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Editorial

Evolution and Progress of Coronary Artery Bypass Grafting: 2025

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History of Coronary Artery Bypass Grafting

Coronary artery bypass grafting (CABG) was revolutionized in the 1960s by René Favaloro, MD [1], at Cleveland Clinic, in an effort to alleviate symptoms and improve survival for patients with coronary artery disease. Studies have confirmed CABG survival benefits, especially in patients with left main and multivessel disease, compared to medical therapy. Two decades later, percutaneous coronary intervention (PCI) emerged as a less invasive alternative, particularly with the advent of drug-eluting stents. PCI is now the standard of care for patients with acute coronary syndromes, but CABG remains the treatment of choice in patients with complex atherosclerotic lesions [2–4].

CABG vs PCI: Who Gets What

The comparison between CABG and PCI use has undergone extensive research due to continual technological advancements and new techniques. Landmark trials have provided a clearer look about the optimal use of PCI and CABG with regard to patient-specific characteristics and outcomes.

Left Main Coronary Disease

Discussion around CABG versus PCI for patients with left main coronary disease is sensitive due to inconsistent findings about the survival benefit of CABG in published studies. In a meta-analysis [5] of all trials regarding left main disease (Synergy Between Percutaneous Coronary Intervention and Cardiac Surgery [SYNTAX], Premier of Randomized Comparison of Bypass Surgery versus Angioplasty Using Sirolimus-Eluting Stent in Patients with Left Main Coronary Artery Disease [PRECOMBAT], Nordic-Baltic-British Left Main Revascularization [NOBLE], and Evaluation of XIENCE Versus Coronary Artery Bypass Surgery for Effectiveness of Left Main Revascularization [EXCEL]), no statistically significant difference was found in all-cause mortality over 5 years between the PCI and CABG groups. However, a Bayesian statistical approach demonstrated a survival benefit for CABG over PCI. Patients who underwent PCI had a higher rate of repeat revascularization and spontaneous myocardial infarction. Data solidifies the advantage that CABG holds with regard to myocardial protection and freedom from reintervention.

Multivessel Disease

CABG has cemented its role in the treatment of patients with multivessel disease. Major trials like Future Revascularization Evaluation in Patients with Diabetes Mellitus: Optimal Management of Multivessel Disease (FREEDOM) [4] and SYNTAX [6] have consistently shown that CABG is superior to PCI especially when there is a high atherosclerotic disease burden (SYNTAX score $\geq$33). PCI has an important complementary role in acute coronary syndromes and in patients with low atherosclerotic burden, particularly when complete revascularization can be achieved. PCI also provides symptomatic relief in patients with stable coronary artery disease who are at high surgical risk.

CABG Conduits in 2025

The survival benefit of CABG stems from the durability of its grafts and the strategic choice of the best conduits to bypass the most important, diseased coronary targets (reaching >75% towards the apex of the heart) [7,8]. Following its introduction in the seminal paper by Loop *et al*. in 1986 [9] at Cleveland Clinic, the use of an internal thoracic artery (ITA) as a conduit to bypass the left anterior descending has been and continues to be the standard of care, owing to its superior long-term outcomes and freedom from reintervention. Furthermore, utilizing both right and left ITAs conferred an even greater survival benefit as compared to the use of one [10]. Not all coronary targets are created equal; bilateral (B)ITA grafting that maximizes myocardial mass with BITA inflow achieves the best long-term survival [7,8]. Although the Arterial Revascularization Trial (ART), the largest multicenter, randomized controlled trial to compare BITA with left (L)ITA strategy in multivessel disease, was negative, the as-treated analysis displayed significantly better 10-year survival and protection from myocardial infarction and stroke for patients who received multiarterial versus single arterial grafting [11].

Multiarterial grafting has proven its superiority over single arterial in large observational studies [10–12], but not all patients are candidates. BITA grafting is associated

with an increased risk of sternal complications [13], which can be mitigated with good technique and experience. Recently, the radial artery is becoming a more popular conduit [14]. However, care should be taken when using the radial artery because it is susceptible to spasm and higher failure rates when used to bypass coronaries with <70% stenosis [15]. The Veterans Affairs radial trial compared the artery to saphenous vein, which was negative with regard to graft patency rates at 1 year and long-term mortality [16]. The right gastroepiploic artery (RGEA) is most often used in a similar fashion to the radial artery, but it is also susceptible to spasm and competitive flow. Since an abdominal incision is required to harvest the RGEA, which may increase sternal infections and gastrointestinal complication rates, and technical concerns about graft length, size, and distal diameter exist, the RGEA is not commonly used [17]. Regardless of choice, multiarterial grafting benefits should not be disregarded and personalized patient decision-making should be implemented to achieve the best outcomes.

Current consensus supports the superiority of arterial grafting in carefully selected patients undergoing CABG [17]. The Society of Thoracic Surgeons (STS) adult cardiac surgery data shows an increasing population of patients receiving multiarterial grafting, from 10.9% in 2020 to 14.3% in 2021, with increases in both BITA and radial artery usage [14]. No-touch vein harvesting shows promising results approaching that of arterial conduits, but wider adoption is unlikely because of the invasive harvesting technique and risk of leg wound complications [18].

Guideline Discrepancy

Recently, there has been much debate about 2021 ACC/AHA/SCAI coronary revascularization guidelines, where CABG was downgraded relative to medical therapy for patients with triple vessel disease, recommending changes from Class I to Class IIb in patients with normal ejection fraction, and from Class I to Class IIA in patients with mild-to-moderate left ventricular dysfunction. In addition, the radial artery was prematurely awarded a Class 1 recommendation as a CABG conduit, surpassing the recommendation of BITAs [19]. The CABG downgrade was surprising since it was not supported by robust evidence [20]. Several societies, notably the American Association of Thoracic Surgery (AATS) and the STS, did not endorse the 2021 ACC/AHA/SCAI guidelines and instead endorsed the 2024 European guidelines for coronary revascularization [21].

Redo CABG in 2025

With the advancement of medical therapy and operative strategies and increasing use of ITA, redo-CABG frequency has decreased from 6% in 2000 to 2% in 2017. Redo-CABG patients typically have a more complex risk profile and multiple comorbidities [22]. The benefit of multiarterial grafting does not stop at primary CABG but carries over to redo CABG. In a recent, large observational study, multiarterial grafting in redo CABG has been found to be associated with better survival especially in males who subsequently need BITA grafts [23].

Minimally Invasive Techniques

In the early days of CABG an off-pump approach was utilized, but was quickly replaced by on-pump-arrested-heart CABG. Surgeons re-developed an interest in off-pump CABG in the 1990s through the following decade, but this interest waned after 3 major randomized trials showed a lack of benefit of off-pump over on-pump CABG [24]. Concerns were also raised about the increased risk of incomplete revascularization off-pump and potential compromise in graft patency. Nevertheless, there is an agreement that some patients, including those with diseased aorta and liver dysfunction, may benefit from an off-pump approach. Outcomes of off-pump CABG are dependent on surgical expertise and unplanned conversions to on-pump are associated with increased morbidity and mortality.

Innovations in coronary surgery led to the development of mainly minimally invasive techniques—minimally invasive coronary surgery (MICS) CABG, totally endoscopic coronary artery bypass (TECAB), and hybrid coronary revascularization—in an effort to improve patient outcomes. MICS CABG utilizes off-pump CABG with a less invasive access point for coronary anastomosis (like a left anterior thoracotomy), thus reducing possible complications related to the use of cardiopulmonary bypass (CPB) and full conventional sternotomy. MICS CABG allows for multivessel grafting with various in-flow configurations with a good result in graft patency [25]. The Minimally Invasive Coronary Surgery compared to Sternotomy Coronary Artery Bypass Grafting (MIST) trial evaluates clinical outcomes and quality-of-life differences between MICS CABG and conventional sternotomy CABG [26].

TECAB differs from other CABG approaches as it is a fully endoscopic procedure that is performed using a robot. Access to the mediastinum is completed via small incisions for the robotic arms that harvest both ITAs. Its benefits include minimal surgical trauma and reduced hospital stay, and the ability to incorporate multiarterial grafting via BITAs [27]. Unlike MICS, there is no need for a utility incision and no rib spreading. As with MICS, CPB may be necessary to decompress the heart and access lateral and inferior wall targets. Peripheral cannulation is used to establish CPB with or without aortic occlusion depending on the need for an arrested heart or not. Coronary anastomoses are completed robotically. One caveat is the absence of robotic stabilizers in the most recent models; however, this

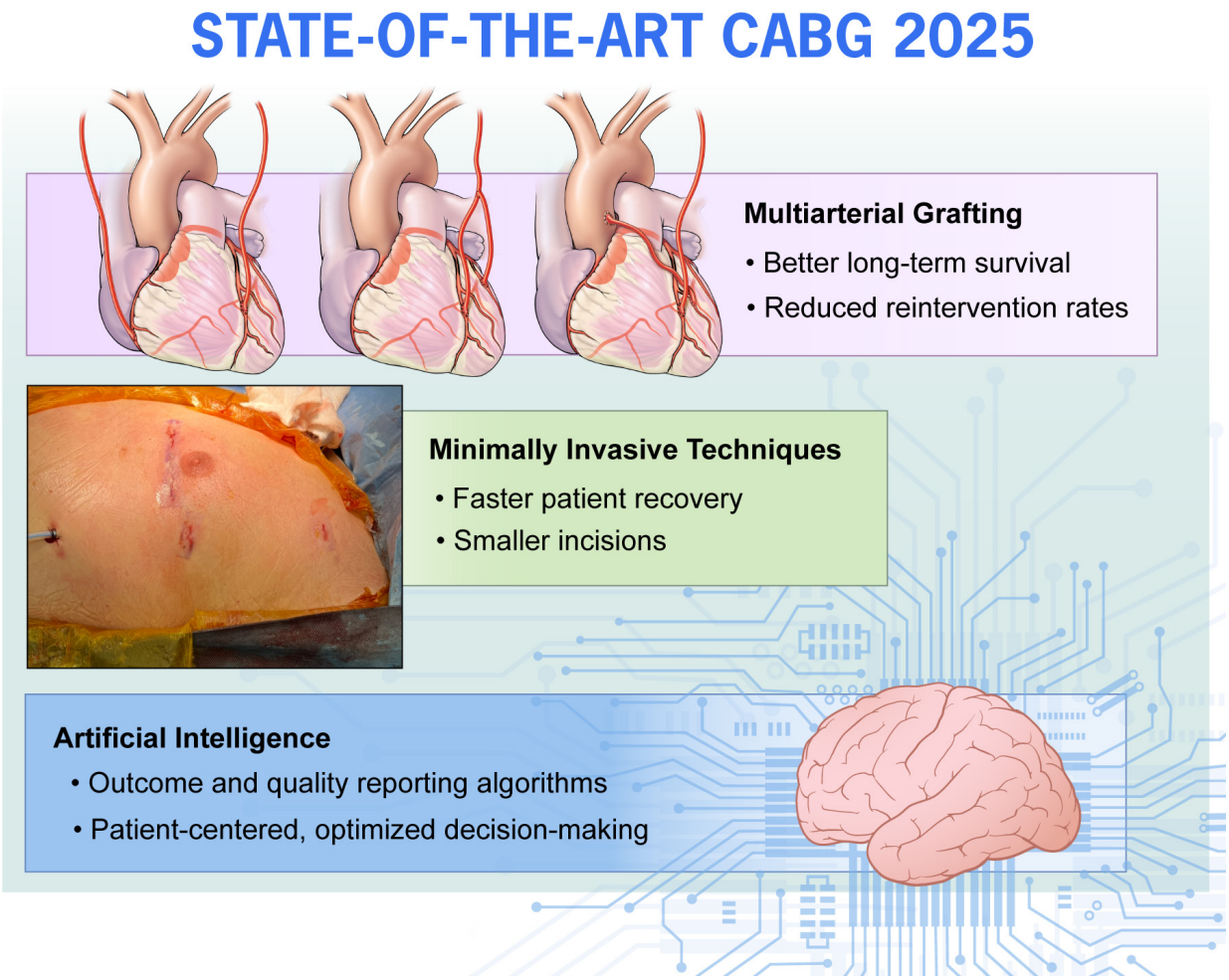

Fig. 1. State-of-the-Art CABG 2025. CABG, coronary artery bypass grafting.

will likely change in the near future. Multivessel TECAB is an advanced and complex operation in the spectrum of robotic cardiac procedures and requires appropriate patient selection. Advanced specialized training is needed to mitigate the steep learning curve. Thus, TECAB is not readily available and is limited to select patients and by select surgeons. Data on long-term outcomes have been sparse, but excellent results were recently published by Balkhy *et al.* [28].

Hybrid revascularization combines grafting the LAD with LITA, using a minimally invasive CABG technique and PCI to non-LAD coronary lesions. Patients receive a survival benefit from an ITA to LAD, avoiding CPB and sternotomy [29]. Hybrid revascularization is an evolving field with limited data on long-term outcomes. We prefer multiarterial grafting for multivessel disease that involves the LAD and other important target vessels because of the survival advantage associated with MAG in those scenarios.

Where to Now?

The future of CABG lies in broadening access, addressing guidelines and practice discrepancies, and widening implementation of multiarterial grafting and minimally invasive techniques in carefully selected patients (Fig. 1).

The quest for the perfect public reporting scorecard continues to evolve to encompass the wide variety and complexity of cardiac surgery practices [30]. The American Association for Thoracic Surgeons has taken the lead to improve outcome reporting and quality assurance with its quality gateway, providing real time, risk-adjusted outcome prediction for all types of cardiac surgery, utilizing advanced statistical algorithms and virtual twin analysis as a step towards more personalized medical care [31]. Moreover, with the advent of artificial intelligence (AI), efforts are underway to incorporate it into the decision-making process to optimize patient care and CABG outcomes. Areas of application vary from automated image readings, including coronary angiograms, cardiovascular risk profiling from

raw electrocardiographic and imaging data, and identifying patient-specific interventions. AI-driven robotic cardiac surgery under human supervision is no longer science fiction and may be within reach during the next 5 to 10 years.

Author Contributions

MA, MK, and FGB all contributed to the concept and design of the manuscript, as well as drafting and revising the manuscript. All authors followed the ICMJE guidelines. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

Not applicable.

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Conflict of Interest

The authors declare no conflict of interest.

References

[1] Favaloro RG. Saphenous vein autograft replacement of severe segmental coronary artery occlusion: operative technique. The Annals of Thoracic Surgery. 1968; 5: 334–339. https://doi.org/10.1016/s0003-4975(10)66351-5.

[2] Stone GW, Kappetein AP, Sabik JF, Pocock SJ, Morice MC, Puskas J, *et al*. Five-Year Outcomes after PCI or CABG for Left Main Coronary Disease. The New England Journal of Medicine. 2019; 381: 1820–1830. https://doi.org/10.1056/NEJMoa1909406.

[3] Park SJ, Kim YH, Park DW, Yun SC, Ahn JM, Song HG, *et al*. Randomized trial of stents versus bypass surgery for left main coronary artery disease. The New England Journal of Medicine. 2011; 364: 1718–1727. https://doi.org/10.1056/NEJMoa1100452.

[4] Farkouh ME, Domanski M, Sleeper LA, Siami FS, Dangas G, Mack M, *et al*. Strategies for multivessel revascularization in patients with diabetes. The New England Journal of Medicine. 2012; 367: 2375–2384. https://doi.org/10.1056/NEJMoa1211585.

[5] Sabatine MS, Bergmark BA, Murphy SA, O'Gara PT, Smith PK, Serruys PW, *et al*. Percutaneous coronary intervention with drug-eluting stents versus coronary artery bypass grafting in left main coronary artery disease: an individual patient data meta-analysis. Lancet (London, England). 2021; 398: 2247–2257. https://doi.org/10.1016/S0140-6736(21)02334-5.

[6] Serruys PW, Morice MC, Kappetein AP, Colombo A, Holmes DR, Mack MJ, *et al*. Percutaneous coronary intervention versus coronary-artery bypass grafting for severe coronary artery disease. The New England Journal of Medicine. 2009; 360: 961–972. https://doi.org/10.1056/NEJMoa0804626.

[7] Bakaeen FG, Ravichandren K, Blackstone EH, Houghtaling PL, Soltesz EG, Johnston DR, *et al*. Coronary Artery Target Selection and Survival After Bilateral Internal Thoracic Artery Grafting. Journal of the American College of Cardiology. 2020; 75: 258–268. https://doi.org/10.1016/j.jacc.2019.11.026.

[8] Bakaeen FG, Ghandour H, Ravichandren K, Zhen-Yu Tong M, Soltesz EG, Johnston DR, *et al*. Right Internal Thoracic Artery Patency Is Affected More by Target Choice Than Conduit Configuration. The Annals of Thoracic Surgery. 2022; 114: 458–466. https://doi.org/10.1016/j.athoracsur.2021.09.015.

[9] Loop FD, Lytle BW, Cosgrove DM, Stewart RW, Goormastic M, Williams GW, *et al*. Influence of the internal-mammary-artery graft on 10-year survival and other cardiac events. The New England Journal of Medicine. 1986; 314: 1–6. https://doi.org/10.1056/NEJM198601023140101.

[10] Lytle BW, Blackstone EH, Sabik JF, Houghtaling P, Loop FD, Cosgrove DM. The effect of bilateral internal thoracic artery grafting on survival during 20 postoperative years. The Annals of Thoracic Surgery. 2004; 78: 2005–2005–2012; discussion 2012–2014. https://doi.org/10.1016/j.athoracsur.2004.05.070.

[11] Taggart DP, Gaudino MF, Gerry S, Gray A, Lees B, Dimagli A, *et al*. Effect of total arterial grafting in the Arterial Revascularization Trial. The Journal of Thoracic and Cardiovascular Surgery. 2022; 163: 1002–1009.e6. https://doi.org/10.1016/j.jtcvs.2020.03.013.

[12] Sabik JF, 3rd, Mehaffey JH, Badhwar V, Ruel M, Myers PO, Sandner S, *et al*. Multiarterial vs Single-Arterial Coronary Surgery: 10-Year Follow-up of 1 Million Patients. The Annals of Thoracic Surgery. 2024; 117: 780–788. https://doi.org/10.1016/j.athoracsur.2024.01.008.

[13] Dai C, Lu Z, Zhu H, Xue S, Lian F. Bilateral internal mammary artery grafting and risk of sternal wound infection: evidence from observational studies. The Annals of Thoracic Surgery. 2013; 95: 1938–1945. https://doi.org/10.1016/j.athoracsur.2012.12.038.

[14] Kim KM, Arghami A, Habib R, Daneshmand MA, Parsons N, Elhalabi Z, *et al*. The Society of Thoracic Surgeons Adult Cardiac Surgery Database: 2022 Update on Outcomes and Research. The Annals of Thoracic Surgery. 2023; 115: 566–574. https://doi.org/10.1016/j.athoracsur.2022.12.033.

[15] Buxton BF, Hayward PA, Raman J, Moten SC, Rosalion A, Gordon I, *et al*. Long-Term Results of the RAPCO Trials. Circulation. 2020; 142: 1330–1338. https://doi.org/10.1161/CIRCULATIONAHA.119.045427.

[16] Goldman S, McCarren M, Sethi GK, Holman W, Bakaeen FG, Wagner TH, *et al*. Long-Term Mortality Follow-Up of Radial Artery Versus Saphenous Vein in Coronary Artery Bypass Grafting: A Multicenter, Randomized Trial. Circulation. 2022; 146: 1323–1325. https://doi.org/10.1161/CIRCULATIONAHA.122.062343.

[17] Aldea GS, Bakaeen FG, Pal J, Fremes S, Head SJ, Sabik J, *et al*. The Society of Thoracic Surgeons Clinical Practice Guidelines on Arterial Conduits for Coronary Artery Bypass Grafting. The

Annals of Thoracic Surgery. 2016; 101: 801–809. https://doi.org/10.1016/j.athoracsur.2015.09.100.

[18] Tian M, Wang X, Sun H, Feng W, Song Y, Lu F, *et al*. No-Touch Versus Conventional Vein Harvesting Techniques at 12 Months After Coronary Artery Bypass Grafting Surgery: Multicenter Randomized, Controlled Trial. Circulation. 2021; 144: 1120–1129. https://doi.org/10.1161/CIRCULATIONAHA.121.055525.

[19] Lawton JS, Tamis-Holland JE, Bangalore S, Bates ER, Beckie TM, Bischoff JM, *et al*. 2021 ACC/AHA/SCAI Guideline for Coronary Artery Revascularization: A Report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines. Circulation. 2022; 145: e18–e114. https://doi.org/10.1161/CIR.0000000000001038.

[20] Bakaeen FG, Chu D, Dayan V. 2021 Coronary Revascularization Guidelines-Lessons in the Importance of Data Scrutiny and Reappraisal of Evidence. JAMA Surgery. 2023; 158: 233–234. https://doi.org/10.1001/jamasurg.2022.4796.

[21] Dayan V, Sabik JF, 3rd, Ono M, Ruel M, Wan S, Svensson LG, *et al*. Multisociety endorsement of the 2024 European guideline recommendations on coronary revascularization. The Journal of Thoracic and Cardiovascular Surgery. 2025; 169: 1251–1253. https://doi.org/10.1016/j.jtcvs.2024.10.038.

[22] Bakaeen FG, Akras Z, Svensson LG. Redo coronary artery bypass grafting. Indian Journal of Thoracic and Cardiovascular Surgery. 2018; 34: 272–278. https://doi.org/10.1007/s12055-018-0651-1.

[23] Iacona GM, Bakhos JJ, Houghtaling PL, Tipton AE, Ramsingh R, Smedira NG, *et al*. Multiarterial grafting in redo coronary artery bypass grafting: Type of arterial conduit and patient sex determine benefit. The Journal of Thoracic and Cardiovascular Surgery. 2024. https://doi.org/10.1016/j.jtcvs.2024.10.018. (online ahead of print)

[24] Patel V, Unai S, Gaudino M, Bakaeen F. Current Readings on Outcomes After Off-Pump Coronary Artery Bypass Grafting. Seminars in Thoracic and Cardiovascular Surgery. 2019; 31: 726–733. https://doi.org/10.1053/j.semtcvs.2019.05.012.

[25] McGinn JT, Jr, Usman S, Lapierre H, Pothula VR, Mesana TG, Ruel M. Minimally invasive coronary artery bypass grafting: dual-center experience in 450 consecutive patients. Circulation. 2009; 120: S78–S84. https://doi.org/10.1161/CIRCULATIONAHA.108.840041.

[26] Guo MH, Wells GA, Glineur D, Fortier J, Davierwala PM, Kikuchi K, *et al*. Minimally Invasive coronary surgery compared to sternotomy coronary artery bypass grafting: The MIST trial. Contemporary Clinical Trials. 2019; 78: 140–145. https://doi.org/10.1016/j.cct.2019.01.006.

[27] Nisivaco S, Bhasin R, Kitahara H, Patel B, Coleman C, Grady K, *et al*. Bilateral internal thoracic artery grafting in robotic beating-heart totally endoscopic coronary artery bypass: 10-year outcomes. Annals of Cardiothoracic Surgery. 2024; 13: 354–363. https://doi.org/10.21037/acs-2024-rcabg-0016..

[28] Balkhy HH, Nisivaco SM, Hashimoto M, Torregrossa G, Grady K. Robotic Total Endoscopic Coronary Bypass in 570 Patients: Impact of Anastomotic Technique in Two Eras. The Annals of Thoracic Surgery. 2022; 114: 476–482. https://doi.org/10.1016/j.athoracsur.2021.10.049.

[29] Puskas JD, Halkos ME, DeRose JJ, Bagiella E, Miller MA, Overbey J, *et al*. Hybrid Coronary Revascularization for the Treatment of Multivessel Coronary Artery Disease: A Multicenter Observational Study. Journal of the American College of Cardiology. 2016; 68: 356–365. https://doi.org/10.1016/j.jacc.2016.05.032.

[30] Ghandour H, Weiss AJ, Gaudino M, Halkos M, Chu D, Taylor BS, *et al*. Public reporting for coronary artery bypass graft surgery: The quest for the optimal scorecard. The Journal of Thoracic and Cardiovascular Surgery. 2023; 166: 805–815.e1. https://doi.org/10.1016/j.jtcvs.2022.01.051.

[31] Svensson LG, Jones DR. American Association for Thoracic Surgery Quality Gateway (AQG): Interim report. The Journal of Thoracic and Cardiovascular Surgery. 2024; 167: 1–2. https://doi.org/10.1016/j.jtcvs.2023.10.036.