

Safety and Feasibility of Axillary Artery Cannulation in Robotic Assisted Minimally Invasive Coronary Revascularization

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ABSTRACT

Purpose: Axillary artery cannulation is associated with safer results and fewer complications compared to femoral artery cannulation in minimally invasive cardiac surgery. Coronary artery bypass surgery patients present with a high atherosclerotic burden, and thus may also benefit greatly from antegrade axillary artery cannulation. The aim of this study was to compare outcomes in axillary and femoral cannulation in robotic-assisted minimally invasive coronary artery bypass surgery.

Methods: Between March 2022 and May 2024, 96 consecutive patients underwent on-pump robotic-assisted minimally invasive coronary artery bypass surgery at our institution. Preoperative computed tomography scans were assessed for atherosclerosis to guide cannulation strategy. Axillary cannulation was performed in 57 (59.4%) patients and femoral cannulation in 39 (40.6%) patients. Patient demographics and perioperative data were retrospectively analyzed. The primary endpoint of the study was peri-operative complications including stroke and in-hospital mortality.

Results: There were no cases of post-operative mortality or stroke in either group. No complications including hematomas, cannulation site infections, emboli, dissection, neurovascular injury or brachial plexus injuries were observed in either group. No other complications were encountered in femoral cannulation patients except for seromas at the cannulation site in 3 (7.7%) of the patients.

Conclusions: Direct cannulation of the axillary artery is a safe method for establishment of cardiopulmonary bypass in robotic-assisted minimally invasive coronary revascularization patients. This approach can benefit patients with severe peripheral arterial and aortic calcification or thrombi with safe outcomes in robotic-assisted minimally invasive coronary revascularization.

Keywords: axillary cannulation, femoral cannulation, minimally-invasive surgery, robotic cardiac surgery, coronary artery bypass surgery, coronary revascularization

ÖZET

Amaç: Aksiller arter kanülasyonunun, minimal invaziv kalp cerrahisinde femoral arter kanülasyonuna kıyasla daha güvenli sonuçlar ve daha az komplikasyon ile ilişkili olduğu bildirilmiştir. Koroner arter bypass cerrahisi uygulanan hastalarda aterosklerotik yükün yüksek olması nedeniyle, bu hastalar da antegrad aksiller arter kanülasyonundan önemli ölçüde fayda sağlayabilir. Bu çalışmanın amacı, robotik yardımcı minimal invaziv koroner arter bypass cerrahisinde aksiller ve femoral arter kanülasyonunun sonuçlarını karşılaştırmaktır.

Yöntem: Mart 2022-Mayıs 2024 tarihleri arasında merkezimizde pompalı robotik yardımcı minimal invaziv koroner arter bypass cerrahisi uygulanan ardışık 96 hasta çalışmaya dahil edildi. Kanülasyon stratejisinin belirlenmesine rehberlik etmek amacıyla ameliyat öncesi bilgisayarlı tomografi görüntüleri ateroskleroz açısından değerlendirildi. Elli yedi hastada (%59,4) aksiller arter kanülasyonu, 39 hastada (%40,6) femoral arter kanülasyonu uygulandı. Hastaların demografik özellikleri ve perioperatif verileri retrospektif olarak analiz edildi. Çalışmanın primer sonlanım noktası, inme ve hastane içi mortalite dahil olmak üzere perioperatif komplikasyonlardı.

Bulgular: Her iki grupta da ameliyat sonrası mortalite veya inme görülmedi. Her iki grupta da hematoma, kanülasyon bölgesi enfeksiyonu, emboli, diseksiyon, nörovasküler yaralanma veya brakial plexus yaralanması gibi komplikasyonlar gözlenmedi. Femoral arter kanülasyonu uygulanan hastalarda, kanülasyon bölgesinde 3 hastada (%7,7) gelişen seromalar dışında başka bir komplikasyon saptanmadı.

Sonuç: Aksiller arterin doğrudan kanülasyonu, robotik yardımcı minimal invaziv koroner revaskülarizasyonda kardiyopulmoner bypassın sağlanması için güvenli bir yöntemdir. Bu yaklaşım, özellikle ciddi periferik arteriyel veya aortik kalsifikasyon ya da trombüs bulunan hastalarda, robotik yardımcı minimal invaziv koroner revaskülarizasyonda güvenli sonuçlar sağlayarak önemli bir fayda sunabilir.

Anahtar Kelimeler: Aksiller kanülasyon, femoral kanülasyon, minimal invaziv cerrahi, robotik kalp cerrahisi, koroner arter bypass cerrahisi, koroner revaskülarizasyon

Robotic-assisted minimally invasive approach reduces surgical trauma and enhances patient outcomes in cardiac surgery. Minimally invasive cardiac surgery mostly requires the usage of peripheral cannulation techniques. Femoral cannulation is usually the standard approach with inherent disadvantages. Lymphorrhea, infection, hematoma, irritation of the femoral nerve and risk of embolic stroke in patients with high atherosclerotic burden who have peripheral arterial calcification and/or thrombi can be considered among the potential complications of femoral cannulation. (1) Axillary artery is an alternative site for cannulation that can be used to avoid these complications, especially in patients who are undergoing minimally invasive coronary artery bypass surgery, as this patient population usually presents with a higher atherosclerotic burden and peripheral arterial calcification compared to other patient groups. Most studies in literature comparing peripheral cannulation techniques in minimally invasive cardiac surgery are from studies involving mitral valve procedures. This data may not be fully applicable to minimally invasive coronary artery bypass surgery due to previously mentioned higher atherosclerotic burden of its patient population. The aim of this study was to evaluate if the choice of axillary artery cannulation guided by computed tomography and patient criteria is safe and feasible for cannulation in robotic-assisted minimally invasive coronary bypass surgery.

Material and Method

Study Population

Between March 2022 and May 2024, 104 consecutive patients underwent robotic-assisted minimally invasive coronary artery bypass surgery at our institution. All procedures were completed by a single surgical team with Da Vinci Robotic Systems. Off-pump patients were excluded and the remaining 96 patients were included in the study. Emergent cases, patients with severe comorbidity, left pleural adhesions, or ascending aortic disease prohibiting robotic surgery did not undergo robotic-assisted coronary artery bypass surgery during the study period. Pre-operative patient demographics, perioperative and post-operative data of the patients including mortality, stroke, cannulation site vessel injury and extremity ischemia were retrospectively collected and analyzed. The primary endpoint of the study was perioperative complications including stroke and in-hospital mortality.

Preoperative Planning And Choice Of Cannulation Site

Following the preoperative computed tomography to evaluate iliofemoral and aortic atherosclerotic burden, axillary or femoral artery cannulation was accordingly planned.

The following were factors in favour of choosing axillary cannulation:

- Severe iliofemoral stenosis,
- Severe aortoiliac atherosclerotic disease (**Figure 1**),
- Any aortoiliac free floating thrombus/mural thrombus (**Figure 2**),
- Severe iliofemoral soft plaque formation
- Insufficient femoral vessel diameter,
- Previous injury or operation to femoral vessels/pseudoaneurysm formation,
- Local groin infection/lymphadenomegaly in the groin region.

Surgical Technique

Robotic-assisted surgery is carried out using the Da Vinci XI system. Our surgical set-up for robotic-assisted minimally invasive coronary revascularization was previously described. (2) Following the steps of patient positioning, anesthetic preparation and robotic docking, the left internal mammary artery (LIMA) is robotically harvested. After the completion of LIMA harvest, bleeding control of the thoracic wall is performed with robotic assistance and the robotic trocars are undocked subsequently. At this stage, peripheral cannulation, either axillary or femoral as planned according to preoperative CT findings, is performed under TEE guidance. If any extensive atherosclerotic disease or thrombi at any level of the aorta or the iliofemoral vessels are observed, axillary artery cannulation via surgical exposure is preferred.

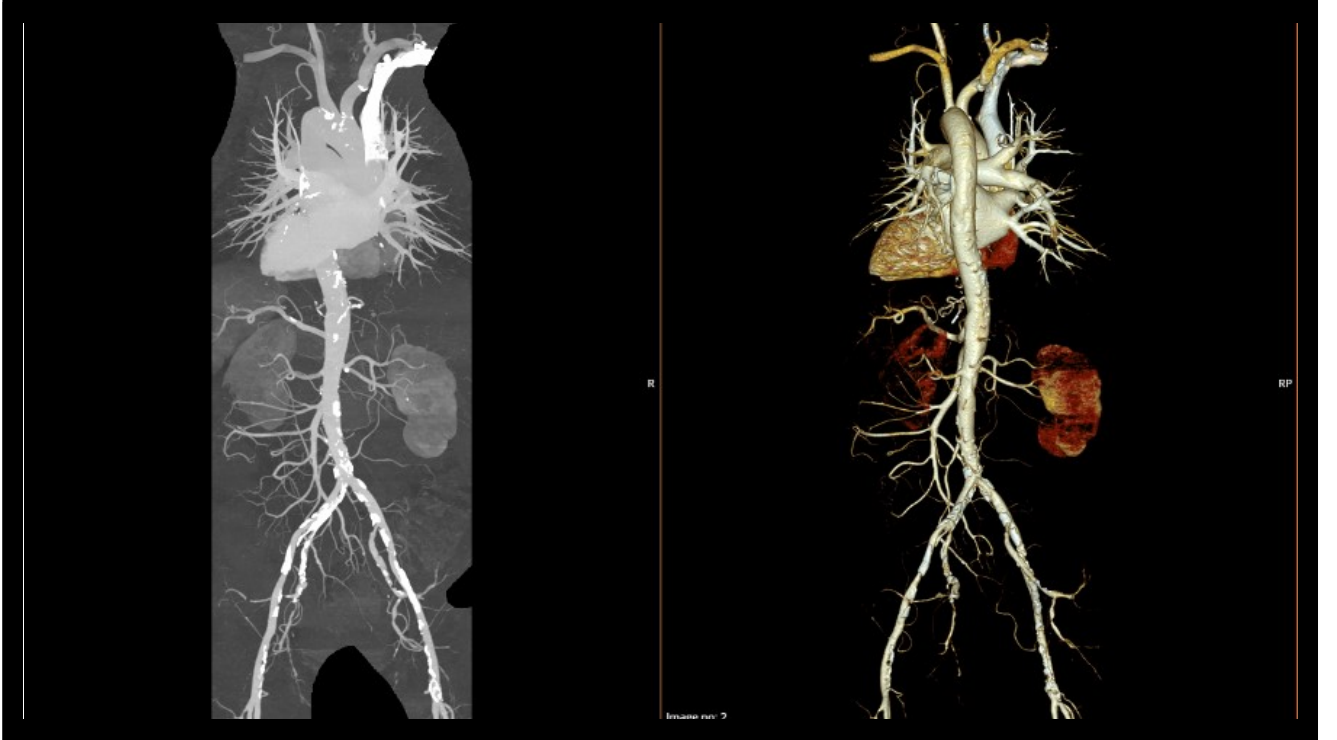


Figure 1. Preoperative computed tomography images of a patient with extensive atherosclerotic disease



Figure 2 (A and B). Evaluation of the aorta and the iliofemoral vessels on preoperative computed tomography. (A) Severe calcifications; (B) Thrombi prohibit femoral cannulation and axillary cannulation is opted for in these patients.

Femoral and axillary cannulations are carried out through a 2-3 cm mini-incision with ultrasound guidance (**Figure 3**). After the skin incision is made, the pectoralis major muscle is divided and the infraclavicular fat tissue is dissected. The dissection of tissues are performed closer to the medial portion of the clavicle as much as possible to avoid any injury to the brachial plexus. The axillary artery is visualised and encircled with vascular tape close to the proximal part of the thoracoacromial artery and pulled to lie more superficially. This enables safe exposure and safe cannulation of the artery due to a decreased angle of needle puncture. Following these steps, a purse string suture with 5-0 prolene is placed with a snare on the axillary artery, close to the proximal part of the thoracoacromial artery. The guidewire is then advanced

through direct puncture of the vessel. The position of the guidewire is confirmed with visualization of the ascending or descending thoracic aorta with TEE. After systemic heparinization with a target activated clotting time of greater than 400 seconds, direct cannulation of the axillary artery with Seldinger technique under TEE guidance is performed. A pulse oximeter is placed on the cannulated extremity until decannulation. Percutaneous femoral vein cannulation is performed along with axillary artery cannulation. If femoral cannulation is opted for, it is carried in the same manner under TEE guidance as axillary cannulation with a 2-3 cm incision. Cardiopulmonary bypass is then initiated and minimally invasive coronary bypass surgery is performed.

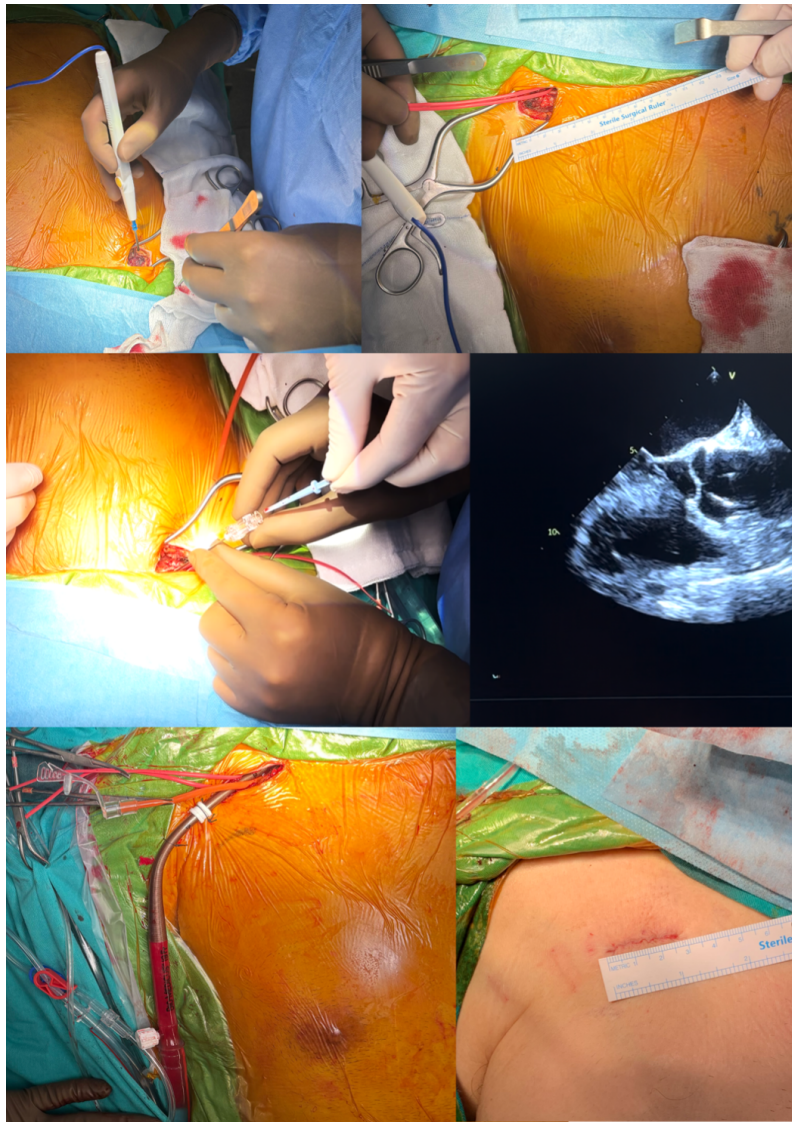


Figure 3. Direct cannulation of the axillary artery through a 2-3 cm incision with Seldinger technique under TEE guidance of the guidewire

Our surgical technique for robotic assisted CABG, including the techniques used for both distal coronary and proximal anastomoses, has been described in detail elsewhere. (3) For decannulation, the arterial cannula is removed while the assistant surgeon holds the snare and tightens the purse string suture. A U-shaped suture is placed and tied, then the purse string suture is tied as well. With this technique, major bleeding and complications are avoided to a great extent. The incision is then closed, no minovac or hemovac drains are routinely placed to the incision site.

Ethical Statement

The study was conducted in accordance with the Declaration of Helsinki. Patient data for this study was retrieved from the institutional database retrospectively. Approval from Acibadem Maslak Hospital Institutional Review Board was obtained before establishing the study.

Statistical Analysis

IBM SPSS Statistics, Version 25.0 (IBM Corp., Armonk, NY, USA) and RStudio (Posit, Boston, MA, USA) with ggplot package were used for statistical analysis. Continuous parameters are given as mean and standard deviation, while categorical parameters are given as numbers and percentages. The Shapiro–Wilk test was used to assess the normal distribution of parameters. The Student's *t* test was used for comparisons between 2 groups of normally

distributed quantitative variables, and the Mann–Whitney *U* test was used for comparisons between two groups of non-normally distributed quantitative variables.

Results

Robotic-assisted on-pump coronary artery bypass surgery with axillary or femoral arterial cannulation was performed on 96 consecutive patients between March 2022 and May 2024. Axillary artery was the choice of cannulation site in 57 (59.4%) patients and femoral artery in 39 (40.6%). There were 8 (14%) female and 49 (86%) male patients in the axillary cannulation group, whilst there were 5 (13%) female and 34 (87%) male patients in the femoral cannulation group ($p=0.864$). The mean age was 64.5 ± 7.4 in axillary cannulation vs. 61.9 ± 9.5 in femoral cannulation groups ($p=0.082$). The mean BMI was 27.8 ± 4.1 and 29.4 ± 3.6 in axillary and femoral cannulation groups, respectively ($p=0.072$). The mean EuroSCORE II of the patients was 2.3 ± 1.7 in the axillary cannulation group and 1.8 ± 2.0 in the femoral cannulation group ($p=0.089$). 54.4% of the patients in the axillary cannulation group and 54% of the patients in the femoral cannulation group were in NYHA Class 2 ($p=0.441$). 65% of the patients in the axillary cannulation group and 54% of the patients in the femoral cannulation group had pre-existing hypertension ($p=0.276$). Pre-operative characteristics were similar between two groups. The patient demographics are summarized in **Table 1**.

Table 1. Preoperative characteristics of patients (n=96)

Demographics	Axillary Cannulation (59.4%)	Femoral Cannulation (40.6%)	p
Age (years)	64.5 ± 7.4	61.9 ± 9.5	0.082
Female Gender	8 (14%)	5 (13%)	0.864
Euroscore II	2.3 ± 1.7	1.8 ± 2.0	0.089
NYHA			0.441
Class 1	23 (40.3%)	18 (46%)	
Class 2	31 (54.4%)	21 (54%)	
Class 3	3 (5.3%)	0 (0%)	
BMI	27.8 ± 4.1	29.4 ± 3.6	0.072
Diabetes Mellitus	30 (53%)	20 (51%)	0.897
Hypertension	37 (65%)	21 (54%)	0.276
Hypercholesterolemia	40 (70%)	28 (72%)	0.864
Smoking			0.098
Never smoker	12 (21%)	16 (41%)	
Ex-smoker	24 (42%)	11 (28%)	
Current smoker	21 (37%)	12 (31%)	

BMI: Body Mass Index, NYHA: New York Heart Association

The cross clamp times were 64.1 ± 16.9 mins in the axillary cannulation group and 80.3 ± 20.8 in the femoral cannulation group ($p < 0.001$). Cardiopulmonary bypass times were 153.7 ± 40.3 mins and 155.6 ± 43.5 mins respectively. The mean number of revascularized vessels were 2.9 ± 0.8 and 3.0 ± 1.1 in two groups, respectively ($p = 0.927$). Mechanical ventilation times were 4.2 ± 1.9 hours and 5.3 ± 3.6 hours respectively in the axillary and femoral cannulation groups ($p = 0.114$). The ICU stay was 19.7 ± 4.7 hours and 19.9 ± 5.4 hours ($p = 0.997$); and the hospital stay was 7.3 ± 2.5 days and 7.6 ± 2.7 days respectively in the axillary and femoral cannulation groups ($p = 0.695$). Total drainage from chest tube was 500 ± 463.1 mL and 514.9 ± 454.2 mL, respectively ($p = 0.666$).

There were no cases of post-operative mortality or stroke in either group. No complications including neurovascular

injury, hematomas, emboli, dissection, brachial plexus injury, limb ischemia or cannulation site infections were observed in any of the patients in either group. No patient required additional arterial cannulation or conversion to a side-graft cannulation due to inadequate perfusion. One patient (2.6%) in the femoral cannulation group was reoperated for mediastinal bleeding. No other complications were encountered in patients with femoral artery cannulation except for seromas at the cannulation site in 3 (7.7%) of the patients ($p = 0.064$), and this low rate of complications was attributed to the elaborative preoperative investigation of patients with severe calcification and the preference of axillary artery cannulation if atherosclerotic disease is present. Operative data and postoperative outcomes are presented in **Table 2**.

Table 2. Operative Data and Postoperative Outcomes (n=96)

Variables	Axillary Cannulation (59.4%)	Femoral Cannulation (40.6%)	p
Cross-clamp time (min)	64.1 ± 16.9	80.3 ± 20.8	<0.001
Cardiopulmonary bypass time (min)	153.7 ± 40.3	155.6 ± 43.5	0.830
Number of revascularized vessels	2.9 ± 0.8	3.0 ± 1.1	0.927
Mechanical ventilation time (h)	4.2 ± 1.9	5.3 ± 3.6	0.114
ICU stay (h)	19.7 ± 4.7	19.9 ± 5.4	0.997
Hospital stay (days)	7.3 ± 2.5	7.6 ± 2.7	0.695
Chest tube drainage in ICU (ml)	500 ± 463.1	514.9 ± 454.2	0.666
Post-operative stroke	0 (0%)	0 (0%)	
Post-operative dialysis	0 (0%)	0 (0%)	
Neurovascular Injury	0 (0%)	0 (0%)	
Hematoma	0 (0%)	0 (0%)	
Pseudoaneurysm	0 (0%)	0 (0%)	
Reoperation for bleeding	0 (0%)	1 (2.6%)	>0.999
Brachial plexus injury	0 (0%)	0 (0%)	
Infection at cannulation site	0 (0%)	0 (0%)	
Limb ischemia	0 (0%)	0 (0%)	
Dissection	0 (0%)	0 (0%)	
Emboli	0 (0%)	0 (0%)	
Reintubation	0 (0%)	0 (0%)	
Seroma	0 (0%)	3 (7.7%)	0.064
Pulmonary complications	0 (0%)	0 (0%)	
In-hospital mortality	0 (0%)	0 (0%)	

Discussion

Minimally invasive techniques in cardiac surgery enable better operative outcomes in terms of bleeding, postoperative pain, patient mobility, and better cosmetic results with minimal scars. (4) The choice of cannulation site in robotic-assisted CABG may be a determining factor for the surgical outcomes and in our series of 96 consecutive robotic-assisted CABG patients, we have observed that axillary cannulation can be safely performed with excellent results.

Minimally invasive cardiac surgery mostly requires the usage of peripheral cannulation techniques. The most commonly performed minimally invasive cardiac procedures are mitral valve procedures. Femoral cannulation for cardiopulmonary bypass is the most commonly used cannulation approach in minimally invasive cardiac surgery including minimally invasive mitral procedures. (5,6) Despite this, axillary artery cannulation has been shown in many studies to yield safer results and fewer complications compared to femoral artery cannulation in minimally invasive mitral valve surgery. A study by Petersen et al. reported that the use of antegrade axillary artery perfusion in patients with severe atherosclerosis showed similar post-operative outcomes as compared to lower risk patients undergoing retrograde femoral perfusion and that patients presenting with higher perioperative risk and severe atherosclerotic disease can be safely treated using the minimally invasive approach with the use of antegrade axillary perfusion. (7)

In a study by Cheng et al. comparing minimally invasive mitral valve surgery to standard sternotomy, an increased stroke risk was reported in minimally invasive approach. (6) This increased risk for neurological complications during minimally invasive mitral valve surgery was attributed to the use of retrograde perfusion for cardiopulmonary bypass in other studies in the literature. (8) Murzi et al. compared retrograde and antegrade arterial perfusion strategies in minimally invasive mitral-valve surgery, and reported that the use retrograde arterial perfusion with femoral cannulation was an independent risk factor for stroke (5 vs 1%; $P=0.002$) and postoperative delirium (14 vs 5%, $P=0.001$) in high-risk patients with peripheral vascular disease or disease of the aorta. The importance of pre-operative evaluation of the aorta and distal vasculature was emphasized to reduce the incidence of stroke in this study. (9)

Robotic-assisted coronary bypass surgery should be further distinguished in terms of cannulation choice from other robotic and minimally invasive cardiac procedures, as the patient population highly differs in terms of atherosclerotic burden. Robotic assisted minimally invasive coronary bypass surgery patients present with an higher atherosclerotic burden when compared to other minimally invasive cardiac surgical patient groups, thus may present with an higher risk of neurological complications when retrograde femoral artery cannulation is opted for. This is why axillary cannulation can greatly benefit this patient group, in terms of post-operative complication avoidance such as stroke and cannulation site complications.

It has also been previously shown in various studies that direct cannulation of the axillary artery can be safely performed as a routine technique with low complication rates in aortic and complex cardiac surgery. (10-12) Other than in complex reoperations and aortic repair surgery, axillary artery cannulation can also be beneficial for patients with advanced atherosclerotic disease undergoing minimally invasive cardiac surgery requiring peripheral arterial cannulation.

Antegrade axillary perfusion is considered as a more physiological perfusion strategy compared to retrograde perfusion strategies, and the risk of plaque embolization and iatrogenic aortic dissection are reduced while complications related to groin incisions can be avoided with the antegrade perfusion technique. (13) Femoral artery cannulation also has an increased risk of aortic injury, as retrograde aortic flow can predispose to aortic dissection. (14)

In a study by Nakamura et al., a CT-based perfusion strategy with either axillary or femoral cannulation was adopted and it was shown that axillary cannulation can be a good alternative to prevent brain embolization for minimally invasive cardiac surgery patients with advanced atherosclerotic disease. The authors developed a CT-based algorithm for patient selection in terms of axillary or femoral cannulation considering the atherosclerotic disease burden. (15)

Axillary cannulation also has some potential complications and risks that can be avoided through careful practice of cannulation. Arterial damage or dissection of the axillary artery or the aorta, brachial plexus injury, axillary artery thrombosis or local wound infection are among these

complications reported in literature. (16) Axillary artery is more fragile and prone to dissection compared to the femoral artery, this is why the dissection of surrounding tissues should be performed with fine movements and the cannula should not be advanced without visualization of the guidewire with TEE. Unnecessary traction and sharp dissection should be avoided in order to prevent any damage to the brachial plexus. (17) TEE guidance helps us minimize the risk of these potential complications, and in our group of patients, we haven't encountered any of these complications.

Our study demonstrates that antegrade axillary perfusion during robotic-assisted minimally invasive coronary bypass surgery is a safe, feasible procedure associated with excellent results and low complication rates. As axillary cannulation is a perfusion technique that is already more frequently preferred in patients undergoing redo operations or those with severe atherosclerotic disease, this perfusion approach may be considered as the first choice of cannulation in robotic-assisted minimally invasive coronary revascularization.

There are certain limitations to our study. Firstly, it was a non-randomized retrospective observational study. Patients with severe atherosclerotic disease were not included in the femoral cannulation group, which makes it hard to directly compare the benefits of axillary versus femoral cannulation in these patients. However, it is shown that with axillary artery cannulation, good outcomes and low complication rates can be achieved, which can lead to the consideration of this cannulation approach as the first choice in robotic-assisted minimally invasive coronary bypass surgery. Complications resulting from cannulation are low in number and this may limit the ability to detect differences with choice of cannulation site. Lastly, our results are reported from a single center with a single group of operating surgeons, therefore external validation of our results may be necessary.

Conclusion

Direct cannulation of the axillary artery is a safe method for establishment of cardiopulmonary bypass in robotic-assisted minimally invasive coronary revascularization patients. This approach can be used especially in patients with severe peripheral arterial and aortic calcification or thrombi. As severe peripheral arterial or aortic calcification and thrombi are more frequently encountered in coronary artery bypass surgery patients, this patient group may

benefit greatly from antegrade axillary artery cannulation with safe outcomes in robotic-assisted minimally invasive coronary revascularization.

Declaration

Conflicts of Interest

The authors declare no conflicts of interest.

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Availability of Data and Materials

The data supporting the findings of this study are available from the corresponding author upon request.

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The authors have nothing to acknowledge.

Authors' contributions

All authors have read and approved the final version of the article.

Ethics Statement

The study was conducted in accordance with the principles of the Declaration of Helsinki. Institutional Review Board approval was obtained from the Acibadem Maslak Hospital Ethics Committee (Approval No: Maslak/154-2024, dated April 15, 2024).

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