

# Radial artery occlusion after percutaneous coronary interventions – an underestimated issue

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## Abstract

The femoral approach is the most common arterial access for percutaneous coronary artery interventions. Despite the convenience and simplicity of this approach, it is burdened with a high risk of arterial puncture bleeding, which worsens the prognosis of the patient. An alternative approach through the radial artery has been gaining more and more popularity in recent years. This is due to a significant reduction of local bleeding complications as compared with the femoral artery approach. The use of the radial approach in patients with ST-segment elevation myocardial infarction improves outcome, reducing the risk of death, subsequent myocardial infarction and stroke, and is the preferred approach according to the latest ESC guidelines. In addition to improving safety, it is beneficial for improving patient comfort, with a shorter recovery after the procedure, shorter hospitalization and lower medical costs. One of the major complications of procedures performed through the radial approach is radial artery occlusion (RAO). Although it usually has an asymptomatic course, RAO eliminates the ability to use the radial artery as an access in the future. A number of factors that contribute to the occurrence of RAO have been identified, such as the size of the sheath and the catheter, diameter ratio of the sheath to the diameter of the radial artery, insufficient anticoagulation and, above all, the way of obtaining hemostasis at the puncture site: the duration of artery compression after sheath removal and the preservation of artery patency during compression (so-called patent hemostasis). This paper presents the current state of the art about the factors that contribute to the occurrence of RAO and methods for preventing this complication.

**Key words:** radial artery occlusion, percutaneous coronary interventions, radial approach, bleeding complications.

## Introduction

In catheter laboratories around the world the most commonly used arterial approach for percutaneous coronary artery interventions is the femoral access. This is due to the simplicity of the large femoral artery puncture and maneuvering of the catheters and thus shortening the duration of the procedure and X-ray exposure. The disadvantage of this approach is the relatively high frequency of local bleeding, reaching 2–8% [1]. This is due to the difficulties in obtaining local hemostasis after sheath removal in patients treated with anticoagulants and antiplatelet agents, and often with IIb/IIIa-receptor blockers, as occurs in patients with acute coronary syndromes (ACS) [2, 3]. No evidence has been clearly demonstrated that occluder devices that close a hole in the femoral ar-

tery resulted in reducing the incidence of bleeding complications at the puncture site [4].

Moreover, in patients with peripheral artery disease, with Leriche syndrome, as well as those requiring the use of chronic anticoagulation, the femoral approach is difficult and often impossible to perform. An alternative percutaneous vascular approach is radial access. The first coronary angiography through the radial approach was performed by Campeau in 1989 [5], and the first percutaneous coronary intervention (PCI) was performed in 1993 by Kiemeneij [6, 7]. Since then, the number of diagnostic and interventional procedures performed through the radial approach has been growing, both in terms of scheduled procedures and in patients with ACS. Despite the obvious benefits, the popularity of this method is significantly different between the individual operators, cath-

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eter laboratories and countries. Popular in Europe (UK, France, Italy, Sweden), Japan and China, it is rarely used in the US [8]. According to the report of the Association of Cardiovascular Interventions of the Polish Heart Society in Poland in 2009, nearly 20% of coronary artery interventions were performed through the radial approach [9].

### Comparison of radial and femoral approach

The main reason for the increasing popularity of the radial approach is the simplicity of achieving effective hemostasis of the superficial running radial artery. This translates into a significant reduction in local bleeding events compared with access via the femoral artery [10–12]. Bleeding complications after percutaneous procedures are associated with an increased risk of morbidity and mortality [3]. It should be noted, however, that the choice of approach does not affect bleeding events outside the arterial puncture site, mainly within gastrointestinal and genitourinary tracts [13].

In the STEMI-RADIAL study, presented at the TCT congress in 2012, the radial and femoral approaches were compared in patients with ST-segment elevation myocardial infarction (STEMI) and radial access was associated with a 80% reduction in the incidence of complications at the puncture site and local bleeding [14]. A meta-analysis of 23 randomized trials comparing the radial with the femoral approach indicated a 73% reduction in major bleeding events in patients who were treated with radial access, and a trend toward a reduction in the composite endpoint of death, myocardial infarction and stroke [15]. Another meta-analysis of a total of 3324 patients with STEMI showed that the radial, compared to the femoral approach, reduces cardiac mortality by 46% (OR: 0.54 (95% CI: 0.33 to 0.86),  $p = 0.01$ ) and death, myocardial infarction, need for urgent revascularization or stroke by 44% (OR: 0.56 (95% CI: 0.39 to 0.79),  $p = 0.001$ ) [16]. Importantly, the radial approach did not prolong the duration of the procedure or the time to reperfusion.

The recently published RIVAL study comparing the radial with the femoral approach in patients with ACS showed a significant reduction in major vascular complications at the puncture site: large hematomas, arteriovenous fistulas and false aneurysms requiring surgery in favor of radial access (1.4% vs. 3.6%,  $p < 0.001$ ). The risk of death, myocardial infarction, stroke and bleeding not related to coronary artery bypass grafting (CABG) was similar in both groups. A subgroup analysis revealed that in the group of patients with STEMI the use of radial, versus femoral access, reduced not only the risk of major bleeding, but also the risk of death, myocardial infarction and stroke (3.1% vs. 5.2%,  $p < 0.001$ ) [17]. The RIFLE-STEACS study gave similar results. In patients with STEMI the use of the radial, compared to the femoral approach decreased cardiac mortality (2% vs. 5.2%,  $p = 0.02$ ), the incidence of bleeding complications (7.8% vs.

12.2%,  $p = 0.026$ ) and length of hospital stay (5 days vs. 6 days,  $p = 0.03$ ) [18].

In the most recent guidelines of the European Society of Cardiology for the treatment of STEMI, the radial approach is preferred. It is emphasized, however, that the condition is sufficient operator experience in performing procedures with this approach (class of recommendation IIa, level of evidence B) [19]. Both angiography and PCI performed through the radial approach require a lot of experience from the operator, and are more difficult to carry out than through the femoral approach, due to the small diameter of the radial arteries, their tendency to spasm, frequent anatomical anomalies and different rules of catheter maneuvering. The learning curve is clearly visible and the failure rate at the beginning of the training is approximately 5% [20]. However, procedures performed by an experienced operator through the radial approach are as effective as through femoral access [21, 22].

In the aforementioned STEMI-RADIAL study, which was conducted in four centers in the Czech Republic in patients with STEMI, by experienced operators in radial approach, the treatment was equally effective through radial access as through classical, femoral access, in terms of time from symptoms onset to reperfusion (symptom-to-balloon time). Vascular access was slightly more likely changed by the radial approach (crossover rate 3.7% vs. 0.6%:  $p = 0.03$ ). The radial approach was associated with less contrast use (170  $\pm$  71 ml vs. 182  $\pm$  60 ml,  $p = 0.01$ ) and shorter stay in the intensive care unit (2.5  $\pm$  1.7 days vs. 3.0  $\pm$  2.9 days,  $p = 0.0016$ ) [14].

The benefits of the radial approach were also demonstrated in STEMI patients over 75 years of age. Such patients constitute a steadily increasing population, with particularly high risk of bleeding complications, due to multiple co-morbidities. The use of the radial approach, in relation to the femoral approach, in this group of patients allowed a reduction of the incidence of bleeding complications at the puncture site, and, what is important, did not prolong in-hospital delay (door-to-balloon time) [23].

Also in women the radial approach, in relation to the femoral, brings benefits in terms of reducing the risk of bleeding at the puncture site. Women are a population with increased risk of bleeding related to femoral access, but on the other hand are more demanding patients in the radial approach, because of the smaller diameter of the radial artery, frequent discomfort during the procedure and vascular smooth muscle hyperreactivity with tendency to spasm. Unsuccessful radial artery puncture occurs more frequently in women than in men. In one study, the difference was: 9.6% in women vs. 1.6% in men ( $p > 0.01$ ) [24].

In summary, the use of the radial instead of the femoral approach is beneficial not only due to the reduction in the incidence of bleeding complications in the vascular access site, but also allows mortality and the risk of

cardiac ischemic complications to be reduced in high-risk patients. Significantly, the radial approach is also associated with more comfort and satisfaction of the patient, the possibility of earlier recovery after the procedure than through femoral access, and, what goes with it, shortening of hospitalization stay and lower costs of treatment. In a meta-analysis of randomized trials comparing the radial to the femoral approach, Mitchell showed savings of \$275 per procedure, in favor of radial access [25].

### Complications of radial approach

In comparison to femoral access, radial access is associated with a significantly lower incidence of local complications. Moreover, in most cases, they are easier to predict and to treat. The safety and efficacy of the procedure, and thus the number of complications, depend largely on the experience of the operator and on the number of transradial procedures performed. The learning curve for the radial approach is very clear.

Failure of radial artery cannulation is more common than for the femoral artery (7.3% vs. 2.0%,  $p < 0.01$ ) [26]. It is associated with a small vessel diameter and the tendency to spasm of the artery, when the first puncture attempts fail [21]. In the most recent registries, with growing experience of operators, it does not exceed 1.5% [27]. Apart from the risk of hematoma and the need for opposite radial artery or femoral artery puncture, it does not result in additional consequences. The most common complication is radial artery occlusion (RAO) [28], described in detail later in this article.

Radial artery spasm is a frequent complication, which occurs, depending on the definition, in 2–22% of patients. The radial artery has a well-developed muscle layer, provided with a number of  $\alpha$ -adrenergic receptors, provoking contraction under the influence of circulating catecholamines, abundantly secreted under the stress and pain associated with the procedure [29]. Spasm is the second cause of procedure failure, apart from radial artery anomalies. It proceeds with a sore arm, leading to difficulties in catheter manipulation and, in extreme cases, to complete immobilization of the catheter. Spasm predictors include older age, small height, small radial artery diameter, female sex, diabetes, smoking, and repeated unsuccessful attempts to puncture the radial artery [30–32]. Determination of endothelial dysfunction before radial artery cannulation was in the study by Deftereos *et al.* [33] a predictor of spasm. The influence of endothelial dysfunction and radial artery contraction on RAO occurrence, although logical from a pathophysiological point of view, has not yet been proven [30–32].

Proper hydration of the patient before the procedure, sedation, effective local analgesia and the use of intra-arterial spasmolytic drugs can effectively prevent excessive spasm of the radial artery. Proper technique of the procedure (reducing to a minimum manipulation of catheters)

is also important. The correct choice of equipment is also stressed: the use of hydrophilic vascular sheaths and catheters with the smallest possible diameter [34].

The intravascular ultrasound examination (IVUS) of the radial artery (even patent) after cannulation showed segmental neointimal proliferation, thickening of the intima-media complex and negative remodeling. These images were similar to those described in restenosis in coronary arteries and demonstrate the systemic arterial response to mechanical stress [35, 36]. Similar phenomena were observed using optical coherence tomography. Sixty-seven percent of patients had radial artery endothelial dysfunction after cannulation and 36% had arterial wall dissections [37].

Catheterization of a thin radial artery, with a diameter close to the diameter of the sheath, causes long-term consequences such as endothelial dysfunction, not only in the area of the forearm, but also in the brachial artery. It has been proven that higher incidence of endothelial dysfunction occurs in smokers and in patients undergoing complex intervention that requires the use of (and replacement of) several catheters [38]. Endothelial dysfunction and impaired diastolic response to vasodilators and to hyperemia is a chronic phenomenon after cannulation. It has been reported 9 weeks after the procedure. According to the authors, the radial artery after cannulation is not suitable for use as a single graft during coronary artery bypass graft (CABG) or as a dialysis shunt [39].

Approximately in 5% of patients during sheath introduction into the radial artery general symptoms may occur, in the form of bradycardia and hypotension, associated with vasovagal reflex, but easily manageable with intravenous fluids and atropine [40]. Bleeding complications at the arterial puncture site, such as hematoma, occur in about 1% of cases and are easy to manage because of the superficial course of the radial artery over bone structures [41]. Radial artery perforation is a rare complication described in 0.05% of procedures. In most cases, it causes local hematoma and no treatment is required [41]. In extreme cases, it can lead to the compartment syndrome. Early diagnosis and effective treatment prevents acute limb ischemia.

Pseudoaneurysms after the radial approach occur much less often than after the femoral approach, with a frequency of  $< 0.5\%$ , and are associated with insufficient hemostasis or prolonged bleeding. They occur more frequently in patients receiving anticoagulants chronically. Treatment with thrombin or compression bandage in most cases is effective, but sometimes surgery is required [42]. Other complications such as arteriovenous fistulas, radial artery avulsion during sheath removal and nerve damage are rare, as are cases of complex regional pain syndrome (CRPS) of the upper limb, associated with reflex sympathetic dystrophy [43, 44]. Local inflammatory reactions at the puncture site after the use of hy-

drophilic sheaths were reported, with histopathological features of non-inflammatory granulomas, but that was specific to a particular type of sheath, no longer used nowadays [45].

### Radial artery occlusion

Radial artery occlusion is one of the major complications of procedures performed through the radial approach, a kind of “Achilles heel” [26, 46]. The incidence of this complication, evaluated shortly after the treatment, varies widely in the literature, ranging from 1.5% to even 30.5%, with an average of 5–12% [26, 47]. Radial artery occlusion depends on a number of demographic, clinical and periprocedural factors, as well as on the time that elapsed from the procedure to the patency examination. It is even 50% lower if the examination is performed 30 days after the procedure, in relation to the immediate examination after compression bandage removal. This demonstrates frequent spontaneous recanalization of the radial artery [48, 49].

During the 20 years of use of the radial approach, a reduction in the incidence of RAO has been observed. This is due to the growing appreciation of the importance of the problem and understanding the pathogenetic mechanisms causing RAO. This allowed for recognition and implementation of effective prevention methods [8]. In our catheter laboratory, in an unselected group of 352 consecutive patients, the incidence of RAO, evaluated within 12–24 h after the procedure by plethysmography and Doppler examination, was 15% (unpublished data).

A direct pathophysiological factor of RAO is a thrombus [50]. Introduction the sheath and catheters into the artery, then providing effective hemostasis after the procedure, causes damage to the endothelium, arterial smooth muscle contraction and slow-flow/no-flow of the blood stream. This is quite a favorable environment for the formation of thrombi. Pancholy described several cases of mechanical recanalization of the occluded radial artery. The material aspirated from the artery in histopathological evaluation proved to be a thrombus [51]. The role of endothelial injury in the pathogenesis of RAO was demonstrated in a number of imaging studies [34, 50].

### Predictors of radial artery occlusion

A number of factors that contribute to the occurrence of RAO have been defined. In a classic study from 1997 Stella *et al.* found that RAO is often accompanied by low body weight, hypotension during the fitting of a compression bandage and hematoma at the puncture site with concomitant discomfort [28, 52]. Factors that increase the risk of RAO are also prolonged cannulation [53] and small diameter of the radial artery [54], particularly in relation to the sheath and the catheter. If the ratio of the artery diameter to the diameter of the sheath was  $< 1$ , a higher incidence of RAO was observed [55].

Another predictor of RAO is insufficient anticoagulation during the procedure [56] and a lack of blood flow in the radial artery during bandage compression [48]. Radial artery occlusion is frequently observed in women, which is associated with a smaller diameter of the radial artery and its greater predisposition to contraction [56]. Additionally, the presence of diabetes [57], peripheral arterial disease [58] and smoking [36] are predictors of this complication.

### Symptoms of radial artery occlusion

Radial artery occlusion is usually asymptomatic, due to complex blood flow through the hand, provided by the radial, ulnar and intercostal arteries. These arteries form connections among themselves and supply superficial and deep palmar arches as well as the dorsal and palmar wrist networks [59]. Due to the extensive collateral circulation, there is no hand ischemia in spite of the obstruction of one of the forearm arteries. Only both radial and ulnar artery occlusion causes this complication. For this reason, the actual incidence of RAO is underestimated.

Barbeau *et al.* [60] evaluated by plethysmography the sufficiency of collateral circulation in the forearm and the hand in 1010 patients. Only in 1.5% of patients was no pulse wave on plethysmograph displayed after 2 min of radial artery compression, which indicates insufficient collateral circulation between the radial and ulnar arteries. In some patients with an initially negative test, a return of pulse curve was observed after a while, which indicates gradual recruitment of collateral vessels. Only isolated cases of acute ischemia of the hand and fingers have been described so far [61–63]. Most of them were related to chronic, several-day radial artery cannulation in intensive care units [53]. Unclear, however, is the mechanism of ischemia. The possibility of peripheral embolization of the thrombotic material from the occluded radial artery or poorly developed collateral circulation are taken into account [63].

Rhyné *et al.* described a case of hand ischemia, successfully treated by percutaneous angioplasty [64]. Similar findings have also been presented by other authors [51, 65, 66]. It should be noted, however, that attempts to mechanically recanalize the radial artery can be performed only in acute hand ischemia. This treatment is associated with a risk for thrombus embolization and necrosis of the fingers. The occurrence of RAO alone and asymptomatic ischemia, according to the current opinions, does not require any treatment [8].

A small group of patients with RAO may suffer local pain at the puncture site, without signs of hand ischemia. This pain may be caused by an inflammatory reaction (arteritis) in response to injury and thrombus. The prognosis is good and typical anti-inflammatory treatment is effective enough. Zankl *et al.* [67] recognized RAO by Doppler in 10.5% of 488 patients undergoing

coronary angioplasty. Surprisingly high was the proportion of symptomatic patients in this group complaining of forearm pain – 58.5%. None of these individuals had symptomatic hand ischemia. The use of low molecular weight heparin (LMWH) in this group for 4 weeks resulted in artery recanalization in 86.7% of them and relief of symptoms. No bleeding complications were noted. In another study, 42.5% of patients with the diagnosis of RAO suffered pain in the puncture site immediately after the procedure, with another 7% of patients with symptoms that appeared after a few days. There were no signs of hand ischemia. Fifty-nine percent of patients with confirmed RAO received LMWH. Recanalization, assessed after 14 days, was significantly more common in the LMWH group as compared to the group treated symptomatically (55.6% vs. 13.5%,  $p < 0.001$ ) [42].

It should be stressed that these reports are isolated. Both other authors' as well as our own experience show that occurrence of pain is rare after radial artery cannulation [8, 21].

### Diagnosis of radial artery occlusion

Radial artery occlusion is diagnosed by palpation and finding no pulse on the radial artery. It should be, however, confirmed by plethysmography or Doppler [60]. Plethysmography is the simplest and most effective test of arterial forearm and palmar arch patency. The presence on the screen of a clear plethysmographic wave after manual compression of the ulnar artery is evidence of radial artery patency. In some patients, after radial artery cannulation the artery is occluded, although with usually poorly sensed pulse. In the registry from Leipzig [42] in 19.5% of patients the pulse was palpable, despite the ultrasonographic features of RAO. Palpable pulse is provided by the backward flow of blood, flowing from the ulnar artery to the site of occlusion by the superficial and deep palmar arches.

### Clinical significance of radial artery occlusion

Most attention of operators performing percutaneous interventions through the radial approach, especially at the beginning of the learning curve, focuses on procedure technique and overcoming any difficulties. An important issue, RAO is however poorly understood. There are relatively few publications in the world literature and a lack of such publications in Polish. Performing several years of percutaneous interventions through the radial approach, in daily practice, we treat more and more patients after radial artery cannulation, who require re-intervention, and we find radial artery occlusion or even bilateral RAO. Radial artery occlusion, although with asymptomatic course, eliminates the ability to use the radial artery as a percutaneous access in the future, to use it as a free graft for patients undergoing CABG, or to use it for dialysis fistula.

### Prevention of radial artery occlusion

Proper selection of equipment for the percutaneous radial approach, individually selected for the individual patient, can reduce the risk of RAO. The use of vascular sheaths and catheters with the smallest possible diameter is recommended. In the registry from Leipzig [42] the incidence of RAO during hospitalization was evaluated and was as follows: for 5 Fr sheaths 13.7%, and for 6 Fr sheaths up to 30.5%. Nagai underlines the usefulness of radial artery diameter assessment by Doppler before cannulation, in finding the right equipment [57]. In this study, the ratio of the sheath diameter to the radial artery diameter  $> 1$  was associated with a higher risk of RAO (38% vs. 14%,  $p < 0.01$ ). Similar conclusions can be drawn from the study of Saito [55]. The ratio of the sheath diameter to the radial artery diameter  $> 1$  was associated with the occurrence of RAO in 13% of patients, compared to 4%, when the ratio was  $< 1$ . In another study, the predictor of RAO was radial artery diameter  $< 2.7$  mm evaluated by Doppler [52]. There was no evidence that the length of the sheath or hydrophilic coating influenced the occurrence of RAO [68].

The way of obtaining hemostasis is critical in preventing RAO. In the past, attention was paid only to providing effective hemostasis and to avoiding compression of the surrounding veins and nerves. Currently, this element of the study is pointed out with a focus on efforts to reduce the incidence of RAO.

It has been shown that the removal of the sheath from the radial artery immediately after the procedure, as compared to the removal after 3 h, is associated with significantly lower risk of RAO (0% vs. 5%) [69]. The duration of bandage compression after removal of the sheath is also important. Shortening this time from 6 h to 2 h was associated with a reduction in RAO, evaluated within 24 h after the procedure, from 12% to 5.5% ( $p = 0.025$ ), with no increase in the incidence of bleeding complications [70]. The use of hemostatic devices containing on their surface kaolin, which induces rapid hemostasis, allows for significant shortening of compression duration and reduces the risk of RAO [71].

A key factor in reducing the incidence of RAO is to maintain the blood flow in the radial artery during compression – so-called patent hemostasis (PH). Constant blood flow in the artery prevents the formation of blood clots causing the obstruction. The first observations were published in 2007 [48]. Blood flow obstruction in the radial artery under compression was an independent predictor of RAO (OR = 6.7, 95% CI: 1.95–22.9,  $p = 0.002$ ). The importance of PH, as one of the most important factors in the prevention of RAO, was confirmed in prospective randomized clinical trials. In the PROPHET study 436 patients undergoing coronary angiography through the radial approach were divided into two groups: using a classic compression bandage and using compression with

PH. The incidence of RAO was assessed after 24 h and after 30 days. In the group of patients receiving compression with PH a significant reduction in the incidence of RAO was observed, in two periods of time: 59% reduction of RAO frequency after 24 h and 75% after 30 days ( $p < 0.05$ ) [72]. In the PHARAOH study 400 patients admitted to elective coronary angiography were divided into two equal groups. In the first group a heparin dose of 50 IU/kg was administered. In the second group heparin administration was stopped until a compression bandage was fitted and depended on obtaining PH. After confirming the patency of the artery under compression, administration of heparin was abandoned. Heparin was given in a group of 48 patients (26%) who failed to obtain PH. In both groups a similar incidence of RAO was observed, 24 h after the procedure – 7.5% vs. 7.0% ( $p = 0.84$ ) – and 30 days after the procedure – 4.5% vs. 5.0% ( $p = 0.83$ ) [56].

Another strategy for obtaining PH was the compression band (TR Band, Terumo), in which the pressure in the pneumatic element compressing the puncture site was individually adjusted, according to the average blood pressure of the patient. This allowed for a significant reduction in the incidence of RAO, as compared to the classic occlusive compression (1.1% vs. 12%,  $p = 0.0001$ ) [73].

From a practical point of view, it should be noted that obtaining PH using a standard compression bandage is difficult. In the PROPHET study [72] PH was obtained using a pneumatic compression band (TR Band, Terumo), allowing for precise titration of artery compression and also for assessing the bleeding from the puncture site, thanks to the construction of a transparent material. In the PHARAOH study [56], despite the use of this equipment, PH was achieved only in about 74% of patients. It raises practical problems: how to maintain the patency under band compression and simultaneously obtain effective hemostasis, using even such high-tech devices.

## Anticoagulation

Given the proven role of the thrombus in the pathogenesis of RAO, proper anticoagulation is important in the prevention of this complication. Spaulding *et al.* diagnosed RAO after radial artery cannulation in up to 71% of patients who were not given heparin, and only in 4.3% of patients who received a dose of 5000 IU of heparin ( $p < 0.05$ ) [53]. In a study evaluating the effects of two different doses of unfractionated heparin (2000 IU vs. 5000 IU) on the occurrence of RAO, it was found that the use of higher doses can reduce the incidence of RAO from 5.9% to 2.9% ( $p = 0.17$ ). In this study, in patients who experienced RAO, an interesting experiment was conducted: compression of the homolateral ulnar artery for 60 min with obstruction of blood flow, under careful observation of blood supply to the hand. This treatment was safe and effective. It allowed the incidence of RAO in the low-dose heparin group to be reduced from 5.9% to 4.1% and in the high-dose group from 2.9% to 0.8% ( $p = 0.03$ ) [74].

Currently, the recommended dose during coronary angiography is usually a dose of 50 IU/kg up to 5000 IU, intravenous or more often intra-arterial through a vascular sheath. If necessary, in case of PCI, an additional dose of heparin, 70–100 IU/kg, based on the ACT test, should be given [8, 47]. The route of heparin administration, intravenous or intra-arterial through the sheath, does not affect the occurrence of RAO [52].

There are few reports on the efficacy of enoxaparin in the prevention of RAO. In a study with a group of 39 patients the effect of 60 mg enoxaparin, given to the radial artery sheath, on the occurrence of RAO was evaluated. The incidence of RAO assessed at discharge was low and was 4% [75]. The use of bivalirudin in the prevention of RAO has also been reported. This anticoagulant has a short action time that allows for shortening of the compression duration [76].

## Conclusions

The radial approach for percutaneous coronary artery interventions, compared to the femoral approach, brings a number of benefits, in terms of reducing the incidence of bleeding complications at the puncture site and mortality reduction in patients with STEMI. There is also a significant improvement in patient comfort, the ability to quickly recover after the procedure, shorter hospital stay and lower costs of treatment. Most of the attention of operators performing percutaneous intervention through the radial approach is focused on procedure technique, which requires a lot of experience. However, the important issue of RAO is relatively poorly understood and often underestimated. In an online survey, among 1107 invasive cardiologists from 75 countries performing procedures through the radial approach, more than half admitted that they routinely do not assess the patency of the radial artery after the procedure [47].

Radial artery occlusion occurs in approximately 5–12% [26, 47] of patients undergoing procedures through the radial approach and therefore relates to a substantial patient population, especially in high-volume centers. Despite the generally asymptomatic course, RAO limits the use of the radial approach for percutaneous interventions in the future. The prevention of this complication requires multidirectional efforts to improve the operators skills, individual choice of equipment, adequate anticoagulation and paying close attention to the way of achieving hemostasis. Interventions through the radial approach should always be followed by evaluation of radial artery patency before discharging the patient from hospital.

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