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ORIGINAL ARTICLE / ÖZGÜN MAKALE

Evaluation of anastomosis quality with intraoperative transit time flowmeter in minimally invasive multi-vessel coronary artery bypass grafting via left anterior mini-thoracotomy

Sol anterior mini torakotomi ile minimal invaziv çoklu damar koroner arter baypas greftlemesinde intraoperatif transit-time akım ölçer ile anastomoz kalitesinin değerlendirilmesi

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ABSTRACT

Background: In this study, we aimed to describe our intraoperative transit-time flow measurement results as an integral component of the operation and evaluate the graft patency and anastomosis quality in patients who underwent minimally invasive multi-vessel coronary artery bypass grafting via mini-thoracotomy.

Methods: Between May 2020 and September 2021, a total of 45 consecutive patients (32 males, 13 females; mean age: 51.2±8.6 years; range, 41 to 72 years) who underwent minimally invasive multi-vessel coronary artery bypass grafting via left anterior mini-thoracotomy were retrospectively analyzed. We used the technique of intraoperative transit-time flowmetry in all patients. The patients were operated under cardiopulmonary bypass. A saphenous vein graft was used in all anastomoses, except for the left internal thoracic artery.

Results: The mean left internal mammary artery flow rate was 36.2±14.1 mL/min, mean flow rate of the diagonal grafts was 48.2±13.1 mL/min, mean flow rate of the circumflex grafts was 41.2±21.1 mL/min, and mean flow rate of the right coronary artery grafts was 52.2±11.3 mL/min. Wave patterns and flow parameters of all grafts were normal in the intraoperative measurements, since the pulsatility index values in all anastomoses were within normal limits. The operation was completed after anastomotic openings and graft patency were ensured.

Conclusion: The use of an intraoperative flowmeter to show the graft patency and anastomosis quality gives confidence both to the surgeon and the patient. In multi-vessel coronary artery bypass grafting via mini-thoracotomy, anastomosis quality can be evaluated well with this technique.

Keywords: Minimally invasive direct coronary artery bypass, mini-thoracotomy, multi-vessel bypass, transit-time flowmetry.

ÖZ

Amaç: Bu çalışmada mini torakotomi ile minimal invaziv çoklu damar koroner arter baypas greftleme yapılan hastalarda ameliyatın tamamlayıcı bir parçası olarak intraoperatif transit-time akım ölçüm sonuçlarımız tanımlandı ve greft açıklığı ve anastomoz kalitesi değerlendirildi.

Çalışma planı: Mayıs 2020-Eylül 2021 tarihleri arasında sol anterior mini torakotomi ile minimal invaziv çoklu damar koroner arter baypas greftleme yapılan toplam 45 hasta (32 erkek, 13 kadın; ort. yaş: 51.2±8.6 yıl; dağılım, 41-72 yıl) retrospektif olarak incelendi. Tüm hastalarda intraoperatif transit-time akım ölçer tekniği kullanıldı. Hastalar kardiyopulmoner baypas altında ameliyat edildi. Sol internal torasik arter haricinde tüm anastomozlarda safen ven grefti kullanıldı.

Bulgular: Ortalama sol internal mammarian arterin akım hızı 36.2±14.1 mL/dk., diyagonal greftlerin ortalama akım hızı 48.2±13.1 mL/dk., sirkumfleks greftlerin ortalama akım hızı 41.2±21.1 mL/dk. ve sağ koroner arter greftlerinin ortalama akım hızı 52.2±11.3 mL/dk. idi. Tüm anastomozların pulsatilite indeks değerleri normal sınırlar içinde olduğundan, tüm greftlerin dalga paternleri ve akım parametreleri intraoperatif ölçümlerde normal izlendi. Anastomoz açıklığı ve greft açıklığından emin olunduktan sonra ameliyat tamamlandı.

Sonuç: Greft açıklığını ve anastomoz kalitesini göstermek için intraoperatif akım ölçer kullanımı hem cerraha hem de hastaya güven verir. Mini torakotomi ile gerçekleştirilen çoklu damar koroner arter baypas greftlemede anastomoz kalitesi bu teknik ile iyi bir şekilde değerlendirilebilir.

Anahtar sözcükler: Minimal invaziv direkt koroner arter baypas, mini torakotomi, çoklu damar baypas, transit-time akım ölçer.

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Although standard sternotomy is still the routine method used worldwide in coronary artery bypass grafting (CABG), minimally invasive methods continue to develop and become widespread. This method has many advantages in terms of patient recovery and postoperative results. The main limitations of minimally invasive techniques are technical difficulties, prolonged procedural time, more complexity than conventional methods, and long learning curve which delays the development.[1,2]

The most important factor that facilitates the spread of minimally invasive techniques is proving that the success rates are high. Graft patency remains an important issue in coronary surgery. Early graft occlusion is a frequent cause of early death and perioperative myocardial infarction (MI). In coronary surgery, the quality of the anastomoses, rather than the difference in technique, considerably affects the whole result, and even becomes the main determinant for mortality.[3]

In the present study, we aimed to describe our intraoperative transit-time flow measurement (TTFM) results as an integral component of the operation we performed to ensure the quality of the graft and anastomosis in patients who underwent minimally invasive multi-vessel CABG.

PATIENTS AND METHODS

This single-center, retrospective study was conducted at Hisar İntercontinental Hospital, Department of Cardiovascular Surgery between May 2020 and September 2021. A total of 226 consecutive patients who underwent minimally invasive on-pump multi-vessel CABG through the left anterior mini-thoracotomy were screened. Only the final 45 consecutive patients (32 males, 13 females; mean age: 51.2±8.6 years; range, 41 to 72 years) who underwent minimally invasive on-pump multi-vessel CABG through the left anterior mini-thoracotomy in the fourth intercostal space were included.

Minimally invasive left anterior thoracotomy was applied to all patients who were scheduled for coronary revascularization, regardless of risk factors. Patients who had additional CABG and additional cardiac surgery were excluded from the study. To determine the surgical strategy preoperatively, all patients were evaluated preoperatively by contrast-enhanced computed tomography in terms of the location, depth, area of calcification, and amount of calcification of the aorta. The left internal mammary artery (LIMA) graft was routinely used in all patients who underwent surgery. The saphenous vein was used as a graft for all anastomoses, except for the LIMA.

Data including demographic characteristics (age and sex), concomitant diseases (chronic obstructive pulmonary disease, hypertension, diabetes mellitus, or hyperlipidemia), number of postoperative revisions, arrhythmia or dysrhythmia, length of stay in the intensive care unit (ICU) and hospital, and mortality rates were recorded.

Surgical technique

Double-lumen endotracheal intubation was performed in all patients, allowing single-lung ventilation. Endotracheal tube placement was checked with the help of fiberoptic bronchoscopy after intubation. Then, jugular vein cannula was inserted preoperatively for the patients to facilitate venous drainage during CPB.

As a routinely, a skin incision of approximately 5 cm is made between the sternum and the nipple at the fourth intercostal space. After single-lung ventilation is initiated, the left thoracic artery is ready for harvesting. The LIMA harvesting was performed with a special retractor (Delacroix-Chevalier, Paris, France). The LIMA was harvested totally under direct vision.

Suitable inguinal area for cannulation was exposed with a small incision of about 3 cm (femoral artery, femoral vein). The femoral artery and vein were cannulated with arterial cannula and venous cannula via open Seldinger technique. For other anastomoses, all saphenous veins were harvested endoscopically. Only one side of the vein graft was marked with methylene blue to avoid twisting of proximal anastomosis. The distance between the aorta and the pulmonary vein was dissected with the

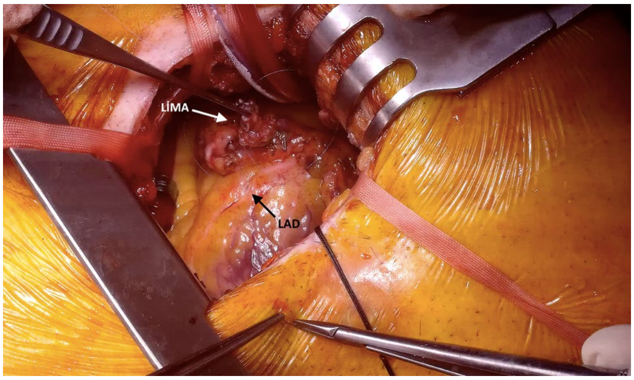

Figure 1. Image of the intraoperative LIMA-LAD anastomosis stage.

LIMA: Left internal mammary artery; LAD: Left anterior descending.

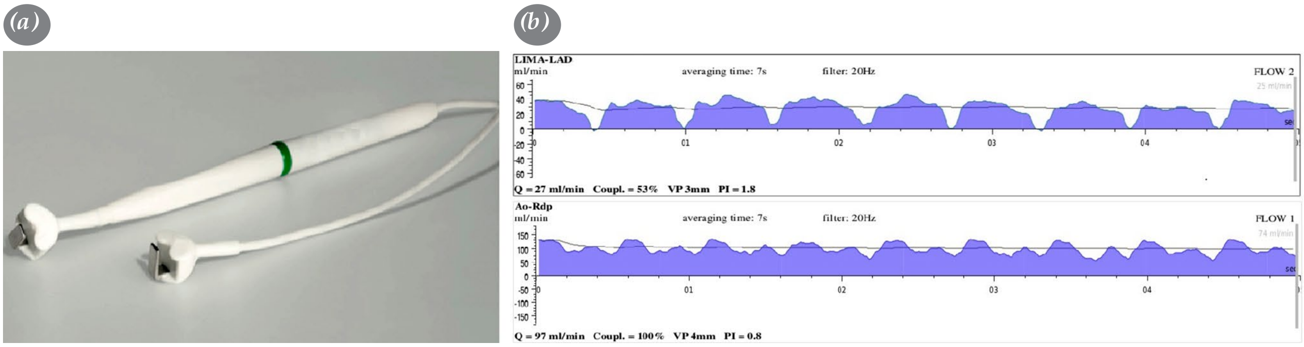

Figure 2. (a) Flow probes used for transit-time flow measurement with flexible cord for difficult access minimally invasive coronary artery bypass graft surgery, **(b)** TTFM measurement recording of LIMA and saphenous vein grafts in normal ranges.

TTFM: Transit-time flow measurement; LIMA: Left internal mammary artery.

blunt dissection technique and encircled with a 6-mm tape.

Antegrade cardioplegia cannula was inserted by pulling the aorta to the left with the help of the tape. A Chitwood clamp was inserted through the anterior axillary line of the second intercostal space to clamp the aorta. After cardiac arrest, the pulmonary veins were encircled with a 6-mm tape. Then, the inferior vena cava was encircled with a 6-mm tape. The left anterior descending (LAD) artery anastomosis was completed (Figure 1). All coronary anastomoses were completed with the standard anastomotic technique. A side-bite clamp was, then, placed on the ascending aorta. Standard 6-0 polypropylene sutures and standard coronary instruments were used for all proximal anastomoses.

After distal and proximal anastomoses were completed, a TTFM probe (QuickFit™; Medistim AS, Oslo, Norway) was used for flow velocity and pulsatility index (PI) measurements in all grafts (Figure 2a). All TTFM measurements were made at a mean constant mean arterial pressure (MAP) of 65 to 70 mmHg. The surgeon decided on the probe size (3 or 4 mm) based on a visual estimation of the external graft diameter. Before each TTFM measurement, ultrasound gel was applied to fill the graft probe lumen. Graft directions and canal angle of the TTFM probe were fixed and verified. All measurements were made one by one from all grafts and recorded. After making sure that the wave patterns, flow rate and PI values in the measurements made were within normal ranges, the operation was completed.

The PI is calculated by dividing the difference between maximum flow and minimum flow by the average flow: Nominal values should be between 1 and 5, values above 5 indicate a problem with the coronary graft anastomosis and review of the anastomosis is recommended.[3]

Statistical analysis

Normal distribution assumption of independent variables was checked by Kolmogorov-Smirnov test. The relationship between the dependent variables were evaluated using the Student-t test when they fit the normal distribution, and the Mann-Whitney U test when they didn't fit the normal distribution. Analysis results are considered statistically significant if the confidence interval is 95% and p values are less than 0.05.

RESULTS

Baseline demographic and clinical characteristics of the patients are presented in Table 1.

Table 1. Baseline demographic and clinical characteristics of patients

	n	%	Mean±SD
Age (year)			51.2±8.6
Sex			
Male	32		
Female	13		
COPD	4	8.8	
Hypertension	26	57.7	
Diabetes mellitus	28	62.2	
Hyperlipidemia	24	53.3	
PAD	1	2.2	
Ejection fraction <30	2	4.4	

SD: Standard deviation; COPD: Chronic obstructive pulmonary disease; PAD: Peripheral arterial disease.

Table 2. Mean flow rate and pulsatility index measurements of grafts with TTFM

	Anastomosis		Flow rate (mL/min)	Pulsatility index
	n	%	Mean±SD	Mean±SD
LIMA to LAD	45	100	36.2±14.1	1.2±1.1
Ao-SVG-OM	28	62	41.2±21.1	1.6±1.5
Ao-SVG-diagonal	24	53	48.2±13.1	1.4±1.1
Ao-SVG-RCA	36	80	52.2±11.3	2.5±1.7

TTFM: Transit-time flow measurement; SD: Standard deviation; LIMA: Left internal mammary artery; LAD: Left anterior descending; Ao: Aortic artery; SVG: Saphenous vein graft; OM: Obtuse marginal; RCA: Right coronary artery.

The patients included in our study were selected among patients who underwent isolated minimally invasive on-pump multi-vessel CABG, and patients who underwent additional cardiac surgery were not included in our study. A total of 133 anastomoses were performed; LAD-left internal thoracic artery (LITA) (n=45), diagonal (n=24), circumflex (n=28), and right coronary artery (RCA) (n=36). A saphenous vein graft (SVG) was used in all anastomoses, except for LITA.

The mean LIMA flow rate was 36.2±14 mL/min. The mean flow rate of the diagonal grafts was 48.2±13.1 mL/min, the mean flow rate of the circumflex grafts was 41.2±21.1 mL/min, and the mean flow rate of the RCA grafts was 52.2±11.3 mL/min. Wave patterns and flow parameters of all grafts were normal in intraoperative measurements, since the PI values in all anastomoses were within normal limits. The mean PI was found to be 1.2±1.1 in LIMA-LAD anastomosis grafts, 1.6±1.5 in aortic artery-SVG-obtuse marginal (Ao-SVG-OM) grafts, 1.4±1.1 in Ao-SVG-diagonal grafts, and 2.5±1.7 in Ao-SVG-RCA grafts, respectively.

The operation was completed after anastomotic openings and patency were ensured. Details of the mean TTFM rate and PI measurements of distal anastomoses and grafts are shown in Table 2. No pathological condition was detected in any patient and in any anastomosis. No anastomosis needed to be renewed. The recording image of a normal LIMA graft and SVG measurements are given in Figure 2b. While there was a significant difference in the flow rates between the LIMA graft and venous grafts ($p<0.001$), there was no significant difference between the LIMA and venous grafts in terms of PI ($p>0.05$) (Figure 3).

The mean length of hospital stay was 6.2±1.4 days with a mean ICU stay of 1.4±0.5 days. We had five (11%) patients who developed atrial fibrillation postoperatively, and rhythm restoration was achieved in all of them with medical treatment. No postoperative MI was observed in any of the patients. There was one

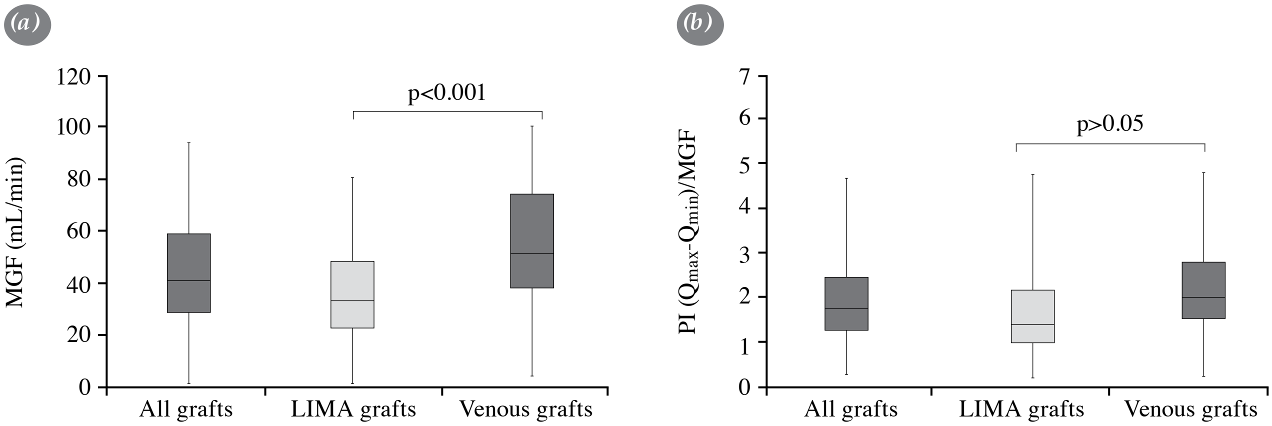

Figure 3. (a) Mean graft flows and **(b)** pulsatility indices of LIMA grafts, venous grafts, and all grafts.
MGF: Mean graft flow; PI: Pulsatility index; LIMA: Left internal mammary artery.

revision due to postoperative bleeding. There was no in-hospital mortality. Pleural effusion was observed in the left hemithorax in three (6.6%) patients in the postoperative period, and applied thoracentesis. No surgery-related infection was observed in the postoperative period, and mediastinitis did not occur in any patient.

DISCUSSION

Coronary artery revascularization has been among the most common operations in cardiac surgery for many years. With the development of minimally invasive techniques in recent years, conventional methods have been replaced by smaller incisions and less trauma. Even multi-vessel coronary revascularizations can be routinely performed via left anterior mini-thoracotomy currently.[3]

The CABG is an operation that has been performed for many years and has a significant mortality and mortality risk. Despite technological advances, the most important factor affecting perioperative success is the quality of grafts and anastomosis. Re-occlusion of SVGs at a rate of 10 to 15% in the first month and the same in the first year suggests failure of the surgical technique.[4] Shortening of the graft length, bending, tension, or restriction of the passage through the anastomosis can be considered the main risk factors.

Whether coronary revascularization surgeries are minimally invasive or conventional, the most important issue is the quality of the anastomosis and the flow state in the new grafts, which determine the success of the operation. As the thoracotomy method in multi-vessel coronary revascularization is technically more difficult and the learning curve process is available, demonstrating the quality and success of the operation with concrete evidence would increase the reliability and acceptability of the technique. Various techniques have been used in the past years to perform intraoperative evaluation of graft patency and flow.

It is usually accepted that surgeons choose to stay conservative more, as it is a reliable way. It can be sometimes difficult for any innovation to be accepted in terms of its applicability and results in surgery. Therefore, science and evidence-based approaches can facilitate the acceptance of new techniques. The most needed issue for this method, which has recently started to become widespread in multi-vessel CABG all over the world, is to show that successful results can be achieved with the surgical technique. We believe that the most effective method for this proof should be the use of a technology that can produce quantitative results. The most common and applicable of this technology is accepted as TTFM. Many surgeons applying the TTFM technique have reported very successful results in detecting technical errors and simultaneously solving the problem intraoperatively for coronary revascularization.[4,5]

Perfusion requirement in surgical areas and peripheral vascular resistance are among the main factors affecting graft flow and patency. It is not possible for us to identify these basic factors clinically or to visualize them with direct vision. With a proper handling technique, the TTFM can provide detailed information about graft flow and patency. The main parameters used to evaluate graft patency and flow are the mean graft flow (MGF) and PI.[6] As an indicator, these two parameters should be evaluated together.

Although it has a serious clinical benefit when used, unfortunately, TTFM has not found a widespread use yet. Among the reasons for this is the lack of large-volume studies that can provide definitive proof of the effectiveness of TTFM.[7] In line with the European Society of Cardiology (ESC)/European Association for Cardio-Thoracic Surgery (EACTS) guidelines, a decision can be made based on the threshold values specified for the MGF and PI. However, the diagnostic accuracy of TTFM is still a matter of debate, with different sensitivity and specificity values reported in various publications.[8] In addition, the lack of a definite cut-off value accepted by the whole scientific world and the fact that different studies result in different values continues this situation.

Review of literature reveals that the recently published the Registry for Quality Assessment With Ultrasound Imaging and TTFM in Cardiac Bypass Surgery (REQUEST) study is the first multi-center, prospective study to examine the effect of intraoperative graft evaluation with TTFM in deciding graft patency and flow in multi-vessel CABG.[9] The authors suggested that TTFM might improve the quality, safety and efficacy of CABG and should be considered as a routine procedural aspect.

Another point of general agreement is that MAP affects MGF. In cases where we assume that the coronary vascular resistance is constant, MGF is directly proportional to MAP.[10] To minimally affect the graft patency and flow velocity measurements after extracorporeal circulation discontinued, we measured an MAP of 60 to 70 mmHg. As the extracorporeal pump flow can affect the flow rate and flow rate in the grafts, it would be more accurate to make these measurements off-pump.

Again, based on the studies in the literature, it is accepted that intraoperative TTFM findings are a determining factor in the prediction of early graft patency.[11] We did not need to renew any anastomosis, as we found no value that would be suspicious in all the measurements we made. Afterwards, we did not observe any complication related to anastomosis or graft patency in the postoperative period. In particular, the PI is a good indicator of flow and, thus, anastomotic quality. This value is obtained by dividing the difference between the maximum flow and the minimum flow by the average flow value. From a pathophysiological point of view, the PI increases in direct proportion to vascular resistance. As a consequence, a high PI is the most important parameter for our decision making and is an indication of poor-quality graft or anastomosis and requires regeneration of the anastomosis. In our own surgeries, we considered the PI value as more valuable. We obtained results directly proportional to the flow rates.

With this technique, vital predictions can be obtained intraoperatively. The TTFM, which is of considerable importance even in conventional surgery, is an integral part of minimally invasive coronary surgery. Since, in minimally invasive coronary surgery, exploration is made through a small incision of approximately 4 to 5 cm and the exposure area is very narrow. Surgical techniques applied in this small area are also more difficult compared to the conventional method. To reduce these difficulties, besides making use of technological innovations such as surgical materials and port and camera support, methods such as marking one side of the grafts with paint to prevent twisting are applied. However, the use of TTFM is necessary to ensure that technical problems such as stenosis in the anastomotic passage, plaque rupture in the anastomotic region, or dissection problems before or after anastomosis can be accurately diagnosed and that technical problems such as folded, twisted or twisted problems do not occur.

The lack of a comparison group and relatively small sample size are the main limitations to this study. However, based on our clinical and surgical experience, we can secure the surgery we perform with this procedure.

In conclusion, we believe that transit-time flow measurement is a component method, particularly for this minimally invasive technique, as it can be decided intraoperatively and corrected at the same time in case of detection of negativity. This would create safety, particularly for surgeons who are at the beginning of the learning curve in minimally invasive surgery. Although we recommend this method to all surgeons, there is a need for further large-scale studies.

Ethics Committee Approval: The study protocol was approved by the Health Sciences University, Umraniye Training and Research Hospital Ethics Committee (date: 30.09.2021, no: 2021/278). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Idea/concept, analysis and/or interpretation: B.Ç., H.S.; Design: references and fundings: B.Ç., H.S.; Control/supervision: B.Ç.; Data collection and/or processing, literature review: B.Ç., H.S.; Writing the article: H.S.; Critical review: B.Ç.; Materials: B.Ç, H.S.

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