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Impaired Heart Rate Recovery May Predict Radial Artery Spasm in Patients Undergoing Coronary Angiography Via Radial Access

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ABSTRACT

Introduction: Radial artery spasm (RAS) is associated with several pathophysiological pathways, including endothelial and autonomic dysfunction, and causes failed coronary interventions. Heart rate recovery (HRR) is a simple measurement of autonomic nervous system dysfunction. We aimed to investigate the relationship between HRR and RAS during coronary angiography (CA) in the present study.

Patients and Methods: This study included 167 patients (mean age 54.6 ± 8.2, 131 males) who underwent a treadmill stress test (TST) according to the Bruce protocol before trans-radial CA. HRR in the first minute (HRR1) was calculated as the difference between peak heart rate and heart rate one minute after the TST. Patients were divided into two groups according to the presence of RAS.

Results: Among the study population, RAS developed in 26 patients (15.5%). HRR1 and HRR in the third minute (HRR3) were lower in the RAS group. Also, the abnormal HRR1 rate was higher in the RAS group (35.5% vs. 76.9%, p< 0.001). Total procedural time, more than one puncture attempt, more than one catheter use, fluoroscopy time, radiation exposure, contrast volume was higher in the RAS group. Female gender, total procedural time, more than one catheter use, and abnormal HRR1 were independent predictors of RAS.

Conclusion: The current data suggest that a significant relationship was found between abnormal HRR1 and RAS. HRR, a simple autonomic dysfunction parameter, can provide additional information regarding the success of radial procedures.

Key Words: Coronary angiography; heart rate recovery; radial artery spasm.

Radyal Yolla Koroner Anjiyografi Uygulanan Hastalarda Radyal Arter Spazmını Tahmin Etmede Kalp Hızı Toparlanma İndeksi

ÖZ

Giriş: Başarısız radyal koroner girişimlerin en önemli nedenlerinden biri olan radyal arter spazmı (RAS), otonomik disfonksiyon dahil olmak üzere çeşitli patofizyolojik yollarla ilişkilidir. Kalp hızı toparlanma indeksi (heart rate recovery; HRR), otonom sinir sistemi disfonksiyonunun basit bir göstergesidir. Bu çalışmada, koroner anjiyografi (KAG) sırasında gelişen RAS ile egzersiz stres testi (EST) parametrelerinden HRR arasındaki ilişkinin araştırılması amaçlanmıştır.

Hastalar ve Yöntem: Çalışmaya, transradyal yolla (TRY) yapılan KAG öncesi Bruce protokolüne göre EST uygulanan 167 hasta (ortalama yaş 54.6 ± 8.2, 131 erkek) dahil edildi. HRR1, EST'den bir dakika sonraki kalp hızı ile en yüksek kalp hızı arasındaki fark olarak hesaplandı. Hastalar RAS gelişip gelişmemesine göre iki gruba ayrıldı.

Bulgular: Hastaların 26 (%15.5)'sında RAS gelişmiştir. Üçüncü dakikadaki HRR (HRR3) ve HRR1 RAS grubunda daha düşük bulunmuştur. Ayrıca, anormal HRR1 oranı RAS grubunda daha yüksek tespit edilmiştir (%35.5'e %76.9, p< 0.001). Toplam işlem süresi, birden fazla ponksiyon denemesi, birden fazla kateter kullanımı, floroskopi süresi, radyasyon dozu, kontrast hacmi RAS grubunda daha yüksek saptanmıştır. Kadın cinsiyet, toplam işlem süresi, birden fazla kateter kullanımı ve anormal HRR1, RAS'ın bağımsız öngördürücüleri olarak bulunmuştur.

Sonuç: Çalışmamız sonucunda, anormal HRR1 ve RAS arasında anlamlı bir ilişki bulunmuştur. Otonom disfonksiyonu göstermede basit bir parametre olarak kullanılabilecek HRR, radyal işlemlerin başarısını artırmada ek fayda sağlayabilir.

Anahtar Kelimeler: Kalp hızı toparlanma indeksi; koroner anjiyografi; radyal arter spazmı.

INTRODUCTION

Transradial access (TRA) for coronary angiography (CA) has become a primarily preferred method in many centers. Vascular complications such as bleeding, hematoma, pseudoaneurysm are lower in TRA than femoral access[1,2]. Since the blood flow of the hand is

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provided by the dual artery system (ulnar and radial), the blood continues even in radial artery occlusion; hence, the incidence of embolic and ischemic complications of vascular structures in coronary interventions via TRA is relatively low[3]. Coronary interventions through TRA also provide early mobilization of patients, increasing patient comfort and shortening hospital stay[4]. Besides, the popularity of non-coronary angiographic procedures such as cerebral and peripheral interventions via TRA has increased in recent years[5].

Due to its structure, spasm is more common in radial artery than other arteries. Previously, several studies have shown that radial artery spasm (RAS) develops between 4-20% during CA[6]. The development of RAS prolongs the procedure time during CA, as well as the risk of complications. Moreover, the RAS may also reduce patient comfort due to pain and cause procedure failure. Hence, it may be necessary to determine the risk factors before the procedure to predict RAS occurrence[7]. Some clinical, anatomical and procedural factors such as diabetes mellitus (DM), peripheral artery disease (PAD), age, hypertension (HT), female gender, radial artery vessel diameter, tortuosity, catheter diameter are associated with RAS[8]. Also, endothelial dysfunction and autonomic dysregulation may cause radial artery spasm during coronary interventions[9,10].

Heart rate recovery (HRR) is a simple treadmill stress test (TST) parameter defined as the difference between the peak heart rate during peak exercise and heart rate during the recovery[11]. Sympathetic withdrawal and parasympathetic reactivation are accompanied by maximal post-exercise recovery time[12,13]. Especially during the TST, the reduced HRR calculated at the 1st minute during the recovery period is associated with cardiac autonomic dysfunction[10,11]. Several researchers have previously stated that autonomic dysfunction is associated with poor prognosis and increased mortality in cardiovascular diseases[11,14,15]. The relationship between impaired HRR and endothelial dysfunction has also been reported in previous studies[16]. The aim of this study is to investigate the relationship between HRR and RAS in patients who underwent CA via TRA after the TST.

PATIENTS and METHODS

Study Population

This prospective study included a total of 167 consecutive patients (mean age: 54.6 ± 8.2 years; male: 131) who underwent CA via TRA due to suspected stable coronary artery disease (CAD) with an abnormal TST in our tertiary center between September 2020 and February 2021. Patients with moderate-to-severe valvular heart disease, heart failure, arrhythmias, congenital heart disease, acute or chronic infectious or systemic disease, previous CAD, inability to reach 85% of their age-predicted maximum heart rate, chronic pulmonary disease, and the use of beta-blockers or calcium channel blockers were excluded from the study. The study was conducted in accordance with the principles of the Helsinki Declaration and approved by the local Institutional Review Board (2020/76). Written informed consent was obtained from each patient. Body mass index (BMI) was calculated using BMI= weight/height^2 (kg/m^2). As confirmed by most investigators, CAD was determined as if > 50% stenosis was present in at least two projections and at least one major epicardial coronary artery[17].

Exercise Stress Test Protocol

According to the Bruce protocol, all study patients underwent TST and were in the sitting position during the cool-down period. A 12-lead electrocardiogram of all patients was obtained before exercise. Heart rate, blood pressure, and ECG were recorded at the end of each stage. The formula 'Maximum Heart Rate (beats/minute)= 220-age (years)' was used for the target heart rate. Positive TST was defined according to the following criteria: chest pain during TST, decrease in systolic blood pressure by 10 mmHg or more from initial blood pressure, formation of bradycardia, 1 mm or greater or 0.1 mV or greater of downsloping or horizontal ST-segment depression in three consecutive beats, 1 mm or greater or 0.1 mV of ST-segment elevation above the PQ point at 60 ms after the J point in three consecutive beats. However, upsloping ST depression without typical chest pain was not considered a positive criterion[18]. HRR1 was calculated as the difference between peak heart rate and heart rate at one minute after the TET. Patients with an HRR1 of 21 or less at the first minute were considered abnormal, as previously described by Georgoulias et al.[19,20].

Coronary Angiography Via Transradial Access

Coronary angiography was performed in all cases by a single experienced cardiologist. Before the CA, an informed consent form was obtained from all patients in our clinic, indicating that they accepted the CA procedure. Local subcutaneous anesthesia (1 mL of 2% prilocaine) was used three minutes before radial artery puncture. The right radial artery was cannulated with a 6F introducer set in all patients. A radial cocktail containing 2 mg of diltiazem, 200 mcg nitroglycerin, and heparin 5000 IU were injected prophylactically along the sheath to prevent RAS and thromboembolic events. 6F Ultra 4.0 diagnostic catheters (DxTerity TRA, Medtronic, Minneapolis, MN, USA) were used as a first choice. If the left main or right coronary artery was not engaged with this catheter, another catheter was used. Clinical RAS was defined as follows: I) persistent forearm pain (extending beyond the period of catheter manipulation), II) pain response to catheter manipulation (maneuvers of the catheter other than withdrawal, such as rotation or small movements to

obtain optimal catheter position), III) pain response to catheter withdrawal, difficult catheter manipulation after being trapped by the radial artery, and considerable resistance on withdrawal of the sheath. If there are two of the five parameters, it was defined as clinical RAS[21]. Moreover, total procedural time, number of puncture attempts, number of catheters, fluoroscopy time, radiation exposure dose were also recorded.

Statistical Analysis

Statistical analyses were performed using the computer software Statistical Package for Social Sciences (IBM SPSS Statistics for Windows, version 21.0 released 2012, IBM Corp., Armonk, New York, USA). The Kolmogorov-Smirnov test was performed to detect the distribution of the variables. Normally distributed variables were presented as mean ± standard deviation, and nonnormally distributed variables were presented as median (25^{th} to 75^{th} percentile). Categorical variables were expressed as number (%). The Student t-test and Mann-Whitney U test were used to compare quantitative variables with the normal and non-normal distribution. The Pearson's chi-square and Fisher exact tests were performed to compare categorical variables where appropriate. We generated a multivariable logistic regression model to determine the radial spasm's independent predictors with heart rate recovery and the classical parameters known as radial spasm predictor. A p value < 0.05 was considered statistically significant.

RESULTS

A total of 167 patients (mean age: 54.6 ± 8.2 years; male: 131) who underwent CAG via TRA were enrolled in this study. The RAS was detected in 26 patients (15.5%) in the study population. Patients were divided into two groups according to the presence of RAS. Baseline characteristics of the patients are summarized in Table 1. Both groups were balanced in terms of age, gender, HT, DM, dyslipidemia, CAD, and laboratory parameters

Table 1. Baseline characteristics of the patients according to the occurrence of radial artery spasm

	All patients (n= 167)	RAS (-) (n= 141)	RAS (+) (n= 26)	p
Age (years)	54.6 ± 8.2	55 ± 8	52 ± 9.2	0.147
Male gender, n (%)	131 (78.4)	114 (80.9)	17 (65.4)	0.078
Body mass index (kg/m^2)	28.1 (29.9-30.7)	28.7 (26-30.5)	27.8 (25.8-30.8)	0.646
Hypertension, n (%)	93 (55.7)	81 (57.4)	12 (46.2)	0.287
Diabetes mellitus, n (%)	42 (25.1)	34 (24.1)	8 (30.8)	0.472
Hyperlipidemia, n (%)	77 (46.1)	67 (47.5)	10 (38.5)	0.395
Current smoker, n (%)	71 (42.5)	52 (36.9)	19 (73.1)	**0.001**
Coronary artery disease, n (%)	71 (42.5)	59 (41.9)	12 (46.2)	0.683
Total cholesterol (mg/dL)	196 ± 50	196 ± 51	198 ± 47	0.846
LDL cholesterol (mg/dL)	117 ± 46	118 ± 46	116 ± 46	0.855
HDL cholesterol (mg/dL)	43 (37-51)	43 (38-51)	41 (32-49)	0.259
Triglyceride (mg/dL)	157 (112-209)	155 (111-204)	171 (127-239)	0.356
Hemoglobin (g/dL)	13.9 ± 1.7	14 ± 1.6	13.6 ± 2.2	0.337
Creatinine (mg/dL)	0.79 (0.69-0.9)	0.79 (0.7-0.9)	0.79 (0.64-0.91)	0.369
Treadmill stress test				
Resting heart rate (bpm)	86 ± 12	84 ± 11	95 ± 14	**< 0.001**
Resting systolic blood pressure (mmHg)	140 ± 19	139 ± 19	143 ± 17	0.349
Resting diastolic blood pressure (mmHg)	84 ± 11	83 ± 11	85 ± 10	0.437
Peak heart rate (bpm)	149 ± 11	148 ± 11	151 ± 9	0.083
Peak systolic blood pressure (mmHg)	183 ± 20	184 ± 20	182 ± 20	0.643
Peak diastolic blood pressure (mmHg)	87 ± 12	87 ± 12	86 ± 9	0.519
Functional capacity (METs)	10 (8.5-10.4)	10 (8-10.3)	10.1 (9-10.9)	0.124
HRR1 (bpm)	24 (19-30)	26 (20-30)	20 (18-26)	**0.003**
HRR3 (bpm)	45 (39-56)	48 (42-58)	38 (36-45)	**0.001**
Heart rate reserve (bpm)	62 ± 13	64 ± 13	56 ± 13	**0.005**
Abnormal HRR1, n (%)	70 (41.9)	50 (35.5)	20 (76.9)	**< 0.001**

HRR: Heart rate recovery, METs: Metabolic equivalents, RAS: Radial artery spasm.

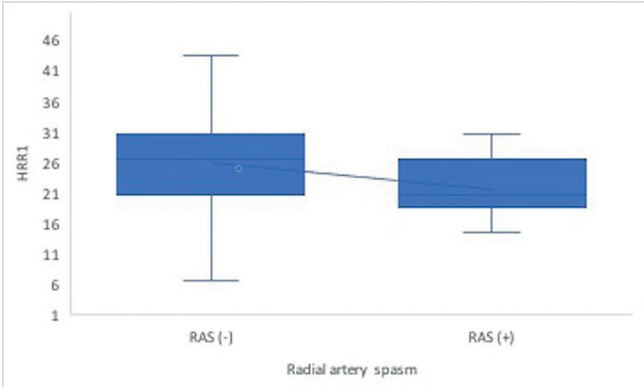

Figure 1. Comparison of HRR in the first minute (HRR1) according to the occurrence of radial artery spasm (RAS).

(hemoglobin, creatinine, cholesterol panel). However, women were tended to be higher in the RAS group [27 (19.1%) vs. 17 (34.6%), p= 0.078]. Patients with RAS had higher incidences of smoking [52 (36.9%) vs. 19 (73.1%), p= 0.001]. When TST parameters were examined, the abnormal HRR1 rate (35.5% vs. 76.9%, p< 0.001) was higher, while HRR1 [26 (20-30) vs. 20 (18-26), p= 0.003] (Figure 1), HRR3 [48 (42-58) vs. 38 (36-45), p= 0.001], and heart rate reserve (64 ± 13 vs. 56 ± 13, p= 0.005) were lower in the radial spasm group.

Table 2 demostrates the patients' baseline characteristics according to the HRR's cut-off value of 21. The abnormal HRR was seen in 70 (41.9%). The abnormal HRR group was older (53.2 ± 7.6 vs. 56.5 ± 8.2, p= 0.011) and had higher rates of smoking [32 (33%) vs. 39 (55.7%), p= 0.003] and DM [18 (18.5%) vs. 24 (34.3%), p= 0.021]. The abnormal HRR group had significantly higher RAS [6 (6.2%) vs. 20 (28.6%), p< 0.001).

Procedure-related information of the patients according to the occurrence of RAS is shown in Table 3. Total procedural time [20 (15-25) vs. 25 (20-30), p< 0.001], more than one puncture attempts [27 (19.1%) vs. 10 (38.5%), p= 0.029], more than one catheter use [25 (17.7%) vs. 10 (38.5%), p= 0.017], fluoroscopy time [2.5 (1.7-3.6) vs. 3.9 (2.8-6.2), p< 0.001], radiation exposure [192 (113-291) vs. 361 (314-541),

Table 2. Baseline characteristics of the patients according to the cut-off value of heart rate recovery

	Normal HRR (> 21) (n= 97)	Abnormal HRR (≤ 21) (n= 70)	p
Age (years)	53.2 ± 7.6	56.5 ± 8.2	**0.011**
Male gender, n (%)	78 (80.4)	53 (75.7)	0.466
Body mass index (kg/m2)	27.7 (25.1-30.2)	28.3 (27-30.8)	0.059
Hypertension, n (%)	51 (52.6)	42 (60)	0.341
Diabetes mellitus, n (%)	18 (18.5)	24 (34.3)	**0.021**
Hyperlipidemia, n (%)	48 (49.5)	29 (41.4)	0.303
Current smoker, n (%)	32 (33)	39 (55.7)	**0.003**
Coronary artery disease, n (%)	41 (42.3)	30 (42.9)	0.939
Total cholesterol (mg/dL)	199 ± 51	193 ± 49	0.464
LDL cholesterol (mg/dL)	120 ± 47	114 ± 45	0.477
HDL cholesterol (mg/dL)	43 (39-52)	43 (36-51)	0.425
Triglyceride (mg/dL)	155 (109-204)	171 (117-236)	0.330
Hemoglobin (g/dL)	14.1 ± 1.6	13.7 ± 1.9	0.197
Creatinine (mg/dL)	0.78 (0.66-0.9)	0.79 (0.7-0.9)	0.384
Treadmill stress test			
Resting heart rate (bpm)	81 ± 10	90 ± 11	**< 0.001**
Resting systolic blood pressure (mmHg)	138 ± 20	143 ± 17	0.078
Resting diastolic blood pressure (mmHg)	83 ± 10	84 ± 12	0.804
Peak heart rate (bpm)	149 ± 11	147 ± 10	0.488
Peak systolic blood pressure (mmHg)	183 ± 20	184 ± 20	0.585
Peak diastolic blood pressure (mmHg)	87 ± 12	87 ± 11	0.871
Functional capacity (METs)	10.1 (8.5-10.6)	9.3 (8.5-10.2)	0.062
HRR1 (bpm)	28 (26-35)	19 (14-20)	**< 0.001**
HRR3 (bpm)	53 (45-62)	40 (36-44)	**< 0.001**
Heart rate reserve (bpm)	67 ± 12	56 ± 12	**< 0.001**
Radial artery spasm, n (%)	6 (6.2)	20 (28.6)	**< 0.001**

HRR: Heart rate recovery, METs: Metabolic equivalents.

Table 3. Procedure-related information of the patients according to the occurrence of radial spasm

	All patients (n= 167)	Radial spasm (-) (n= 141)	Radial spasm (+) (n= 26)	p
Total procedural time (min)	20 (18-25)	20 (15-25)	25 (20-30)	**< 0.001**
More than one puncture attempts, n (%)	37 (22.2)	27 (19.1)	10 (38.5)	**0.029**
More than one catheter use, n (%)	35 (21)	25 (17.7)	10 (38.5)	**0.017**
Fluoroscopy time (min)	2.7 (1.8-3.9)	2.5 (1.7-3.6)	3.9 (2.8-6.2)	**< 0.001**
Radiation exposure (mGy)	208 (122-347)	192 (113-291)	361 (314-541)	**< 0.001**
Contrast volume (mL)	80 (65-90)	70 (60-80)	90 (80-100)	**< 0.001**

Table 4. Multivariate logistic regression analyses for predictors of radial artery spasm

	OR	95% CI	p
Age	0.965	0.897-1.028	0.240
Female gender	3.671	1.087-12.392	0.036
Hypertension	0.770	0.265-2.236	0.631
Diabetes mellitus	1.045	0.338-3229	0.937
Current smoker	2.581	0.834-7.989	0.100
Body mass index	0.953	0.844-1.076	0.439
Total procedural time	1.085	1.010-1.165	0.025
Contrast volume	1.003	0.996-1.009	0.470
More than one puncture attempts	0.862	0.629-1.180	0.354
More than one catheter use	3.941	1.210-12.834	0.023
Abnormal HRR1	4.799	1.408-16.356	0.012

CI: Confidence interval, HRR: Heart rate recovery, OR: Odds ratio.

p< 0.001] , and contrast volume [70 (60-80) vs. 90 (80-100), p< 0.001] were significantly higher in the RAS group. We used 5F catheters in 79% of the patients.

Multivariable logistic regression analyses revealed that abnormal HRR1 (OR= 4.799, CI= 1.408-16.356, p= 0.012), female gender (OR= 3.671, CI= 1.087-12.392, p= 0.036), total procedural time (OR= 1.085, CI= 1.010-1.165, p= 0.025), and more than one catheter use (OR= 3.941, CI= 1.210-12.834, p= 0.023) were independent predictors of the occurrence of RAS (Table 4).

DISCUSSION

Three major findings of the current study are: I) a higher rate of impaired first-minute HRR in patients with RAS during CAG, II) smoking and resting heart rate had an association with RAS, III) female gender, total procedure time, multiple catheter use, and abnormal HRR were independent predictors of RAS.

Coronary interventions with the radial approach are methods that are suggested primarily all over the world[4,5]. The most important advantages of radial artery interventions are higher patient comfort and lower access site complications than femoral interventions. However, some complications may develop due to radial artery interventions[22]. RAS is one of the most important of these complications. The radial artery is a vessel with a tendency to vasospasm because of its muscular structure and the dense alpha adrenoreceptors. Activation of the sympathetic system, stimulation of alpha-1 adrenoreceptors, and mechanical stimulation created by the angiography procedure can cause vascular smooth muscle contraction and consequently vasospasm[7,23]. The frequency of RAS is between 4-20% and a percentage varying significantly between centers. In our study, the frequency of RAS was determined as 15.5%. Some factors associated with RAS are patient-related factors such as female gender, young age, low BMI, narrow radial artery diameter, diabetes, and anxiety[24]. Besides, factors such as technical factors (low radial-artery-to-sheath ratio, non-hydrophilic coated sheaths, unsuccessful access at first attempt, prolonged cannulation, multiple catheter exchanges, excessive catheter manipulations, limited operator experience) can also cause this complication[2,21,25]. RAS may cause severe pain, reduce patient comfort, prolong the procedure, and decrease procedural success. Preventing spasm is, therefore, an essential procedural objective of all operators using the transradial approach.

Endothelial dysfunction is an important predictor of RAS. Endothelial dysfunction has a triggering effect on arterial spasm by disrupting the mechanism of nitric oxide (NO)-mediated vasodilation and increasing alpha-1 receptor density[26]. Previously, Deftereos et al. reported that a positive correlation was found between flow-mediated dilatation, one of the important indicators of endothelial dysfunction, and RAS[25]. One of the easy-to-use parameters associated with endothelial dysfunction is impaired heart rate recovery. HRR is commonly defined as the decrease of heart rate at the first minute after cessation of the TST. Huang et al. have previously indicated that an impaired HRR immediately after exercise was significantly related to, and may predict, endothelial dysfunction[16]. Based on the results of our study, the relationship between impaired first-minute HRR, which is one of the important indicators of endothelial dysfunction, and RAS, in which endothelial dysfunction is involved in its pathophysiology, seems to be explained in this context. Also, publications confirm the relationship between HRR and some factors such as DM,

arterial stiffness, anxiety, and smoking, which were previously shown to be associated with RAS[27-29].

In healthy people, the first increase in heart rate during exercise occurs due to the inactivation of the parasympathetic system that is normally active at rest, but the sympathetic system handles the increase in heart rate during the rest of the exercise. After exercise, the sympathetic system is inactivated and affects heart rate reduction. However, reactivation of the parasympathetic system is the primary mechanism in heart rate decrease after exercise[12,13,30]. An insufficient decrease in heart rate after exercise is defined as impaired heart rate recovery. So, impaired heart rate recovery is an indicator of parasympathetic system dysfunction. Parasympathetic system dysfunction, alias autonomic dysfunction, negatively affects the vascular system[31,32]. Although the parasympathetic system does not create a direct vasodilator effect, it contributes to vasodilation by increasing NO synthesis through M3 receptors[33]. Vasodilation is an important defense mechanism in preventing RAS, and the reduced vasodilator response shows an increasing effect on RAS[7]. Recently, Kocayiğit et al. have reported that the high ADMA levels, which restrict vasodilation by inhibiting NO, were associated with increased RAS[10]. This mechanism can explain the relationship between impaired HRR, which naturally shows autonomic dysfunction, and RAS. Moreover, another study by Kim et al. indicated that impaired HRR was an independent predictor of vasospastic angina presence and a link between coronary artery spasm and autonomic dysregulation[34]. Although HRR1 below 12 beats is widely accepted as abnormal in the upright position during the recovery period, there are studies where HRR1 measured in sitting position is used because it reflects passive recovery better. In our study, the cut-off value of 21 beats was used for HRR1 in a sitting position after exercise, which was defined by Georgoulias et al.[19,20]. There is no data regarding the relationship between impaired HRR and RAS in the literature to the best of our knowledge. Moreover, impaired HRR is an important predictor of autonomic dysfunction, and its relationship to RAS has not been previously demonstrated.

LIMITATIONS

The present study had several limitations. The first and most obvious limitation of the current study was that the radial artery size was not systematically recorded. Nevertheless, a small radial artery makes radial artery catheterization difficult and could, for this reason, increase RAS. Second, this was a single-center study and enrolled a relatively small patient population. Third, angiographic confirmation of the RAS was not performed. Lastly, the patients' anxiety scores were not measured, and radial artery anomalies among the rarer possible causes of RAS were not evaluated in detail.

CONCLUSION

In conclusion, a significant relationship was found between impaired HRR and RAS. Moreover, the present study indicated that impaired HRR, which shows autonomic dysfunction and is associated with endothelial dysfunction, predicts RAS. Evaluation of HRR in patients undergoing TST may provide information in terms of the outcomes of radial procedures. It may be beneficial to be more careful when applying radial interventions to patients with impaired HRR, use higher doses of vasodilator agents, and perhaps prefer femoral interventions.

Ethics Committee Approval: This study was approved by the Mehmet Akif Ersoy Thoracic and Cardiovascular Surgery Training and Research Hospital Ethics Committee (Decision number: 2020/76, Date: 27.04.2021).

Informed Consent: Informed consent was obtained.

Peer-review: Externally peer-reviewed.

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REFERENCES

1. Jolly SS, Amlani S, Hamon M, Yusuf S, Mehta SR. Radial versus femoral access for coronary angiography or intervention and the impact on major bleeding and ischemic events: a systematic review and meta-analysis of randomized trials. Am Heart J 2009;157:132-40. [Crossref]
2. Hetherington SL, Adam Z, Morley R, de Belder MA, Hall JA, Muir DF, et al. Primary percutaneous coronary intervention for acute ST-segment elevation myocardial infarction: changing patterns of vascular access, radial versus femoral artery. Heart Br Card Soc 2009;95:1612-8. [Crossref]
3. Miletin J, Sukop A, Baca V, Kachlik D. Arterial supply of the thumb: systemic review. Clin Anat N Y N 2017;30:963-73. [Crossref]
4. Mitchell MD, Hong JA, Lee BY, Umscheid CA, Bartsch SM, Don CW. Systematic review and cost-benefit analysis of radial artery access for coronary angiography and intervention. Circ Cardiovasc Qual Outcomes 2012;5:454-62. [Crossref]
5. Posham R, Biederman DM, Patel RS, Kim E, Tabori NE, Nowakowski FS, et al. Transradial approach for noncoronary interventions: a single-center review of safety and feasibility in the first 1,500 cases. J Vasc Interv Radiol JVIR 2016;27:159-66. [Crossref]
6. Ho HH, Jafary FH, Ong PJ. Radial artery spasm during transradial cardiac catheterization and percutaneous coronary intervention: incidence, predisposing factors, prevention, and management. Cardiovasc Revascularization Med Mol Interv 2012;13:193-5. [Crossref]
7. Kwok CS, Rashid M, Fraser D, Nolan J, Mamas M. Intra-arterial vasodilators to prevent radial artery spasm: a systematic review and

pooled analysis of clinical studies. Cardiovasc Revascularization Med Mol Interv 2015;16:484-90. [Crossref]

8. Kristic I, Lukenda J. Radial artery spasm during transradial coronary procedures. J Invasive Cardiol 2011;23:527-31. [Crossref]
9. Hussain HI, Upadhyaya C, Pritchard AW, Sandoo A. Radial artery spasm during cardiac angiography: the impact of endothelial dysfunction and anxiety. J R Coll Physicians Edinb 2019;49:171-4. [Crossref]
10. Kocayigit I, Cakar MA, Kahyaoğlu B, Aksoy MNM, Tatli E, Akdemir R. The relationship between serum asymmetric dimethylarginine levels and radial artery spasm. Anatol J Cardiol 2020;23:228-32. [Crossref]
11. Qiu S, Cai X, Sun Z, Li L, Zuegel M, Steinacker JM, et al. Heart rate recovery and risk of cardiovascular events and all-cause mortality: a meta-analysis of prospective cohort studies. J Am Heart Assoc Cardiovasc Cerebrovasc Dis 2017;6. [Crossref]
12. Phan TT, Shivu GN, Abozguia K, Davies C, Nassimizadeh M, Jimenez D, et al. Impaired heart rate recovery and chronotropic incompetence in patients with heart failure with preserved ejection fraction. Circ Heart Fail 2010;3:29-34. [Crossref]
13. Carnethon MR, Sternfeld B, Liu K, Jacobs DR, Shreiner PJ, Williams OD, et al. Correlates of heart rate recovery over 20 years in a healthy population sample. Med Sci Sports Exerc 2012;44:273-9. [Crossref]
14. Cole CR, Blackstone EH, Pashkow FJ, Snader CE, Lauer MS. Heart-rate recovery immediately after exercise as a predictor of mortality. N Engl J Med 1999;341:1351-7. [Crossref]
15. van de Vegte YJ, van der Harst P, Verweij N. Heart rate recovery 10 seconds after cessation of exercise predicts death. J Am Heart Assoc 2018;7:e008341. [Crossref]
16. Huang PH, Leu HB, Chen JW, Cheng CM, Huang CY, Tuan TC, et al. Usefulness of attenuated heart rate recovery immediately after exercise to predict endothelial dysfunction in patients with suspected coronary artery disease. Am J Cardiol 2004;93:10-3. [Crossref]
17. Knuuti J, Wijns W, Saraste A, Capodanno D, Barbato E, Funck-Brentano C, et al. 2019 ESC Guidelines for the diagnosis and management of chronic coronary syndromes. Eur Heart J 2020;41:407-77. [Crossref]
18. Gibbons RJ, Balady GJ, Beasley JW, Bricker JT, Duvernoy WF, Froelicher VF, et al. ACC/AHA Guidelines for Exercise Testing. A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee on Exercise Testing). J Am Coll Cardiol 1997;30:260-311. [Crossref]
19. Georgoulias P, Orfanakis A, Demakopoulos N, Xaplanteris P, Mortzos G, Vardas P, et al. Abnormal heart rate recovery immediately after treadmill testing: correlation with clinical, exercise testing, and myocardial perfusion parameters. J Nucl Cardiol Off Publ Am Soc Nucl Cardiol 2003;10:498-505. [Crossref]
20. Akyüz A, Alpsoy S, Akkoyun DC, Değirmenci H, Güler N. Heart rate recovery may predict the presence of coronary artery disease. Anadolu Kardiyol Derg 2014;14:351-6. [Crossref]
21. Rathore S, Stables RH, Pauriah M, Hakeem A, Mills JD, Palmer ND, et al. Impact of length and hydrophilic coating of the introducer sheath on radial artery spasm during transradial coronary intervention: a randomized study. JACC Cardiovasc Interv 2010;3:475-83. [Crossref]
22. Sandoval Y, Bell MR, Gulati R. Transradial artery access complications. Circ Cardiovasc Interv 2019;12:e007386. [Crossref]
23. Caputo RP, Tremmel JA, Rao S, Gilchrist IC, Pyne C, Pancholy C, et al. Transradial arterial access for coronary and peripheral procedures: executive summary by the transradial committee of the SCAI. Catheter Cardiovasc Interv 2011;78:823-39. [Crossref]
24. Ho HH, Jafary FH, Ong PJ. Radial artery spasm during transradial cardiac catheterization and percutaneous coronary intervention: incidence, predisposing factors, prevention, and management. Cardiovasc Revascularization Med Mol Interv 2012;13:193-5. [Crossref]
25. Deftereos S, Giannopoulos G, Kossyvakis C, Driva M, Kaoukas A, Raisakis K, et al. Radial artery flow-mediated dilation predicts arterial spasm during transradial coronary interventions. Catheter Cardiovasc Interv Off J Soc Card Angiogr Interv 2011;77:649-54. [Crossref]
26. Kawano H, Ogawa H. Endothelial dysfunction and coronary artery spasm. Curr Drug Targets Cardiovasc Haematol Disord 2004;4:23-33. [Crossref]
27. Giannopoulos G, Raisakis K, Synetos A, Davlouros P, Hahalis G, Alexopoulos D, et al. A predictive score of radial artery spasm in patients undergoing transradial percutaneous coronary intervention. Int J Cardiol 2015;188:76-80. [Crossref]
28. Omaygenc MO, Karaca IO, Ibisoglu E, Günes HM, Kizilirmak F, Cakal B, et al. A novel predictor of radial spasm: arterial stiffness. Blood Press Monit 2018;23:253-9. [Crossref]
29. Ercan S, Unal A, Altunbas G, Kaya H, Davutoglu V, Yuce M, et al. Anxiety score as a risk factor for radial artery vasospasm during radial interventions: a pilot study. Angiology 2014;65:67-70. [Crossref]
30. Cheng YJ, Lauer MS, Earnest CP, Church TS, Kampert JB, Gibbons LW, et al. Heart rate recovery following maximal exercise testing as a predictor of cardiovascular disease and all-cause mortality in men with diabetes. Diabetes Care 2003;26:2052-7. [Crossref]
31. Vivekananthan DP, Blackstone EH, Pothier CE, Lauer MS. Heart rate recovery after exercise is a predictor of mortality, independent of the angiographic severity of coronary disease. J Am Coll Cardiol 2003;42:831-8. [Crossref]
32. Li X, Wang Y, Mi X, Qiao Z, Liang Y. Impaired heart rate recovery as a predictor for poor health-related quality in patients with transient ischemic attack. Medicine (Baltimore) 2019;98:e16938. [Crossref]
33. Sartori C, Lepori M, Scherrer U. Interaction between nitric oxide and the cholinergic and sympathetic nervous system in cardiovascular control in humans. Pharmacol Ther 2005;106:209-20. [Crossref]
34. Kim H, Cho SH, Cho KI, Kim BJ, Im SI, Heo JH. Blunted heart rate recovery is associated with coronary artery spasm in patients with suspected vasospastic angina. Clin Hypertens 2017;23:24. [Crossref]