166	1.009 (0.996–1.021)			
HDL	0.402	1.020 (0.973–1.096)			
TC	0.163	1.007 (0.997–1.017)			

Bold values are statistically significant ($p < 0.05$).

Empty cells indicate variables that were not included in the multivariate analysis

AMI = acute myocardial infarction; BMI = body mass index; BUN = blood urea nitrogen; CAD = coronary artery disease; CAG = coronary angiography; CI = confidence interval; CKD = chronic kidney disease; DM = diabetes mellitus; e-GFR = estimated glomerular filtration rate; ft3 = free T3; ft4 = free T4; HDL = high-density lipoprotein; HL = hyperlipidaemia; HT = hypertension; LDL = low-density lipoprotein; OR = odds ratio; TC = total cholesterol; TG = triglyceride; TSH = thyroid-stimulating factor; WBC = white blood cells.

the potential loss of future access for cardiac catheterization or use as a graft for CABG. Compared with the previous studies, our RAT rates were slightly high but were acceptable. There could be some explanations for these results: firstly, 6F radial sheath was used in all of our patients. However, in previous studies, 4F and 5F radial sheaths were used in diagnostic CAG, which have better outcomes with regard to RAT.^{16,17} Second, RAT was evaluated 4–6 h after the procedure in our study, while some other studies checked it 24 hours after the procedure or before discharge.^{10,11,17,18} Some of the early RATs could spontaneously recanalize in 24–72 hours. Previous studies may not be able to diagnose some of the early RATs, which could have been spontaneously recanalized soon before the evaluation. This may have caused an increase in the frequency of RAT in our study. Thirdly, a lower dosage of heparin was administered

in our study compared with the previous ones.^{10,14,19} The radial artery (RA) puncture was performed without ultrasonography (USG) guidance in our centre, which in turn may have led to some recurrent punctures and subintimal damages. Additionally, the number of catheters used in the procedure was not investigated in our study; there may have been more catheter changes than in other studies. There is a positive correlation of RAT with the increased number of catheter use. We could not assess the duration of the procedure and the number of recurrent radial accesses, which could also alter the RAT rates.¹⁹

The conventional risk factors for CAD, such as atherosclerosis, HT, hypercholesterolaemia and DM, alter endothelial functions.^{20,21} The balance between vasodilator and vasoconstrictor factors in endothelial

dysfunction deteriorates. In other words, in endothelial dysfunction, dilatory stimulation on endothelium may cause constriction. Typically, HT is expected to increase the RAT frequency by favouring platelet dysfunction and endothelial dysfunction; however, no such association has been shown in previous studies. Additionally, we found that HT is protective against RAT. This could be due to the following factors: (i) the average age of our patients is less than 60 years, most of them use angiotensin-converting enzyme inhibitor/angiotensin receptor blocker and a partial improvement in endothelial function may have been achieved, and (ii) haemostasis in the patients is achieved by inflating the TR band with 12–15 cc of air. This may have resulted in the complete occlusion of the radial artery for 2–6 hours in many patients who are non-hypertensive. Thus, RAT may have been observed more frequently in patients without HT than with HT.

Anti-thrombocyte drugs have been proven to be effective in preventing thrombotic events. Acetylsalicylic acid prevents thrombus formation by blocking thromboxane A₂ formation in cyclooxygenase-1 (COX-1) and cyclooxygenase-2 (COX-2) pathways, while clopidogrel, ticagrelor and prasugrel act on the P2Y₁₂ receptor.²² Endothelial dysfunction and thrombus formation are the common causes of RAT. RAT rates have been shown to be lower in patients under anti-thrombocyte treatment.^{5,23} Our findings are consistent with the results in the literature.

We used only nitroglycerin as a vasodilator in the spasmolytic cocktail. However, it is worth noting that more comprehensive radial cocktails, including combinations of nitroglycerin with calcium-channel blockers, such as verapamil or nifedipine, are used in some studies.²⁴ These expanded cocktails may provide more effective vasodilation and potentially reduce the incidence of radial artery spasm and subsequent thrombosis.²⁴

The compression duration was also shown to be important in RAT rates. A study compared compression duration of 2 hours with 6 hours. A compression duration of 2 hours significantly reduced the risk of RAT after 24 hours compared with 6 hours (5.5 versus 12%, $p=0.025$).¹² In another randomized trial, >4 hours compression duration showed an increased risk of RAT compared with <4 hours (OR=3.11, 95% CI: 1.66–5.82, $p<0.001$).¹³ Politi et al. found that 15 minutes of compression duration reduced the incidence of RAT compared with 2 hours (5% versus 10%, $p=0.05$).²⁵ It was also shown that inflatable TR band compression device reduces the risk of radial artery occlusion in 24 hours (4.4 versus 11.2%, $p<0.005$) and 30 days (3.2 versus 7.2%, $p<0.05$) compared with different haemostatic devices.²⁶ Our study also showed that the longer the compression time, the higher the risk of RAT.

There was a decreased RAT frequency in patients with high haematocrit levels. The relationship between haematocrit levels and RAT has not yet been evaluated in the literature. It can be postulated that higher haematocrit levels may increase intravascular volume and lead to stronger circulation, which can increase pulse pressure and, in turn, reduce thrombosis. Additionally, low haematocrit levels were more common in prolonged procedures, in which multiple catheters may be required. Both the number of catheters needed and procedure duration may contribute to RAT in patients with lower haematocrit levels.

While our study focused on identifying risk factors for RAT, it is crucial to consider potential treatment approaches. Currently, there is no standardized treatment protocol for RAT. Some clinicians opt for a conservative approach, relying on spontaneous recanalization, which can occur in a significant proportion of cases within a few months. For

symptomatic cases or when preservation of radial artery patency is crucial, anti-coagulation therapy may be considered.²⁷ While conventional anti-coagulants, such as low-molecular-weight heparin, have been used, there is a growing interest in the potential role of novel oral anti-coagulants (NOACs), especially apixaban, in treating RAT.²⁸ However, robust clinical trials are needed to establish the efficacy and optimal duration of NOAC therapy for this indication.²⁸ Other approaches being explored include thrombolytic therapy and endovascular interventions, although these are typically reserved for severe cases.

CKD and increased creatinine levels are known to have both pro-coagulant and anti-coagulant effects. However, the net effect of CKD has a tendency for bleeding. Reduction in the expression of glycoprotein Ib and glycoprotein IIb/IIIa receptors in platelets and inhibition of the binding of fibrinogen to glycoprotein IIb/IIIa receptors by uraemic toxins lead to the disruption in the adhesion and aggregation of platelets.²⁹ Degradation of activation after binding of glycoprotein IIb/IIIa receptors to von Willebrand factor and increase in prostaglandin I₂ formation are the other reasons to increase the tendency for bleeding.³⁰ In a previous study, an increase in creatinine levels was found to be associated with increased RAT, while no correlation was found between the creatinine level and RAT in another study.¹¹ In our study, the increase in creatinine level was found to be a protective factor against RAT, which is in line with the literature.

The relationship between age and RAT has been found to be contradictory in the literature.^{9,17} Although some studies have identified advanced age as a predictor of RAT, some other studies have reported higher RAT rates in younger patients.^{9,17} Our study found no significant relationship between age and RAT.

Female gender was found to be an independent predictor of RAT development.^{9,11,17,31–33} Similarly, in our study, RAT was more commonly reported in female gender, but it was not found to be an independent predictor in the multivariate analysis. The small diameter of the radial artery in the female gender, more spasms and the low ratio of radial artery to radial sheath may be related to this condition.

Although it is well known that the effects of endothelial dysfunction increase the incidence of RAT in the literature, the relationship between DM, HL, CVD history and smoking was not statistically significant ($p>0.05$) in our study.^{18,34} Additionally, there was no association between BMI and RAT.

While our study focused on the conventional proximal radial access technique, it is worth noting recent advances in TR access methods, particularly the distal TR or ‘snuffbox’ technique.^{35,36} This approach involves puncturing the radial artery in the anatomical snuffbox, distal to the site used in our study. The snuffbox technique has shown promise in potentially reducing radial artery occlusion rates and preserving the proximal radial artery for future procedures or grafts.^{35,36} Future studies comparing proximal and distal radial access could provide valuable insights into optimizing TR procedures and minimizing RAT rates.

This study has several limitations. Being a single-centre study with a relatively small sample size of 150 patients limits the generalizability of our findings. The exclusion of patients who required conversion to femoral access due to failed radial interventions might have led to an underestimation of RAT incidence. The lack of ultrasound guidance for radial artery puncture could have introduced variability in RAT incidence due to potential subintimal damage. We also did not account for the

duration of the procedure or the number of catheter exchanges, which could influence RAT rates.

Furthermore, our study did not assess the clinical impact of radial artery occlusion or the rate of recanalization at follow-up. We also did not compare outcomes based on the procedure type (diagnostic versus PCI), radial artery diameter or presence of peripheral arterial disease. These factors could provide valuable insights in future studies.

Assessing RAT 4–6 hours post-procedure, rather than at later time points as shown in other studies, might have affected our reported RAT rates. Future studies with longer follow-up periods and assessment of clinical outcomes related to RAT would be beneficial.

Conclusion

RAT remains a significant complication following TR coronary procedures, with our study reporting an incidence of 13.3%. Our findings identify HT, anti-thrombotic drug use, compression duration, haematocrit levels and creatinine levels as independent predictors of RAT. While the immediate clinical impact of RAT is often minimal due to collateral circulation, its occurrence can significantly limit future access options for cardiac

procedures. Based on these findings, we recommend that clinicians pay close attention to patients with HT and those on anti-thrombotic medications, as they are at a higher risk of RAT. Additionally, clinicians should carefully consider and potentially minimize compression time post-procedure, as prolonged compression is associated with an increased RAT risk. While routine use of colour Doppler ultrasonography for post-procedure assessment of radial artery patency may not be cost-effective for all patients, it should be considered for high-risk individuals, as conventional pulse examination may not adequately detect RAT. Alternatively, ultrasound-guided access could be used to potentially reduce RAT risk by minimizing vessel trauma during cannulation. Clinicians should maintain a high index of suspicion for RAT, particularly in patients with identified risk factors, and have a low threshold for ultrasound evaluation when clinically indicated. Furthermore, patients with lower haematocrit and creatinine levels may require closer monitoring. Implementation of these practices could potentially reduce the incidence of RAT and preserve radial access for future procedures. However, further research is needed to establish standardized protocols for the prevention and early detection of RAT and explore the potential benefits of newer techniques such as distal radial access in reducing this complication. □

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