Cukurova Medical Journal
ÇUKUROVA ÜNİVERSİTESİ TIP FAKÜLTESİ

Cukurova Med J 2025;50(4):1053-1061
DOI: 10.17826/cumj.1721130

RESEARCH

Comparison of venous cannulation strategies in minimally invasive direct coronary artery bypass surgery

Minimal invaziv direkt koroner arter baypas cerrahisinde venöz kanülasyon stratejilerinin karşılaştırılması

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Abstract

Purpose: This study aimed to quantitatively compare the efficacy of venous drainage and the requirements for vacuum-assisted venous drainage (VAVD) between bicaval and multistage femoral venous cannulation strategies in minimally invasive direct coronary artery bypass (MIDCAB).

Materials and Methods: In this retrospective, single-center study, 60 patients who underwent MIDCAB between 2018 and 2024 were analyzed. Thirty patients received bicaval cannulation via the right internal jugular and femoral veins (Group 1), while 30 patients underwent single cannulation using a multistage femoral venous cannula (Group 2). Primary outcomes included venous reservoir volume at the initiation of cardiopulmonary bypass (CPB) and the need for VAVD. Secondary outcomes comprised CPB duration and major postoperative complications.

Results: Mean pump flow rate was comparable between groups (Group 1: 4.5 ± 0.4 L/min vs. Group 2: 4.3 ± 0.5 L/min). However, mean initial venous reservoir volume was greater in Group 1 (824 ± 124 mL vs. 641 ± 95 mL). The requirement for VAVD was more frequent in Group 2 (82.7% vs. 24.1%). Additionally, CPB duration was longer in Group 2 (191.9 ± 24.4 min vs. 149.6 ± 39.6 min). No major postoperative complications were observed in either group.

Conclusion: Multistage femoral venous cannulation was associated with inferior venous drainage, necessitating more frequent vacuum support and resulting in prolonged CPB times. Bicaval cannulation may therefore provide a more reliable approach to achieving optimal surgical conditions in MIDCAB.

Keywords: Multistage single venous cannulation, vacuum-assisted venous drainage, minimally invasive direct coronary artery bypass.

Öz

Amaç: Bu çalışma, Minimal invaziv direkt koroner arter baypas (MIDCAB) bikaval ve multistage femoral venöz kanülasyon stratejileri arasında venöz drenaj etkinliği ile vakum destekli venöz drenaj (VAVD) gereksinimlerini nicel olarak karşılaştırmayı amaçlamıştır.

Gereç ve Yöntem: Bu retrospektif, tek merkezli çalışmada, 2018-2024 yılları arasında MIDCAB uygulanan 60 hasta incelendi. Otuz hastaya sağ internal juguler ve femoral venler yoluyla bikaval kanülasyon (Grup 1), 30 hastaya ise tekli multistage femoral venöz kanül ile kanülasyon uygulandı (Grup 2). Birincil sonuçlar, kardiyopulmoner bypass (KPB) başlangıcındaki venöz rezervuar hacmi ve VAVD ihtiyacıydı. İkincil sonuçlar arasında KPB süresi ve majör postoperatif komplikasyonlar yer aldı.

Bulgular: Ortalama pompa akım hızı gruplar arasında benzerdi (Grup 1: 4,5 ± 0,4 L/dakika ve Grup 2: 4,3 ± 0,5 L/dakika). Bununla birlikte, ortalama başlangıç venöz rezervuar hacmi Grup 1'de daha yüksekti (824 ± 124 mL ve 641 ± 95 mL). VAVD gereksinimi Grup 2'de daha sıktı (%82,7 ve %24,1). Ek olarak, KPB süresi Grup 2'de daha uzundu (191,9 ± 24,4 dakika ve 149,6 ± 39,6 dakika). Her iki grupta da majör postoperatif komplikasyon gözlenmedi.

Sonuç: Tek kanülasyon bölgesinin potansiyel avantajlarına rağmen, multistage femoral venöz kanülasyon, bikaval kanülasyona kıyasla daha düşük venöz drenaj, daha sık vakum desteği ihtiyacı ve daha uzun KPB süreleri ile ilişkili bulundu. Bu nedenle, bikaval kanülasyon, MIDCAB'ta optimal cerrahi koşulların sağlanması için daha güvenilir bir strateji sunabilir.

Anahtar kelimeler: Multistage tekli venöz kanülasyon, vakum destekli venöz drenaj, minimal invaziv direkt koroner arter baypas.

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Received: 17.06.2025 Accepted: 26.11.2025

INTRODUCTION

Minimally invasive direct coronary artery bypass surgery (MIDCAB) has gained considerable traction over the past two decades, with its adoption rate increasing substantially due to advancements in endoscopic instrumentation and cannula technology[1, 2]. Compared to conventional sternotomy, MIDCAB reduces surgical trauma and offers documented benefits, including decreased postoperative pain, lower transfusion rates, shorter hospital stays, faster recovery, and improved cosmetic outcomes[3, 4]. Recent systematic reviews have confirmed these advantages while highlighting the technical demands of the procedure and the critical importance of constructing an optimal surgical platform [5, 6].

A principal challenge in MIDCAB is operating within a confined surgical field. Consequently, achieving optimal visualization is paramount and depends primarily on the complete diversion of venous return from the right heart to the cardiopulmonary bypass (CPB) circuit via appropriately sized venous cannulas. The most common access sites are the femoral and internal jugular veins. Although bicaval cannulation (jugular and femoral) was initially the standard approach, concerns regarding complications such as vascular injury, infection, and cosmetic issues associated with jugular cannulation have driven a shift toward single-site multistage femoral venous cannulas designed to drain both the superior and inferior vena cava[7, 8].

The evolution of cannulation strategies in minimally invasive cardiac surgery has been marked by ongoing debate regarding the optimal approach [9]. Traditional peripheral cannulation methods, while convenient, have inherent limitations and carry risks of complications such as retrograde dissection, stroke, and neurologic sequelae. Recent evidence from 2024 indicates that surgical cut-down femoral cannulation, although commonly used, is associated with higher rates of wound complications compared to percutaneous techniques. Furthermore, contemporary trends demonstrate a shift toward percutaneous cannulation combined with arterial closure devices to reduce groin complications [10, 11]. However, the comparative efficacy of different venous drainage strategies—particularly concerning intraoperative hemodynamic performance and the need for vacuum assistance—remains inadequately characterized.

Vacuum-assisted venous drainage (VAVD) has become an increasingly utilized adjunct in minimally invasive cardiac surgery to augment venous return when gravity-dependent drainage is insufficient [12, 13]. While VAVD can effectively improve surgical field visualization, recent studies have raised concerns about its potential adverse effects, including increased hemolysis, air microemboli, and impacts on end-organ function [14, 15]. A 2025 study demonstrated that VAVD applied at –30 mmHg resulted in statistically significant alterations in liver function parameters, underscoring the need for judicious use of this technique [16]. These findings emphasize the importance of achieving adequate venous drainage through optimal cannulation strategies rather than relying heavily on vacuum assistance.

Despite these advances, consensus on the optimal cannulation strategy remains elusive, often depending on surgeon preference and institutional protocols. A recent systematic review highlighted this ongoing debate, noting a lack of robust comparative studies on drainage efficacy between bicaval and multistage femoral cannulation techniques. Although meta-analyses comparing percutaneous versus surgical femoral cannulation have been published [10], few studies have directly quantified the functional differences in venous drainage capacity between dual-site bicaval and single-site multistage approaches. This knowledge gap is particularly significant because inadequate venous drainage can compromise surgical field quality, prolong operative times, and potentially increase the risk of complications.

Our study directly addresses this gap by providing a quantitative, comparative analysis of drainage efficacy between the two predominant venous cannulation strategies employed in contemporary MIDCAB practice. We hypothesized that bicaval cannulation would provide superior venous drainage, reflected in higher venous reservoir volumes and a reduced need for vacuum support, compared to single multistage femoral cannulation. Furthermore, we postulated that these differences in drainage efficacy would translate into measurable impacts on intraoperative efficiency, specifically CPB duration. The novelty of this investigation lies in its focused quantitative assessment of venous drainage parameters—including initial reservoir volumes and vacuum assistance requirements—which have not been systematically compared in previous literature. Therefore, this study aimed to compare these two strategies in terms of intraoperative drainage

parameters and clinical outcomes to establish a more evidence-based approach to venous cannulation in MIDCAB surgery.

MATERIALS AND METHODS

Study design and sample

This single-center, retrospective cohort study was conducted in the Department of Cardiovascular Surgery at Adana City Training and Research Hospital, University of Health Sciences, Turkey. The institution is a tertiary referral center with an established minimally invasive cardiac surgery program, performing approximately 150 to 200 MIDCAB procedures annually. All patient data are maintained in a comprehensive electronic medical record system with strict data security protocols, including encrypted storage, restricted access limited to authorized healthcare personnel, and regular audits to ensure data integrity and patient confidentiality. The hospital's quality assurance program includes systematic documentation of all surgical procedures, intraoperative parameters, and postoperative outcomes, ensuring high reliability of the data used in this analysis.

Following approval from the Institutional Review Board of Adana City Training and Research Hospital, University of Health Sciences (IRB Approval No: 119/2343, Date: 29 December 2022), we screened the medical records of all patients who underwent MIDCAB with CPB between January 2018 and May 2024. The study was conducted in accordance with the Declaration of Helsinki. Given its retrospective nature, the requirement for informed consent was waived by the ethics committee.

Inclusion criteria comprised patients older than 18 years undergoing elective isolated MIDCAB procedures. Exclusion criteria included redo surgery, concomitant cardiac procedures, emergent surgery, preoperative hemodynamic instability or mechanical circulatory support, and significant femoral or jugular vessel pathology precluding cannulation.

A total of 68 consecutive patients who underwent MIDCAB during the study period were initially identified through our institutional database. Of these, eight patients were excluded from the final analysis for the following reasons: three patients underwent concomitant cardiac procedures (two mitral valve repairs and one atrial septal defect closure), two patients required emergent surgery due to acute coronary syndrome with hemodynamic compromise, and three patients had incomplete intraoperative data regarding venous reservoir volumes or vacuum assistance parameters. Consequently, 60 patients were included in the final analysis, with 30 patients in each group. A post-hoc power analysis using G*Power software, with an effect size of 0.8 for the primary outcome (reservoir volume), an alpha of 0.05, and a sample size of 30 per group, yielded a statistical power of 85%.

Surgical technique and cannulation

All operations were performed by a single experienced surgical team comprising two attending cardiac surgeons, each with more than 10 years of experience in minimally invasive cardiac surgery, and a dedicated perfusion team. Surgical access was achieved via a left anterolateral minithoracotomy (5 cm incision) in the fourth intercostal space under general anesthesia with single-lung ventilation. Arterial cannulation was performed via the femoral artery through a standard surgical incision. Cannula size was selected based on body surface area (BSA): 15F for BSA less than 1.6 m^2, 17F for BSA between 1.6 and 2.1 m^2, and 19F for BSA greater than 2.1 m^2, consistent with our institutional protocol.

Patients were divided into two groups according to the venous cannulation strategy employed. Group 1 (Bicaval, n=30) underwent percutaneous cannulation of the right internal jugular vein (RIJV) for superior vena cava (SVC) drainage and surgical cannulation of the ipsilateral femoral vein for inferior vena cava (IVC) drainage. Group 2 (Multistage, n=30) underwent surgical cannulation of the femoral vein using a single multistage venous cannula (Bio-Medicus NextGen, Medtronic) for combined SVC and IVC drainage. The choice of cannulation strategy was determined by the operating surgeon's preference and evolved over the study period, with bicaval cannulation preferentially used in earlier years and multistage cannulation increasingly adopted in recent years as institutional experience with the technique expanded.

All cannulations were performed under ultrasonographic guidance to ensure accurate vessel identification and cannula placement. CPB was initiated following standard transaxillary aortic cross-clamping. Cardiac arrest was achieved using Del Nido cardioplegia solution (approximately 20 mL/kg initially, with repeated doses as needed based on cross-clamp time) administered antegradely through

the aortic root. The left internal mammary artery was used to graft the left anterior descending artery, and autogenous saphenous vein grafts were employed for other target vessels as indicated by preoperative coronary angiography.

Data collection and outcomes

Data were extracted from the hospital's electronic database and patient medical records by two independent investigators. Preoperative demographics, intraoperative variables, and postoperative outcomes were systematically recorded using standardized data collection forms. The primary outcomes were designed to assess the functional efficacy of venous drainage. The first primary outcome was venous reservoir volume, defined as the volume in milliliters present in the venous reservoir at the initiation of full CPB flow, measured before any vacuum application. This parameter directly reflects the efficiency of gravity-dependent venous drainage. The second primary outcome was the requirement for vacuum assistance, defined as the need for and use of vacuum-assisted venous drainage (VAVD) during CPB. This was recorded as a binary variable (yes/no) and expressed as the percentage of patients in each group who required VAVD at any point during the procedure to maintain adequate venous return and surgical field visualization.

Secondary outcomes were selected to evaluate the broader clinical implications of the cannulation strategies. These included CPB duration, measured in minutes from initiation to termination of extracorporeal circulation, and aortic cross-clamp time, measured in minutes from application to removal of the aortic cross-clamp. Additional secondary outcomes included mean pump flow rate, measured in liters per minute and averaged over the entire CPB period, and the number of bypass grafts performed. Major postoperative complications were defined as stroke confirmed by neurology consultation and imaging, prolonged intubation exceeding 24 hours, renal failure requiring new initiation of renal replacement therapy, reoperation for bleeding within 30 days, and mortality within 30 days of the procedure.

Statistical analysis

Statistical analysis was performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). The normality of continuous data was assessed using the Shapiro-Wilk test. Normally distributed data are presented as mean ± standard deviation (SD) and compared using the independent Student's t-test. Non-normally distributed data are presented as median (interquartile range [IQR]) and compared using the Mann-Whitney U test. Categorical variables are presented as frequencies and percentages and compared using the Chi-square or Fisher's exact test, as appropriate. A p-value less than 0.05 was considered statistically significant. Given the sample size and the focus on descriptive comparison of techniques, multivariate Cox regression and Kaplan-Meier analyses were not applicable to the reported outcomes and were therefore not performed.

RESULTS

Baseline demographic and clinical characteristics were comparable between the two groups (Table 1). There were no significant differences in age, gender distribution, body surface area, left ventricular ejection fraction, or preoperative hemoglobin levels. The mean age was 56.8 ± 7.5 years in Group 1 and 58.3 ± 7.4 years in Group 2. Males predominated in both groups, comprising 60.0% of patients in Group 1 and 56.7% in Group 2. The mean body surface area was 1.92 ± 0.18 m^2 in Group 1 and 1.89 ± 0.21 m^2 in Group 2. Left ventricular ejection fraction was preserved in both groups, with mean values of 55.4 ± 6.9% in Group 1 and 52.9 ± 6.1% in Group 2. Preoperative hemoglobin levels were also similar, measuring 13.5 ± 1.4 g/dL in Group 1 and 13.2 ± 1.6 g/dL in Group 2.

Intraoperative outcomes

Intraoperative outcomes are summarized in Table 2. The mean pump flow rate did not differ significantly between groups, with Group 1 achieving 4.5 ± 0.4 L/min and Group 2 achieving 4.3 ± 0.5 L/min. This finding indicates that both cannulation strategies were capable of supporting adequate systemic perfusion during cardiopulmonary bypass (CPB).

However, significant differences were observed in venous drainage efficacy. The initial venous reservoir volume was significantly higher in Group 1 compared to Group 2 (824 ± 124 mL vs. 641 ± 95 mL), representing a 28.6% increase in reservoir volume with bicaval cannulation (Figure 1). This difference was highly statistically significant and clinically meaningful, indicating superior gravity-dependent venous drainage with the bicaval approach.

Table 1. Preoperative patient characteristics

Characteristic	Group 1 (Bicaval, n=30)	Group 2 (Multistage, n=30)	p-value
Age (years)	56.8 ± 7.5	58.3 ± 7.4	0.45
Male Gender, n (%)	18 (60.0)	17 (56.7)	0.79
Body Surface Area (m^2)	1.92 ± 0.18	1.89 ± 0.21	0.55
Ejection Fraction (%)	55.4 ± 6.9	52.9 ± 6.1	0.11
Preoperative Hemoglobin (g/dL)	13.5 ± 1.4	13.2 ± 1.6	0.42

n, number of patients; m^2, square meters; %, percentage; g/dL, grams per deciliter.;
Note: Data are presented as mean ± standard deviation for continuous variables and as number (percentage) for categorical variables. P-values were calculated using the independent Student's t-test for continuous variables and the Chi-square test for categorical variables.

Table 2. Intraoperative outcomes

Outcome	Group 1 (Bicaval, n=30)	Group 2 (Multistage, n=30)	p-value
Pump Flow Rate (L/min)	4.5 ± 0.4	4.3 ± 0.5	0.12
Venous Reservoir Volume (mL)	824 ± 124	641 ± 95	<0.001
VAVD Required, n (%)	7 (24.1)	24 (82.7)	<0.001
CPB Time (min)	149.6 ± 39.6	191.9 ± 24.4	<0.001
Aortic Cross-Clamp Time (min)	92.5 ± 22.1	115.8 ± 19.3	<0.001
Number of Bypass Grafts	1.8 ± 0.4	1.9 ± 0.5	0.38

L/min, liters per minute; mL, milliliters; VAVD, vacuum-assisted venous drainage; n, number of patients; %, percentage; CPB, cardiopulmonary bypass; min, minutes.
Data are presented as mean ± standard deviation for continuous variables and as number (percentage) for categorical variables. P-values were calculated using the independent Student's t-test for continuous variables and the Chi-square test or Fisher's exact test for categorical variables. "VAVD Required" refers to the number and percentage of patients who required vacuum-assisted venous drainage at any point during the cardiopulmonary bypass procedure.

Furthermore, the requirement for vacuum-assisted venous drainage (VAVD) differed markedly between groups. In Group 1, only 7 patients (24.1%) required VAVD during the procedure, whereas in Group 2, 24 patients (82.7%) required VAVD to maintain adequate venous return and surgical field visualization. This represents more than a threefold increase in the need for vacuum assistance with multistage femoral cannulation compared to bicaval cannulation (Figure 3).

Both CPB time and aortic cross-clamp time were significantly longer in Group 2 compared to Group 1. The mean CPB duration was 149.6 ± 39.6 minutes in Group 1 versus 191.9 ± 24.4 minutes in Group 2, representing a 28.3% increase in CPB time with multistage cannulation (Figure 2).

Similarly, the mean aortic cross-clamp time was 92.5 ± 22.1 minutes in Group 1 versus 115.8 ± 19.3 minutes in Group 2, representing a 25.2% increase with multistage cannulation. These differences were statistically significant and suggest that suboptimal venous drainage may have adversely affected surgical efficiency and workflow.

The mean number of bypass grafts performed was similar between groups, with 1.8 ± 0.4 grafts in Group 1 and 1.9 ± 0.5 grafts in Group 2, indicating comparable complexity of revascularization procedures.

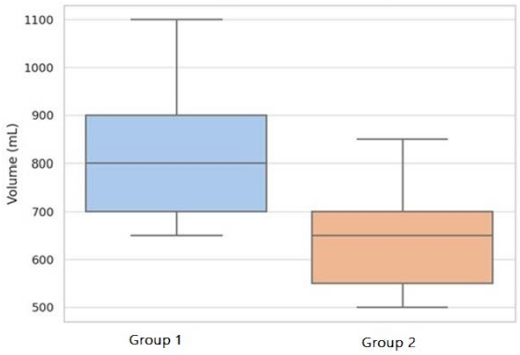

Figure 1. Initial venous reservoir volume

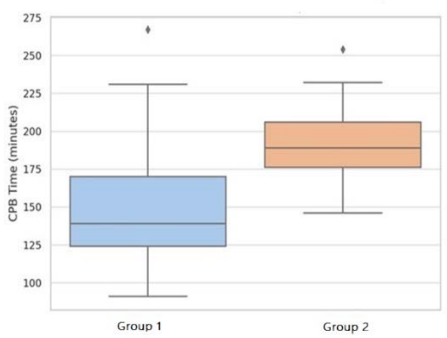

Figure 2. Comparison of cardiopulmonary bypass (CPB) time

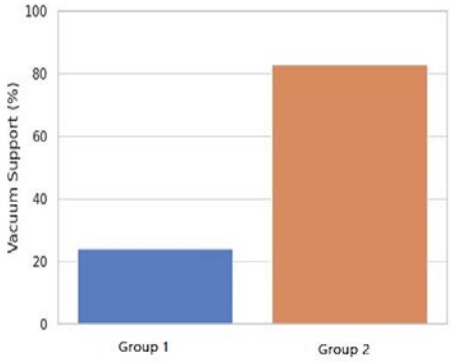

Figure 3. Proportion of patients requiring vacuum-assisted venous drainage

Postoperative outcomes

No major postoperative complications—including stroke, prolonged intubation exceeding 24 hours, renal failure requiring dialysis, reoperation for bleeding, or 30-day mortality—occurred in either group during the immediate postoperative period. This finding suggests that both cannulation strategies can be performed safely in appropriately selected patients by experienced surgical teams.

DISCUSSION

This retrospective study directly compares two venous cannulation strategies for minimally invasive direct coronary artery bypass (MIDCAB) and provides quantitative evidence regarding their relative efficacy. The key finding is that, while both techniques facilitated successful completion of surgery without major complications, bicaval cannulation yielded quantitatively superior venous drainage. This was demonstrated by a significantly higher volume in the venous reservoir upon initiation of cardiopulmonary bypass (CPB) and a markedly reduced reliance on vacuum-assisted venous drainage (VAVD) compared to single multistage femoral cannulation.

The primary objective of venous cannulation in MIDCAB is to achieve complete siphonage of venous return, thereby collapsing the right heart and providing a stable, bloodless field for anastomoses. Our results suggest that the dual-cannula approach creates a lower-resistance pathway for blood to exit the superior vena cava (SVC) and inferior vena cava (IVC) simultaneously, explaining the higher reservoir volumes without auxiliary vacuum. In contrast, the single multistage cannula, despite its design, may introduce functional resistance or present positional challenges in effectively draining the SVC from the femoral approach, often necessitating VAVD to augment drainage. This observation aligns with the findings of Lamelas et al. [1], who noted that jugular cannulation remains the most reliable method for ensuring SVC drainage in minimally invasive settings, a sentiment echoed in other technical reviews [9]. Recent evidence from Liu et al. (2024) [17] further supports this concept, demonstrating that transthoracic central cannulation strategies can circumvent the disadvantages of peripheral cannulation, including the risk of retrograde dissection and neurologic complications.

The significantly longer CPB and cross-clamp times observed in the multistage group are clinically noteworthy. Although not a primary safety endpoint in our study, prolonged CPB time is independently associated with an increased inflammatory response and a heightened risk of end-organ dysfunction [18]. This extended duration may serve as an indirect marker of procedural complexity; the need to repeatedly adjust vacuum levels or cannula position to optimize drainage in the multistage group may have disrupted surgical workflow. Conversely, the significant reduction in CPB time associated with bicaval cannulation may not only reduce the risk of inflammatory response and end-organ dysfunction but also decrease operating room resource utilization. Recent studies by Alaj et al. (2024) [19] have emphasized that MIDCAB is technically demanding and that optimal patient selection and surgical

technique are crucial for procedural safety and efficiency.

A critical balance must be struck between efficacy and invasiveness. Proponents of multistage single cannulation rightly highlight its benefits: a single access site reduces the potential for vascular complications and improves cosmesis. Contemporary trends in minimally invasive cardiac surgery, as reported by Ilcheva et al. (2023) [20], indicate a shift toward percutaneous cannulation and arterial closure devices to reduce groin complications, a trend supported by recent registry data [11]. Furthermore, a 2024 systematic review and meta-analysis by Kirov et al. [10] compared percutaneous versus surgical cutdown femoral cannulation, providing valuable insights into the safety profiles of different access techniques. It is important to note that our study found no major vascular complications in either group, suggesting that with ultrasound guidance and expertise, both techniques can be performed safely. However, the trade-off appears to be a less efficient drainage system with the multistage approach.

The higher VAVD usage in the multistage group represents a double-edged sword; while it effectively augments drainage, it is not without risks, including increased hemolysis and the potential for air microemboli [14,15]. Furthermore, reduced reliance on VAVD may mitigate these risks, potentially improving biochemical outcomes and reducing the need for blood product transfusions, although this specific aspect was not measured in our study and warrants further investigation. Recent research by Köse et al. (2025) [16] demonstrated that VAVD applied at negative 30 mmHg resulted in statistically significant changes in liver function parameters, specifically a decrease in the liver enzyme AST (SGOT). These findings underscore the importance of minimizing vacuum assistance when possible and achieving adequate venous drainage through optimal cannulation strategies rather than relying heavily on adjunctive techniques.

Our study suggests that the choice of cannulation strategy should be individualized based on patient-specific factors and procedural complexity. For straightforward single-vessel left internal mammary artery to left anterior descending artery grafts, a multistage cannula may be sufficient, particularly in patients with smaller body habitus and lower anticipated venous return. However, for multivessel grafting or in patients with a higher body surface area (BSA) where venous return is greater, bicaval cannulation might be preferable to ensure optimal conditions from the outset, minimize CPB time, and avoid the potential drawbacks of vacuum assistance. Recent advances in anesthesiologic management for minimally invasive cardiac surgery, as described by Piekarski et al. (2024) [19], emphasize the importance of comprehensive perioperative protocols that include optimal cannulation strategies as a key component of procedural success.

This study has several limitations inherent to its design. First, its retrospective and single-center nature introduces potential selection bias and limits generalizability to other institutions with different patient populations or surgical protocols. Second, although the sample size was sufficient for the primary endpoints based on post-hoc power analysis, it remains relatively small for robust analysis of rare clinical outcomes such as major complications. The absence of major complications in both groups, while reassuring, may reflect appropriate patient selection and surgical expertise rather than a definitive safety profile generalizable to all practice settings. Third, the lack of long-term follow-up data precludes assessment of late outcomes such as graft patency, recurrent angina, or long-term survival. Fourth, the choice of cannulation strategy was not randomized but evolved over the study period based on surgeon preference and institutional experience, which may have introduced temporal confounding. Fifth, we did not systematically measure biochemical markers of hemolysis or end-organ dysfunction, which could have provided additional insights into the physiological consequences of VAVD use. Sixth, the study did not account for potential learning curve effects or variations in individual surgeon technique, which may have influenced outcomes. Finally, we did not evaluate patient-reported outcomes such as cosmetic satisfaction or quality of life, which are important considerations when comparing techniques differing in number and location of access sites.

Despite these limitations, our study provides valuable quantitative data on a clinically relevant question that has not been adequately addressed in the existing literature. The findings have practical implications for surgical decision-making and highlight the importance of considering venous drainage efficacy as a key factor in cannulation strategy selection. Future prospective, multicenter, randomized controlled trials with larger sample sizes are needed to confirm these findings and to evaluate the impact

of cannulation strategy on long-term clinical outcomes, biochemical markers of hemolysis and organ dysfunction, and patient-reported outcomes. Additionally, cost-effectiveness analyses comparing the two approaches—taking into account factors such as operative time, resource utilization, and complication rates—would be valuable for healthcare systems and policymakers.

In conclusion, this study provides quantitative evidence that venous cannulation strategy impacts intraoperative efficiency in MIDCAB. Bicaval cannulation via the jugular and femoral veins provided more effective venous drainage, resulting in less frequent need for vacuum support and shorter CPB times compared to single multistage femoral cannulation. While the multistage technique offers potential advantages in reducing access sites and improving cosmesis, surgeons should be aware of its limitations in drainage efficacy and the increased likelihood of requiring vacuum assistance. The decision should be tailored to the patient's anatomy, body habitus, and the complexity of the planned procedure, prioritizing the reliable achievement of optimal surgical conditions. Based on our findings, we recommend that bicaval cannulation be strongly considered as the primary strategy for MIDCAB procedures requiring multivessel revascularization or in patients with larger body habitus, where optimal venous drainage is paramount for procedural success and efficiency. For future research, we propose several directions: first, prospective randomized trials comparing these cannulation strategies with standardized protocols and comprehensive outcome measures, including biochemical markers and patient-reported outcomes; second, investigations into novel cannulation technologies or hybrid approaches that may combine the drainage efficacy of bicaval cannulation with the cosmetic advantages of single-site access; third, studies examining the impact of cannulation strategy on long-term graft patency and cardiovascular outcomes; and fourth, cost-effectiveness analyses to guide resource allocation and healthcare policy decisions in the era of value-based care.

Author Contributions: Concept/Design : TOB; Data acquisition: TOB; Data analysis and interpretation: TOB; Drafting manuscript: TOB; Critical revision of manuscript: TOB; Final approval and accountability: TOB, FC; Technical or material support: TOB, FC; Supervision: TOB; Securing funding (if available): n/a.
Ethical Approval: Ethical approval was obtained from Çukurova University Faculty of Medicine Non-Interventional Clinical Research Ethics Committee for this study. (With the date 6.3.2020 and the number 97/1).
Peer-review: Externally peer-reviewed.

Conflict of Interest: The authors declare that they have no conflicts of interest related to the publication of this article.
Financial Disclosure: The authors did not receive any financial support for the research or authorship of this article.
Acknowledgement: I would like to express my sincere gratitude to Prof. Dr. Hasan Uncu for his continued scientific support and for entrusting me with the preparation of this article, despite being designated as the responsible researcher in the ethics committee application for this study. I also extend my appreciation to Assoc. Prof. Dr. Hacı Ali Uçak and Dr. Ahmet Çakallioğlu for their valuable contributions to the planning and execution of the study.

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