



JOURNAL OF EDUCATION, HEALTH AND SPORT

eISSN 2391-8306 · Open Access · Peer-reviewed

apcz.umk.pl/JEHS · Nicolaus Copernicus University in Toruń



Cite as: JĘDRASEK, Tomasz, KORMAN, Adrian, ŚWIĄTKO, Ada, BARAN, Wojciech, BARTKIEWICZ, Patrycja, LACHOWSKA, Ewelina and CHMIELA, Mateusz. **Beyond Median Sternotomy: Minimally Invasive Approaches in Surgical Pulmonary Embolectomy - narrative review.** *Journal of Education, Health and Sport.* 2026;94:72844. <https://doi.org/10.12775/JEHS.2026.94.72844>

ARTICLE TIMELINE

Received: 30.05.2026 Revised: 10.07.2026

Accepted: 10.07.2026 Published: 17.07.2026

INDEXING & EVALUATION

MEiN points: 40 Unique ID: 201159

Disciplines: Physical culture sciences (Field of medical and health sciences); Health Sciences (Field of medical and health sciences).

The journal has been awarded 40 points in the parametric evaluation by the Polish Ministry of Higher Education and Science (Annex to the announcement of 05.01.2024, No. 32318), Unique Journal Identifier: 201159. Scientific disciplines: Physical culture sciences (Field of medical and health sciences); Health Sciences (Field of medical and health sciences).

Punkty Ministerialne z 2019 – aktualny rok 40 punktów. Załącznik do komunikatu Ministra Szkolnictwa Wyższego i Nauki z dnia 05.01.2024 Lp. 32318. Posiada Unikatowy Identyfikator Czasopisma: 201159. Przypisane dyscypliny naukowe: Nauki o kulturze fizycznej (Dziedzina nauk medycznych i nauk o zdrowiu); Nauki o zdrowiu (Dziedzina nauk medycznych i nauk o zdrowiu). © The Authors 2026.

OPEN ACCESS · CC BY-NC-SA 4.0 This article is published with open access under the License Open Journal Systems of Nicolaus Copernicus University in Toruń, Poland, and is distributed under the terms of the Creative Commons Attribution Non-commercial Share Alike License (<http://creativecommons.org/licenses/by-nc-sa/4.0/>), which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the work is properly cited. The authors declare no conflict of interest regarding the publication of this paper.

Beyond Median Sternotomy: Minimally Invasive Approaches in Surgical Pulmonary Embolectomy - narrative review

Tomasz Wiktor Jędrasek¹, ORCID <https://orcid.org/0009-0008-7340-3341>

E-mail tomyjedrasek@gmail.com

¹Provincial Specialist Hospital in Wrocław, 51-124 Wrocław

Adrian Korman¹, ORCID <https://orcid.org/0009-0009-4987-6250>

E-mail adriankorman@wp.pl

¹Provincial Specialist Hospital in Wrocław, 51-124 Wrocław

Ada Świątko¹, ORCID <https://orcid.org/0009-0005-2201-2031>

E-mail adaswiatko.as@gmail.com

¹Provincial Specialist Hospital in Wrocław, 51-124 Wrocław

Wojciech Przemysław Baran¹, ORCID <https://orcid.org/0009-0004-4786-6802>

E-mail wpbaran11@gmail.com

¹Provincial Specialist Hospital in Wrocław, 51-124 Wrocław

Patrycja Anna Bartkiewicz¹, ORCID <https://orcid.org/0009-0003-5365-2803>

E-mail patrycjabartkiewicz22@gmail.com

¹Provincial Specialist Hospital in Wrocław, 51-124 Wrocław

Ewelina Lachowska¹, ORCID <https://orcid.org/0009-0000-7577-3858>

E-mail e.lachowska99@gmail.com

¹Provincial Specialist Hospital in Wrocław, 51-124 Wrocław

Mateusz Chmiela², ORCID <https://orcid.org/0009-0008-2317-0594>

E-mail mchmielusz@gmail.com

²Health Care Center in Oława

Corresponding Author

Tomasz Wiktor Jędrasek, E-mail tomyjedrasek@gmail.com

Abstract

Background

Pulmonary embolism still remains one of the most life-threatening conditions in cardiovascular medicine and remains the third leading cause of death in the United States. Current guidelines recommend surgical treatment of pulmonary embolism in high-risk patients. This procedure is typically performed through a median sternotomy approach with initiation of a cardiopulmonary bypass machine. Patients referred to surgery are often critically ill and burdened with multiple comorbidities that might be a contraindication to conventional surgery.

Aim

This narrative review screened the available literature on minimally invasive surgical approaches in pulmonary embolectomy and evaluated its potential benefits and limitations.

Material and Methods

A targeted literature search was performed using PubMed and Google Scholar databases, supplemented by manual screening of references from relevant articles to identify further eligible studies. Abstracts and full texts were screened, resulting in 8 articles included: 1 research paper, 3 case series, and 4 case reports with a total of 22 patients.

Results

Reported use of minimally invasive approaches in the surgical treatment of pulmonary embolism was described. Across the 22 included patients 1 patient was managed with thoracotomy and 10 patients with a minithoracotomy approach with utilization of various surgical strategies such as: video-thoracoscopic-assistance, or balloon-catheter-assistance. Ministernotomy approach was utilized in 11 patients: 10 patients underwent upper-hemisternotomy with central cannulation, and one patient underwent a right J-ministernotomy.

Conclusions

Median sternotomy remains the gold standard for surgical pulmonary embolectomy, however reported cases of procedures performed using minimally invasive approaches suggest that these techniques may be safe and effective in selected patients with contraindications to conventional approach.

Key words: pulmonary embolectomy; minimally invasive; mini-sternotomy; thoracotomy; surgical treatment of pulmonary embolism

1. Introduction

Venous thromboembolism encompasses deep vein thrombosis and pulmonary embolism (PE). PE is defined as the partial or complete obstruction of the pulmonary artery by embolic material, most commonly originating from the deep veins of the lower extremities, and represents the most severe complication of deep vein thrombosis. Acute PE is one of the most common life-threatening conditions in cardiovascular medicine and remains the third leading cause of death in the United States, following myocardial infarction and malignancies.[1,2] Mortality among patients hospitalized due to PE remains high, ranging from 12% to 21% during hospitalization and an additional 24–39% within the first 12 months after diagnosis.[1] The most important risk factors for PE include age over 40 years, obesity, prior venous thromboembolism, trauma (particularly polytrauma and fractures of long bones and the pelvis), immobilization, heart failure (NYHA class III–IV), malignancy, inherited and acquired thrombophilia, pregnancy and the postpartum period, as well as the use of hormone replacement therapy or hormonal contraception. Iatrogenic factors also play a significant role,

including major surgical procedures, especially involving the lower extremities, pelvis, and abdominal cavity, as well as the presence of central venous catheters.

The diagnosis of pulmonary embolism is based on computed tomography pulmonary angiography (CTPA), complemented by echocardiography. Treatment primarily consists of anticoagulation and, in selected cases, thrombolytic therapy. In recent years, percutaneous catheter-based techniques for thrombus removal have gained increasing importance. In specific clinical scenarios, surgical pulmonary embolectomy is required.

According to the latest European Society of Cardiology guidelines:

- surgical embolectomy is recommended in patients with high-risk PE in whom thrombolysis is contraindicated or has failed.
- It should also be considered as an alternative to rescue thrombolytic therapy in patients with hemodynamic deterioration despite anticoagulation.
- The use of extracorporeal membrane oxygenation (ECMO) in combination with surgical or catheter-based treatment may be considered in patients with refractory hemodynamic collapse or cardiac arrest.
- Furthermore, thrombolysis or surgical embolectomy should be considered in pregnant patients with high-risk PE.[2]

The standard surgical approach for pulmonary embolectomy is median sternotomy, which provides excellent exposure of the operative field and allows for safe performance of the procedure under cardiopulmonary bypass. However, this approach is associated with significant surgical trauma, which is particularly relevant in patients with severe PE, who are often critically ill and burdened with multiple comorbidities that might be contraindication of conventional surgery.

Therefore, less invasive surgical approaches, such as mini-sternotomy and intercostal thoracotomy, have been increasingly explored. Although current evidence is limited and mainly consists of case reports and small case series, these approaches appear to be feasible and safe in selected patients.

This narrative review of case studies gathers and summarizes information on the reported use of minimally invasive approaches in the surgical management of pulmonary embolism,

evaluating the clinical course, surgical techniques, and observed outcomes in comparison with conventional median sternotomy.

2. Material and methods

This study was designed as a narrative review of the literature focusing on minimally invasive surgical approaches in pulmonary embolectomy.

A targeted literature search was performed in April and May 2026 using PubMed and Google Scholar databases, supplemented by manual screening of references from relevant articles to identify further eligible studies. The research query was constructed using a combination of keywords related to PE: “minimally invasive pulmonary embolectomy”, “minimally invasive management of pulmonary embolism”, “mini-sternotomy for pulmonary embolism”, “thoracotomy for pulmonary embolectomy”. Studies and case reports regarding minimally invasive catheter-based therapies were excluded, resulting in 8 articles relevant to the study topic: 1 research paper, 3 case series, and 4 case reports with a total of 22 patients.

3. Results

Table 1. Characteristics of included studies: surgical approach and cannulation technique

Name of the study	Number of patients	Surgical approach	Cannulation technique
Senning A.	1	Left thoracotomy	off-pump
Fallon JM	3	Minithoracotomy with thoracoscopic assistance	femoral cannulation
Lattouf OM	2	Minithoracotomy with thoracoscopic assistance	femoral cannulation
Ayers B	1	Left minithoracotomy	VA-ECMO femoral cannulation

Ashrafian and colleagues	1	J-ministernotomy	off-pump
Pasrija C	10	Upper-hemisternotomy	central cannulation
Kodani N	1	Minithoracotomy with balloon catheter	femoral cannulation
Takahashi M	3	Minithoracotomy	femoral cannulation

The paper entitled “Left anterior thoracotomy for pulmonary embolectomy with 29-year follow-up”[3] written by Åke Senning is one of the first known descriptions of a minimally invasive approach to PE. The author described a 59-year-old woman, 20 hours after intrathoracic thyroid nodule surgery through left anterior thoracotomy, who developed cardiogenic shock due to PE. The patient has been immediately taken to the operating theater, where the left thoracotomy was reopened. Thrombotic material has been successfully removed from the left pulmonary artery under direct vision and from the right pulmonary artery with the use of balloon catheters. The heart action has been successfully restored after six or seven manual contractions within 4 minutes of cardiac arrest. The patient has been discharged without signs of neurological dysfunction on the 21st day. The follow-up 29 years later confirmed the successful outcome and high quality of life. The author concluded that the off-pump technique and emergency thoracotomy in patients with circulatory arrest can prevent neurological complications and offer a clear view of the crucial area for embolectomy.

Fallon et al.[4] from the Department of Cardiothoracic Surgery, Emory University, Atlanta, presented a case series of 3 patients with massive PE who underwent minimally invasive surgical pulmonary embolectomy (MI-SPE) via left anterior thoracotomy with video-assisted thoracoscopy. The case series included: two females aged 53 and 69 and one male, aged 74. All 3 patients were presented with severe RV strain and depressed right heart function; the first patient was after unsuccessful CTD, and the second had been disqualified from CTD due to worsening of hemodynamic functions. Operating technique included double-lumen

endotracheal intubation, femoral cannulation, and 5 cm left anterior thoracotomy in the third intercostal space. A 5-mm thoroscopic camera has been used to guide clot extraction, allowing for excellent inspection of segmental and subsegmental arterial branches. Postoperatively, two patients were extubated on the day of surgery, and the third on the second day, all 3 were discharged within a week without complications.

Lattouf and colleagues from the Department of Cardiothoracic Surgery, Emory University, Atlanta, published a continuation of the study mentioned above. They've presented 2 patients with massive PE managed with the same technique as described above. The authors suggest that the anterior thoracotomy location should be tailored to individual patient anatomy using preoperative imaging and transthoracic echocardiography. When operating on their second patient, they moved from the third to the second intercostal space, which significantly improved surgical exposure and access to the pulmonary artery. Furthermore, to address challenges with incomplete cardiac decompression during peripheral cardiopulmonary bypass, particularly in patients with a higher body mass index, the authors transitioned to a dual venous cannulation strategy involving both the femoral and internal jugular veins.

Brian Ayers et al.[5] reported a case report in which PE was treated with a minimally invasive approach via a 6 cm mini-thoracotomy in the left second intercostal space. 53 years old women, 11 weeks after surgery for a brain aneurysm with massive PE, successfully underwent MI-SPE despite a complicated medical history, including: breast cancer treated with adjuvant therapy, haemodialysis-dependent end-stage renal disease, and reduced ejection fraction cardiomyopathy. She was placed on venoarterial extracorporeal membrane oxygenation (VA-ECMO) via femoral peripheral cannulation, which allow not to use heparin during the procedure. The authors point out that mini-thoracotomy isn't universal to sternotomy but should be more often considered in complex cases within the multidisciplinary team.

Kodani et al.[6] presented a case report of a 78-year-old patient with massive PE one month post-op from acute type A aortic dissection repair. The patient was qualified for right minithoracotomy in the fourth intercostal space, due to the challenges of redo cardiac surgery, such as dissection of scarred tissues. The thrombus in the right pulmonary artery has been extracted under direct vision, and in the left pulmonary artery and main pulmonary arteries by balloon catheters. During surgery, a massive thrombus from the right atrium migrated to the main pulmonary artery, causing sudden hypotension and right ventricular dysfunction. Therefore, rapid initiation of cardiopulmonary bypass from the right atrium through the right femoral vein to the right femoral artery has been performed. Due to poor blood gas analysis results VA-ECMO was utilized. The patient has been transferred to another hospital for

rehabilitation on day 39th post surgery and discharged on day 69th. The authors concluded that the right anterolateral minithoracotomy can be a viable option for embolectomy to avoid the risks of redo sternotomy.

Pasrija and colleagues [7] conducted a retrospective study of 30 patients with massive PE who underwent SPE. They compared 10 patients managed with a minimally invasive approach to 20 patients treated with conventional sternotomy. The minimally invasive approach included a 5- to 7-cm skin incision with upper hemisternotomy to the third intercostal space. 100% in-hospital and 90-day survival, comparable to conventional full sternotomy. Cardiopulmonary bypass times were significantly longer in the minimally invasive group (94 vs. 58 minutes, $P=0.04$), however this approach significantly reduced the median hospital length of stay by 4.5 days ($P=0.005$) and showed a trend toward decreased blood product utilization. Postoperative right ventricular function was effectively restored to none-to-mild dysfunction at discharge. Postoperatively, both groups achieved 100% in-hospital and 90-day survival, and right ventricular function at discharge was mostly effectively restored, with only a few cases of none to mild dysfunction.

Ashrafian and colleagues [8] described a case report of 35-years old women with massive PE after unsuccessful thrombolytic therapy managed with MI-SPE off-pump via minimally invasive right J-ministernotomy. The authors concluded that the off-pump technique allows to reduce oxidative stress, inflammatory response, and potential neurological complications associated with CPB. They point out that the minimally invasive approach reduces postoperative pain and chest trauma, which promotes earlier mobilization and discharge of the patient when compared to conventional sternotomy and minithoracotomy. They state that this technique can be established in a selected group of patients.

Takahashi M et al. [9] presented 3 patients with chronic pulmonary embolism, with severe right heart failure and respiratory distress, who were managed with unilateral pulmonary embolectomy through right thoracotomy. The surgical technique included the incorporation of normothermic partial cardiopulmonary bypass with femoral cannulation. The authors point out that distal counter-incision enabled complete thrombus removal from distal pulmonary artery branches. The follow-up 17 years later confirmed that all 3 patients remained free from recurrence of PE.

4. Discussion

Currently, in the field of cardiac surgery, minimally invasive techniques are increasingly adopted as a promising alternative to the median sternotomy approach, especially in coronary artery and valve surgeries.[10–13]

ESC guidelines recommend SPE in high-risk patients, or in case of unsuccessful thrombolysis.[2] Patients referred to surgery are often in a state of cardiogenic shock, hemodynamically unstable, or after recent surgery.[14] Surgical management of PE is typically performed through a median sternotomy incision to get good access to both pulmonary arteries, and with the initiation of cardiopulmonary bypass.[1] Minimally invasive pulmonary embolectomy (MI-SPE) through thoracotomy or ministernotomy may represent a beneficial alternative to sternotomy, especially in critically ill patients, though its current evidence is limited to retrospective, single-center case reports and small series. [3–9,15,16]

MI-SPE through minithoracotomy offers shorter length of in-hospital and in-ICU stay, earlier extubation, and faster mobilization.[3–6,15] Additionally, this approach seems to be more beneficial in case of potential reoperation rather than redo sternotomy.[6] Several studies in the field of valve surgery indicate that minithoracotomy, when compared to a median sternotomy approach, allows for fewer blood transfusions, less pain, shorter ventilation time, shorter ICU and hospital stays, superior preservation of lung function, and decreased risk of wound infections.[17–20] Moreover, this incision is a safer option for redo surgery when compared to median sternotomy. A clear limitation of the minithoracotomy approach is access to the distal branches of the pulmonary arteries. This issue could be overcome by the implementation of video-assisted thoracoscopy, which enables precise assessment of the operative field as presented by Fallon et al.[4] and Lattouf and colleagues.[15] The important factor is that the location of the minithoracotomy incision should be based on precise computed tomography pulmonary angiography, and have to be individually planned for each patient according to his anatomy.[15]

MI-SPE through ministernotomy and going off-pump allows for avoiding potential complications associated with cardiopulmonary bypass while giving a chance to extend the incision to full sternotomy and going on pump when needed.[7,8] Limitations of the surgical field caused by ministernotomy can be alleviated by the use of peripheral cannulation through the femoral vessels. Several studies in the field of valve surgery indicate that ministernotomy

allows for: quick patient mobilisation and earlier extubation when compared to the minithoracotomy approach, due to preservation of pleural integrity. [21–24]

The successful application of MI-SPE relies on proper patient selection and should be carried out by a multidisciplinary team. Performing embolectomy through a minimally invasive approach requires experience with peripheral cannulation, working in a restricted operative field, and, in some cases, the use of thoracoscopic guidance. Surgeons familiar with minimally invasive cardiac procedures such as hemisternotomy or valve surgery via minithoracotomy may find the transition relatively straightforward.

5. Conclusions

Median sternotomy remains the gold standard for surgical pulmonary embolectomy. Nevertheless, the reported cases of procedures performed using minimally invasive approaches suggest that these techniques may be safe and effective in selected patients. Although technically demanding, minimally invasive approaches may be beneficial in specific clinical scenarios, particularly in patients with contraindications to the conventional approach.

Currently available evidence is limited and is based primarily on case reports and small case series. Careful patient selection and adequate surgical expertise are essential for the successful application of these techniques. Further studies involving larger patient populations are required to better define the role of minimally invasive approaches in the surgical treatment of pulmonary embolism.

6. Disclosure

Supplementary Materials

Not applicable.

Author Contributions

Conceptualization: Tomasz Jędrasek, Adrian Korman, Ada Świątko, Wojciech Baran, Patrycja Bartkiewicz, Ewelina Lachowska, Mateusz Chmiela;

Methodology: Tomasz Jędrasek, Adrian Korman, Ada Świątko;

Data acquisition: Tomasz Jędrasek, Adrian Korman, Ada Świątko;

Data analysis and interpretation: Wojciech Baran, Patrycja Bartkiweicz, Ewelina Lachowska, Mateusz Chmiela;

Drafting of the manuscript: Tomasz Jędrasek, Adrian Korman, Ada Świątko;

Critical revision of the manuscript: Tomasz Jędrasek, Adrian Korman, Ada Świątko, Wojciech Baran, Patrycja Bartkiewicz, Ewelina Lachowska, Mateusz Chmiela;

Final approval: Tomasz Jędrasek, Adrian Korman, Ada Świątko, Wojciech Baran, Patrycja Bartkiewicz, Ewelina Lachowska, Mateusz Chmiela;

Funding Statement

The authors declare that they did not receive any specific grant, financial support, or other assistance from any funding agency, commercial entity, or non-profit organization for the preparation of this manuscript.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

Not applicable.

Acknowledgements

Not applicable.

Conflicts of Interest

The authors declare that no conflicts of interest exist.

Originality

The submission has not been previously published, and it is not under consideration by any other journal.

Use of Artificial Intelligence

During the preparation of this work, the authors used OpenAI GPT-5.4 Thinking and Gemini 1.5 Pro architecture for the purpose of editorial assistance, including language editing, improving clarity and conciseness, and minor stylistic revisions. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the substantive content of the publication.

References

- [1] Cohn LH, Adams DH. Editors. Card. Surg. Adult. 5th ed., New York, NY: McGraw-Hill Education; 2017.
- [2] Konstantinides SV, Meyer G, Becattini C, et al. 2019 ESC Guidelines for the diagnosis and management of acute pulmonary embolism developed in collaboration with the European Respiratory Society (ERS): The Task Force for the diagnosis and management of acute pulmonary embolism of the European Society of Cardiology (ESC). *Eur Respir J* 2019;54:1901647. <https://doi.org/10.1183/13993003.01647-2019>.
- [3] Senning A. Left anterior thoracotomy for pulmonary embolectomy with 29-year follow-up. *Ann Thorac Surg* 1998;66:1420–1. [https://doi.org/10.1016/s0003-4975\(98\)00791-7](https://doi.org/10.1016/s0003-4975(98)00791-7).
- [4] Fallon JM, Greenberg JW, Gupta L, et al. Initial Experience with Non-Sternotomy Minimally Invasive Pulmonary Embolectomy with Thoracoscopic Assistance. *Innovations* 2020;15:180–4. <https://doi.org/10.1177/1556984520909803>.
- [5] Ayers B, Wood K, Bjelic M, et al. Minimally invasive off-pump surgical pulmonary embolectomy for improved patient-centred care. *Eur J Cardio-Thorac Surg Off J Eur Assoc Cardio-Thorac Surg* 2021;59:1126–7. <https://doi.org/10.1093/ejcts/ezaa380>.
- [6] Kodani N, Ohashi T, Iida H, et al. Emergency Pulmonary Embolectomy Using Minimally Invasive Cardiac Surgery. *Ann Thorac Surg* 2016;101:1569–71. <https://doi.org/10.1016/j.athoracsur.2015.04.152>.

- [7] Pasrija C, Shah A, Sultanik E, et al. Minimally Invasive Surgical Pulmonary Embolectomy: A Potential Alternative to Conventional Sternotomy. *Innovations* 2017;12:406–10. <https://doi.org/10.1097/IMI.0000000000000439>.
- [8] Ashrafian H, Kumar P, Athanasiou T, et al. Minimally invasive off-pump pulmonary embolectomy. *Cardiovasc Surg* 2003;11:471–3. <https://doi.org/10.1177/096721090301100609>.
- [9] Takahashi M, Tanaka N, Sawa S, et al. The results of three cases of unilateral pulmonary embolectomy through right thoracotomy approach for chronic pulmonary embolism. *J Cardiovasc Surg (Torino)* 1995;36:195–8. <https://doi.org/https://pubmed.ncbi.nlm.nih.gov/7790343/>.
- [10] Cerny S, Oosterlinck W, Onan B, et al. Robotic Cardiac Surgery in Europe: Status 2020. *Front Cardiovasc Med* 2022;8:827515. <https://doi.org/10.3389/fcvm.2021.827515>.
- [11] Maruszewski B, Deja M, Tobota Z, et al. Analysis of all cardiac surgical procedures in Poland, 2024: data from the National Cardiac Surgery Registry (KROK). *Kardiochirurgia Torakochirurgia Pol J Thorac Cardiovasc Surg Suppl* 2026;2026:1–13. <https://doi.org/10.5114/.2026.160561>.
- [12] Langer NB, Argenziano M. Minimally Invasive Cardiovascular Surgery: Incisions and Approaches. *Methodist DeBakey Cardiovasc J* 2016;12:4–9. <https://doi.org/10.14797/mdcj-12-1-4>.
- [13] Holubec T, Dahle G, Bonaros N. Editorial: Minimally invasive cardiac surgery: state of the art and current challenges. *Front Cardiovasc Med* 2023;10:1286868. <https://doi.org/10.3389/fcvm.2023.1286868>.
- [14] Goldberg JB, Giri J, Kobayashi T, et al. Surgical Management and Mechanical Circulatory Support in High-Risk Pulmonary Embolisms: Historical Context, Current Status, and Future Directions: A Scientific Statement From the American Heart Association. *Circulation* 2023;147:e628–47. <https://doi.org/10.1161/CIR.0000000000001117>.
- [15] Lattouf OM, Laan D, Zapata D, et al. Lessons learned on a new procedure: Nonsternotomy minimally invasive pulmonary embolectomy. *J Card Surg* 2021;36:1258–63. <https://doi.org/10.1111/jocs.15357>.
- [16] 838 Pulmonary Embolectomy: Techniques and Outcomes from The Literature. *ResearchGate* 2026. <https://doi.org/10.1093/bjs/znab259.249>.

- [17] Lange R, Voss B, Kehl V, et al. Right Minithoracotomy Versus Full Sternotomy for Mitral Valve Repair: A Propensity Matched Comparison. *Ann Thorac Surg* 2017;103:573–9. <https://doi.org/10.1016/j.athoracsur.2016.06.055>.
- [18] Modi P, Hassan A, Chitwood WR. Minimally invasive mitral valve surgery: a systematic review and meta-analysis. *Eur J Cardio-Thorac Surg Off J Eur Assoc Cardio-Thorac Surg* 2008;34:943–52. <https://doi.org/10.1016/j.ejcts.2008.07.057>.
- [19] Walther T, Falk V, Metz S, et al. Pain and quality of life after minimally invasive versus conventional cardiac surgery. *Ann Thorac Surg* 1999;67:1643–7. [https://doi.org/10.1016/s0003-4975\(99\)00284-2](https://doi.org/10.1016/s0003-4975(99)00284-2).
- [20] Hlavicka J, Gettwart L, Landgraf J, et al. Minimally Invasive and Full Sternotomy Aortic Valve Replacements Lead to Comparable Long-Term Outcomes in Elderly Higher-Risk Patients: A Propensity-Matched Comparison. *J Cardiovasc Dev Dis* 2024;11:112. <https://doi.org/10.3390/jcdd11040112>.
- [21] Bonacchi M, Dokollari A, Parise O, et al. Ministernotomy compared with right anterior minithoracotomy for aortic valve surgery. *J Thorac Cardiovasc Surg* 2023;165:1022-1032.e2. <https://doi.org/10.1016/j.jtcvs.2021.03.125>.
- [22] Bonacchi M, Prifti E, Bugetti M, et al. Deep sternal infections after in situ bilateral internal thoracic artery grafting for left ventricular myocardial revascularization: predictors and influence on 20-year outcomes. *J Thorac Dis* 2018;10:5208–21. <https://doi.org/10.21037/jtd.2018.09.30>.
- [23] Stoliński J, Musiał R, Plicner D, et al. Respiratory functional status after conventional and minimally invasive aortic valve replacement surgery - a propensity score analysis. *Kardiochirurgia Torakochirurgia Pol Pol J Cardio-Thorac Surg* 2017;14:5–9. <https://doi.org/10.5114/kitp.2017.66922>.
- [24] Trehan N, Malhotra R, Mishra Y, et al. Comparison of ministernotomy with minithoracotomy regarding postoperative pain and internal mammary artery characteristics. *Heart Surg Forum* 2000;3:300–6. <https://doi.org/https://pubmed.ncbi.nlm.nih.gov/11178291/>.