Introduction

Long-term results of surgical myocardial revascularization are determined by the quality of grafts and the progression of atherosclerosis in coronary arteries. The aim of the study was to evaluate the patency rate of internal thoracic artery and great saphenous vein grafts in relation to the hemodynamic properties of revascularized coronary artery. The patency of internal thoracic artery and great saphenous vein grafts was analyzed in relation to the degree of coronary stenosis estimated by angiography and the diameter of distal portion of coronary artery assessed intra-operatively. The long-term patency of great saphenous grafts depends on the distal coronary artery diameter but not on the degree of coronary artery stenosis. The patency of internal thoracic artery graft depends on the degree of coronary artery stenosis but not on the distal coronary artery diameter. The internal thoracic artery is the superior graft in coronary surgery, but the low patency rate in case of moderate coronary artery stenosis emphasizes the importance of selective approach.

Keywords: Coronary Artery Bypass; Myocardial Revascularization; Graft Occlusion, Vascular; Mammary Arteries; Internal Mammary - Coronary Artery Anastomosis; Vascular Patency; Coronary Stenosis
In relation to the angiographic patency rate, the grafts were classified as: occluded grafts, grafts with hemodynamically significant stenosis (estimated stenosis over 75%) and grafts without hemodynamically significant narrowing (estimated stenosis under 75%). The patency of GSV and ITA grafts was analyzed in relation to the hemodynamic characteristics of the target CA. The hemodynamic characteristics included the degree of proximal stenosis assessed by angiography and the intra-operatively verified diameter of revascularized CA. According to the degree of CA stenosis, the grafts were divided into two groups: group I – the grafts on the target CA with moderate stenosis (<75%) and group II – the grafts on the target CA with significant angiographic stenosis (≥75%). In relation to the intra-operatively verified peripheral diameter of the target CA, the grafts were divided into the grafts on the target CA with the diameter smaller than 1.5 mm (group III) and the grafts on CA with the diameter ≥1.5 mm (group IV).

Numerical variables are presented as the arithmetic mean and standard deviation (SD). The categorical variables, expressed as absolute values or percentages, are shown in a summary form of distribution frequency. The characteristics of patients and grafts were compared by using univariate analysis, t-tests for the continuous variables and chi-square test for categorical variables. The level of statistical significance was set at the level of 0.05. The statistical analysis was performed with statistical package SPSS.

## Results

The study included 383 patients and 913 grafts (185 ITA grafts and 728 GSV grafts). The average follow-up period for ITA grafts was 60 months. The left anterior descending artery with stenosis of less than 75% was revascularized with 44 ITA grafts (24%), while the CA with stenosis greater than 75% was revascularized with 141 ITA grafts (76%). For the ITA grafts on the target CA with moderate stenosis (<75%) (group I) the average follow-up period was 58 months, while for the ITA grafts on the target CA with significant stenosis (≥75%) (group II) the average period from surgery to angiography was 61 months. The CA with diameter smaller than 1.5 mm were revascularized with 22 ITA grafts (12%) while the CA with diameter 1.5 mm and more were revascularized with 163 grafts (88%) (Table 1). The average follow-up period of the third and fourth group of ITA grafts was 54 months and 61 months, respectively. Out of 44 ITA grafts on the target CA with moderate stenosis, 23 grafts (52%) were occluded, 3 grafts (7%) were significantly narrowed, while 18 grafts (41%) were pat-

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**Table 1. Distribution of ITA and GSV grafts according to the hemodynamic characteristics of target coronary artery**

<table>
<thead>
<tr>
<th>Group I Diameter of coronary artery &lt; 1.5 mm</th>
<th>Group II Diameter of coronary artery ≥ 1.5 mm</th>
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<tbody>
<tr>
<td>ITA</td>
<td>141</td>
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<tr>
<td>GSV</td>
<td>561</td>
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*TAT - thoracica interna, VSM - v. saphena magna*
diameter of the target CA there was no significant
difference in the ITA graft patency rate (p=0.939)
(Figure 2). This result has relative significance since
the number of ITA grafts on CA with diameter
smaller than 1.5 mm is insufficient to obtain statisti-
cally valid data.

The average follow-up period for the GSV grafts
was 84 months. CA with moderate stenosis were
revascularized with 167 GSV grafts (22%) while the
CA with severe stenosis were revascularized with
561 GSV grafts (78%) (Table 1). For the GSV grafts
on the target CA with moderate stenosis (<75%)
(group I) the average follow-up period was 80
months, while for the GSV grafts on the target CA
with significant stenosis (≥75%) (group II) the aver-
age period from the surgery to angiography was 85
months. CA with intra-operatively measured diam-
ter smaller than 1.5 mm were revascularized with
113 GSV grafts (15%), while the CA with diameter
1.5 mm and larger were revascularized with 615
GSV grafts (85%) (Table 1). The average follow-up
period for the third and fourth group of GSV grafts
was 75 months and 76 months, respectively. Out of
167 GSV grafts on the target CA with moderate ste-
nosis, 73 grafts (44%) were occluded, 19 grafts (11%)
had stenosis greater than 75%, while 75 grafts (45%)
were patent. Out of the GSV grafts on the target CA
with significant stenosis, 191 grafts (34%) were oc-
closed, 80 grafts (14%) had stenosis greater than
75%, while 290 grafts (52%) were patent. There was
no significant difference in the GSV graft patency
rate according to the degree of target (CA stenosis
(p = 0.34) (Figure 3). Out of 113 GSV grafts on the
target CA with diameter smaller than 1.5 mm, 75 grafts
(66%) were occluded, 10 grafts (9%) were signifi-
cantly narrowed, while 28 graft (25%) were patent.
In the group of GSV grafts on the target CA with
diameter 1.5 mm and larger, 185 grafts (30%) were
occluded, 91 grafts (15%) had stenosis greater than
75%, while 335 grafts (55%) were patent. In relation
to the diameter of the target CA, there was a signifi-
cant difference in the GSV graft patency rate with a
lower patency rate in the group of GSV grafts on the
target CA with diameter smaller than 1.5 mm (p
<0.05) (Figure 4).

Discussion
The diameter and quality of the periphery of the
target CA (“run off”) have a significant impact on
the long-term venous graft patency. This sensitivity
of the venous graft in relation to the run off is influ-
enced by the graft to CA diameter mismatch that re-
sults in a slower flow of blood through the graft, and
possible consequent graft thrombosis due to a poor
run off.

In one of the largest published studies aimed at ex-
amining graft patency after coronary revasculariza-
tion, Shah et al [8] reviewed 3715 angiograms of 1607
patients who had undergone coronaryography and
graftography due to recurrent angina following coro-
nary artery bypass surgery (CABG). The average pe-
riod from the operation to coronary re-angiography
was 99 months. The graft with stenosis greater than
80% was considered dysfunctional. The results of this
study indicate that the size of proximal stenosis of the
target CA does not affect the graft patency (p = 0.18).
The venous graft “resistance” to a competitive flow is
interpreted as the absence of auto-regulating mecha-
nisms and lower tendency to spasm. A significant
correlation between the venous graft patency and the
diameter of the peripheral segment of the revascu-
larized CA was confirmed, which explains the influ-
ence of the diameter of CA on the run off and the
speed of flow through the graft [8].

The lower patency of ITA grafted on the CA with
moderate stenosis (<75%) indicates the sensitivity of
this particular graft to the competitive flow. The rea-
son for this may be the influence of the autonomous
regulation and ITA spasm in the presence of a com-
petitive flow and compromised in-flow of blood in
the target CA.

Native ITA is predominantly characterized by the
systolic blood flow. When used as a graft, a prox-
imal segment of the ITA has bi-phase (systolic-di-
astolic) blood flow [9]. During systole the blood fills
the proximal segment of the ITA without myocardial
perfusion. In diastole, with the decrease of vascular resistance, the blood enters the distal part of ITA in the target CA and myocardium [9,10]. The poor quality of the target CA with a pronounced competitive flow is a cause of a reduction of the diastolic flow through the graft [11,12].

Dincer and Barnar reported a rare case of spontaneous recanalization of the previously occluded ITA due to the progression of stenosis in the proximal target CA and the reduction of competitive flow [13]. A diffuse narrowing of distal ITA ("string sign") is seen in the cases with the "low grade" stenosis of the target CA [14]. Villareal and Mathur have found in their study that the competitive flow directly influences the development of diffuse spasm of ITA graft [15]. Other possible causes of the ITA graft malfunction include: venous graft anastomosis in the ITA irrigation zone; ITA graft stenosis [16] ITA "steal" phenomenon [17], poor myocardial contractility in the area of the target CA caused by myocardial infarction [18].

Nasu and associates based their research on the intravascular Doppler assessment of flow through the ITA graft. They found that the flow through the graft was compromised in the case of border proximal stenosis in contrast to significant stenosis or occlusion of the target CA. Similar to other investigations, the competitive blood flow is recognized as a cause of reduced flow through the ITA graft [4].

Madaric et al investigated the functionality of the ITA graft using colour-duplex ultrasound (CDUS) in 452 patients of whom 111 had undergone subsequent control angiography due to the anginous pain or positive stress tests. The data were interpreted in relation to the findings of preoperative angiography where CA stenosis greater than 50% was considered as borderline stenosis, and stenosis over 60% as significant. Revascularization of CA with borderline stenosis was identified as a possible cause of ITA graft malfunction. CDUS is a useful non-invasive diagnostic tool that can functionally assess ITA graft [19].

By comparing the ITA graft patency verified by angiography one year after CABG with the severity of CA stenosis verified preoperatively by Fractional Flow Reserve (FFR), the authors established 91.1% graft patency (target CA with significant stenosis) compared to 78.6% graft patency (target CA with borderline stenosis) [20].

The ITA grafts, as opposed to the venous grafts, are not sensitive to the size of the lumen of the target CA. This can be interpreted by the comparable diameter between ITA graft and coronary blood vessel. On the other hand, the ITA graft with its inherited autonomous flow regulation has the ability to adapt to the native CA peripheral flow.

After the introduction of percutaneous interventions in the treatment of coronary disease, the profile of patients undergoing CABG significantly changed. Cardiac surgeons are frequently faced with the diffuse atheromatous lesions of the CA, which are more technically demanding and increase both operative and postoperative early and late morbidity and mortality.

The quality of the CA, which are designated for surgical revascularization, progressively deteriorates, which is detected by preoperative angiography (minor, poorly visible periphery; diffuse distal atheromatous changes). In this group of patients, the operative mortality is increased while the long-term survival is shortened [21]. Corbineau and associates observed diffuse distal CA disease with minor lumen and poor runoff as predictors of the operative mortality [22]. For this reason, angiographic findings should be scored according to the severity of CA pathology. One such scoring model is based on the intra-operatively verified size of the CA distal to anastomosis and characteristics of distal lesions, which are estimated by means of angiography [23]. Increased mortality in the group of patients with small coronary arteries is explained by the increased risk of coronary thrombosis, technical challenge in creating the anastomosis of small CA, and the short- and long-term graft patency. CASS (Coronary Artery Surgery Study) study found that the operative mortality was in direct relation to the mean diameter of CA [24].

Shah and associates analyzed the factors that influence the long-term ITA graft patency in order to optimize the surgical approach. According to 2117 analyzed grafts (1482 ITAs and 635 RITAs), there is no significant influence of either graft or the native CA diameter on the long-term graft patency [25].

All published studies aimed at analyzing the ITA patency by means of clinical parameters, angiographic and ultrasound examinations unanimously confirmed its superiority even in patients with smaller diameter of coronary arteries and diffuse distal coronary disease. In this group of patients, vein grafting is characterized by the low short-term and long-term graft patency and increased operative and early and late postoperative morbidity and mortality.

### Study limitations

The retrospective nature of this study with all the disadvantages of patient selection and possible bias is a major limiting factor. The higher percentage of occluded grafts and grafts with significant stenosis compared to literature data is explained by the fact that only the patients with postoperative anginous pain and positive stress tests were scheduled to undergo coronary and graft angiography.

### Conclusion

The long-term venous graft patency is partly influenced by the diameter of the peripheral segment of the target coronary artery. There is a significantly higher percentage of occluded venous grafts in the group of patients with diffuse distal coronary disease and diameter of the peripheral segment of the revascularized coronary artery less than 1.5 mm. The degree of stenosis of proximal native coronary
artery has no significant influence on the venous graft patency. There is no statistically significant difference in the long-term patency of internal thoracic artery graft in relation to the diameter of the peripheral segment of the target coronary artery. In the new era of coronary surgery, when the patients with diffuse distal coronary disease not suitable for stenting are referred to cardiac surgeons, internal thoracic artery is a graft of choice. On the other hand, it has been documented that the internal thoracic artery graft patency is significantly lower in the case of revascularization of the target coronary artery with moderate stenosis, which indicates the importance of the selective approach in the implementation of internal thoracic artery graft.

References

Sažetak

Uvod
Dugogodišnji rezultati hirurške revaskularizacije miokarda uslovljeni su kvalitetom implantiranih grafova i brzinom progressije arteroskleroze na nativnim koronarnim arterijama. Cilj ove studije bio je da ispita uticaj hemodinamičkih karakteristika koronarnih arterija na prohodnost grajeta a. thoracicae internae i grajeta v. saphena magna.

Materijal i metode
Retrospektivnom analizom je obuhvaćeno 383 bolesnika podvrgnuta koronarnoj hirurgiji i postoperativno reangiografiji. Prohodnost grafova a. thoracicae internae i v. saphena magna je analizirana u odnosu na angiografski verifikovan stepen stenoze i intraoperativno verifikovan dijametar revaskularizovane koronarne arterije. Grafovi su podeljeni u četiri grupe: grupa I – stenoza ciljne koronarne arterije < 75%, grupa II – stenoza koronarne arterije > 75%, grupa III – dijametar koronarne arterije < 1,5 mm, grupa IV – dijametar koronarne arterije > 1,5 mm.

Rezultati
Studijom je analizirano 913 grajeta (185 grajeta a. thoracicae internae i 728 grajeta v. saphena magna). Prohodnost grafova v. saphena magna grupe I i II je bila 45% (75/167), odnosno 52% (p=0,34). Prohodnost grafova a. thoracicae internae grupe I i II je bila 41% (18/44), odnosno 91% (128/141) (p<0,05). Prohodnost grafova v. saphena magna grupe III i IV bila je 25% (28/113) i 55% (335/611) (p<0,05). Prohodnost grafova a. thoracicae internae grupe III i IV bila je 82% (18/22) i 78% (127/163) (p=0,095).

Zaključak