

## **Überblick über verschiedene temporäre mechanische Kreislaufunterstützungssysteme**

*P. Lanmüller, S. Ott, C. Starck, E. Potapov, D. Lewin*

1. McDonagh TA et al. ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure. *Eur Heart J* 2021; 42: 3599–726
2. van Diepen S et al. Contemporary Management of Cardiogenic Shock: A Scientific Statement From the American Heart Association. *Circulation* 2017; 136: e232–e68
3. Gonzalez LS & Chaney MA. Intraaortic Balloon Pump Counterpulsation, Part I: History, Technical Aspects, Physiologic Effects, Contraindications, Medical Applications/Outcomes. *Anesth Analg* 2020; 131: 776–91
4. Thiele H et al. Intraaortic balloon support for myocardial infarction with cardiogenic shock. *N Engl J Med* 2012; 367: 1287–96
5. Thiele H et al. Intra-aortic balloon counterpulsation in acute myocardial infarction complicated by cardiogenic shock (IABP-SHOCK II): final 12 month results of a randomised, open-label trial. *Lancet* 2013; 382: 1638–45
6. Thiele H et al. Intraaortic Balloon Pump in Cardiogenic Shock Complicating Acute Myocardial Infarction: Long-Term 6-Year Outcome of the Randomized IABP-SHOCK II Trial. *Circulation* 2018
7. Tschope C et al. Mechanical Unloading by Fulminant Myocarditis: LV-IMPELLA, ECMELLA, BI-PELLA, and PROPELLA Concepts. *J Cardiovasc Transl Res* 2019; 12: 116–23
8. Nersesian G et al. Prediction of survival of patients in cardiogenic shock treated by surgically implanted Impella 5+ short-term left ventricular assist device. *Interact Cardiovasc Thorac Surg* 2020; 31: 475–82
9. Nersesian G et al. Temporary mechanical circulatory support for refractory heart failure: the German Heart Center Berlin experience. *Ann Cardiothorac Surg* 2019; 8: 76–83
10. Annamalai SK et al. The Impella Microaxial Flow Catheter Is Safe and Effective for Treatment of Myocarditis Complicated by Cardiogenic Shock: An Analysis From the Global cVAD Registry. *J Card Fail* 2018; 24: 706–10
11. Lorusso R et al. 2020 EACTS/ELSO/STS/AATS Expert Consensus on Post-Cardiotomy Extracorporeal Life Support in Adult Patients. *Ann Thorac Surg* 2021; 111: 327–69
12. Cevasco M et al. Left ventricular distension and venting strategies for patients on venoarterial extracorporeal membrane oxygenation. *J Thorac Dis* 2019; 11: 1676–83
13. Dangas GD et al. Impact of hemodynamic support with Impella 2.5 versus intra-aortic balloon pump on prognostically important clinical outcomes in patients undergoing high-risk percutaneous coronary intervention (from the PROTECT II randomized trial). *Am J Cardiol* 2014; 113: 222–8
14. Katahira S et al. Coronary artery bypass grafting under sole Impella 5.0 support for patients with severely depressed left ventricular function. *J Artif Organs* 2021

15. Bertoldi LF et al. Weaning from Impella and mobilization of Impella patients. *Eur Heart J Suppl* 2021; 23: A41–A5
16. Esposito ML et al. Maximum level of mobility with axillary deployment of the Impella 5.0 is associated with improved survival. *Int J Artif Organs* 2018; 41: 236–9
17. Lauten A et al. Percutaneous left-ventricular support with the Impella-2.5-assist device in acute cardiogenic shock: results of the Impella-EUROSHOCK-registry. *Circ Heart Fail* 2013; 6: 23–30
18. Karami M et al. Mechanical circulatory support in cardiogenic shock from acute myocardial infarction: Impella CP/5.0 versus ECMO. *Eur Heart J Acute Cardiovasc Care* 2020; 9: 164–72
19. Syntila S et al. Comparison of Mechanical Support with Impella or Extracorporeal Life Support in Post-Cardiac Arrest Cardiogenic Shock: A Propensity Scoring Matching Analysis. *J Clin Med* 2021; 10
20. Cheng JM et al. Percutaneous left ventricular assist devices vs. intra-aortic balloon pump counterpulsation for treatment of cardiogenic shock: a meta-analysis of controlled trials. *Eur Heart J* 2009; 30: 2102–8
21. Anderson MB et al. Benefits of a novel percutaneous ventricular assist device for right heart failure: The prospective RECOVER RIGHT study of the Impella RP device. *J Heart Lung Transplant* 2015; 34: 1549–60
22. Pieri M & Pappalardo F. Impella RP in the Treatment of Right Ventricular Failure: What We Know and Where We Go. *J Cardiothorac Vasc Anesth* 2018; 32: 2339–43
23. Belohlavek J et al. Left ventricular unloading and the role of ECpella. *Eur Heart J Suppl* 2021; 23: A27–A34
24. Donker DW et al. Right-Left Ventricular Interaction in Left-Sided Heart Failure With and Without Venoarterial Extracorporeal Membrane Oxygenation Support-A Simulation Study. *ASAIO J* 2021; 67: 297–305
25. Cheng R et al. Lack of Survival Benefit Found With Use of Intraaortic Balloon Pump in Extracorporeal Membrane Oxygenation: A Pooled Experience of 1517 Patients. *J Invasive Cardiol* 2015; 27: 453–8
26. Ott S et al. Management of increased systemic flow requirements in patients with left ventricular assist devices. *Ann Cardiothorac Surg* 2021; 10: 399–401
27. Le Gall A et al. Veno-arterial-ECMO in the intensive care unit: From technical aspects to clinical practice. *Anaesth Crit Care Pain Med* 2018; 37: 259–68
28. Millar JE et al. The inflammatory response to extracorporeal membrane oxygenation (ECMO): a review of the pathophysiology. *Crit Care* 2016; 20: 387
29. Lo Coco V et al. Clinical complications during veno-arterial extracorporeal membrane oxygenation in post-cardiotomy and non post-cardiotomy shock: still the achille's heel. *J Thorac Dis* 2018; 10: 6993–7004
30. Montagner M et al. Single arterial access ECMELLA: A new concept and step-by-step procedure. *Multimed Man Cardiothorac Surg* 2021; 2021: 10

31. Philipp A et al. First experience with the ultra compact mobile extracorporeal membrane oxygenation system Cardiohelp in interhospital transport. *Interact Cardiovasc Thorac Surg* 2011; 12: 978–81
32. Mehlhorn U et al. LIFE BRIDGE: a portable, modular, rapidly available "plug-and-play" mechanical circulatory support system. *Ann Thorac Surg* 2005; 80: 1887–92
33. John R et al. Outcomes of a multicenter trial of the Levitronix CentriMag ventricular assist system for short-term circulatory support. *J Thorac Cardiovasc Surg* 2011; 141: 932–9
34. Bhama JK et al. Clinical experience using the Levitronix CentriMag system for temporary right ventricular mechanical circulatory support. *J Heart Lung Transplant* 2009; 28: 971–6
35. John R et al. Experience with the Levitronix CentriMag circulatory support system as a bridge to decision in patients with refractory acute cardiogenic shock and multisystem organ failure. *J Thorac Cardiovasc Surg* 2007; 134: 351–8

## **Die Vergangenheit und die Zukunft der dauerhaften mechanischen Kreislaufunterstützung**

*D. Lewin, F. Kaßmann, V. Falk, E. Potapov*

1. McDonagh TA et al. 2021 ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure. *Eur Heart J* 2021; 42: 3599–726
2. DeBakey ME. Left ventricular bypass pump for cardiac assistance. Clinical experience. *Am J Cardiol* 1971; 27: 3–11
3. Cooley DA et al. Orthotopic cardiac prosthesis for two-staged cardiac replacement. *Am J Cardiol* 1969; 24: 723–30
4. Copeland JG et al. The total artificial heart as a bridge to transplantation. A report of two cases. *JAMA* 1986; 256: 2991–5
5. Portner PM, et al. Implantable electrical left ventricular assist system: bridge to transplantation and the future. *Ann Thorac Surg* 1989; 47: 142–50
6. Christoph Birner NF et al. Herzinsuffizienz. In: e.V. DH, ed. Deutscher Herzbericht 2020. Frankfurt am Main: Georg Thieme Verlag KG; 2021: 105–20
7. Molina EJ et al. The Society of Thoracic Surgeons Intermacs 2020 Annual Report. *Ann Thorac Surg* 2021; 111: 778–92
8. Michelis KC et al. Dynamic Forecasts of Survival for Patients Living With Destination Left Ventricular Assist Devices: Insights From INTERMACS. *J Am Heart Assoc* 2020; 9:e016203
9. Frazier OH. First use of an untethered, vented electric left ventricular assist device for long-term support. *Circulation* 1994; 89: 2908–14
10. Rose EA et al. Long-term use of a left ventricular assist device for end-stage heart failure. *N Engl J Med* 2001; 345: 1435–43
11. Frazier OH. Evolutionary perspective of mechanical circulatory support as a bridge to heart transplantation. *J Heart Lung Transplant* 2017; 36: 1283–5

12. Potapov EV, et al. Pulsatile flow in patients with a novel nonpulsatile implantable ventricular assist device. *Circulation* 2000; 102: 183–7
13. Wilhelm MJ et al. Clinical experience with nine patients supported by the continuous flow DeBakey VAD. *J Heart Lung Transplant* 2001; 20: 201
14. Muslem R et al. Acquired coagulopathy in patients with left ventricular assist devices. *J Thromb Haemost* 2018; 16: 429–40
15. Nascimbene A et al. Acquired von Willebrand syndrome associated with left ventricular assist device. *Blood* 2016; 127: 3133–41
16. Hetzer R et al. First experiences with a novel magnetically suspended axial flow left ventricular assist device. *Eur J Cardiothorac Surg* 2004; 25: 964–70
17. Morshuis M et al. DuraHeart magnetically levitated centrifugal left ventricular assist system for advanced heart failure patients. *Expert Rev Med Devices* 2010; 7: 173–83
18. Larose JA et al. Design concepts and principle of operation of the HeartWare ventricular assist system. *ASAIO J* 2010; 56: 285–9
19. Ozalp F et al. Four-year outcomes with third-generation centrifugal left ventricular assist devices in an era of restricted transplantation. *Eur J Cardiothorac Surg* 2014; 46: e35–40
20. Uriel N et al. Hemocompatibility-Related Outcomes in the MOMENTUM 3 Trial at 6 Months: A Randomized Controlled Study of a Fully Magnetically Levitated Pump in Advanced Heart Failure. *Circulation* 2017; 135: 2003–12
21. Bourque K et al. Design Rationale and Preclinical Evaluation of the HeartMate 3 Left Ventricular Assist System for Hemocompatibility. *ASAIO J* 2016; 62: 375–83
22. Potapov EV et al. Propensity score-based analysis of long-term follow-up in patients supported with durable centrifugal left ventricular assist devices: the EUROMACS analysis. *Eur J Cardiothorac Surg* 2021
23. Cho SM et al. Cerebrovascular Events in Patients With Centrifugal-Flow Left Ventricular Assist Devices: Propensity Score-Matched Analysis From the Intermacs Registry. *Circulation* 2021; 144: 763–72
24. Rose EA et al. Artificial circulatory support with textured interior surfaces. A counterintuitive approach to minimizing thromboembolism. *Circulation* 1994; 90: 87–91
25. Ferrari A et al. A Novel Hybrid Membrane VAD as First Step Toward Hemocompatible Blood Propulsion. *Ann Biomed Eng* 2021; 49: 716–31
26. Wu X et al. A free-form patterning method enabling endothelialization under dynamic flow. *Biomaterials* 2021; 273: 120816
27. Cohrs NH et al. A Soft Total Artificial Heart-First Concept Evaluation on a Hybrid Mock Circulation. *Artif Organs* 2017; 41: 948–58
28. Latremouille C et al. A bioprosthetic total artificial heart for end-stage heart failure: Results from a pilot study. *J Heart Lung Transplant* 2018; 37: 33–7
29. Martinolli M et al. Extended finite element method for fluid-structure interaction in wave membrane blood pump. *Int J Numer Method Biomed Eng* 2021; 37: e3467
30. Martinolli M et al. Computational Fluid-Structure Interaction Study of a New Wave Membrane Blood Pump. *Cardiovasc Eng Technol* 2021
31. Argiriou M et al. Right heart failure post left ventricular assist device implantation. *J Thorac Dis* 2014; 6 Suppl 1: 52–9

32. Torregrossa G et al. SynCardia: the total artificial heart. *Ann Cardiothorac Surg* 2014; 3: 612–20
33. Potapov EV et al. Biventricular support using 2 HeartMate 3 pumps. *J Heart Lung Transplant* 2016; 35: 1268–70
34. Eulert-Grehn JJ et al. Two implantable continuous-flow ventricular assist devices in a biventricular configuration: technique and results. *Interact Cardiovasc Thorac Surg* 2018; 27: 938–42
35. Loforte A et al. Temporary right ventricular mechanical support in high-risk left ventricular assist device recipients versus permanent biventricular or total artificial heart support. *Artif Organs* 2013; 37: 523–30
36. Dandel M et al. Left ventricular vs. biventricular mechanical support: Decision making and strategies for avoidance of right heart failure after left ventricular assist device implantation. *Int J Cardiol* 2015; 198: 241–50
37. VanderPluym CJ et al. Outcomes following implantation of mechanical circulatory support in adults with congenital heart disease: An analysis of the Interagency Registry for Mechanically Assisted Circulatory Support (INTERMACS). *J Heart Lung Transplant* 2018; 37: 89–99
38. Vierecke et al. Results of primary biventricular support: an analysis of data from the EUROMACS registry. *Eur J Cardiothorac Surg* 2019
39. Netuka I et al. First Clinical Experience With the Pressure Sensor-Based Autoregulation of Blood Flow in an Artificial Heart. *ASAIO J* 2021; 67: 1100–8
40. Abraham WT et al. Patient monitoring across the spectrum of heart failure disease management 10 years after the CHAMPION trial. *ESC Heart Fail* 2021; 8: 3472–82
41. Dual SA et al. Continuous Heart Volume Monitoring by Fully Implantable Soft Strain Sensor. *Adv Healthc Mater* 2020; 9:e2000855
42. Pae WE et al. Does total implantability reduce infection with the use of a left ventricular assist device? The LionHeart experience in Europe. *J Heart Lung Transplant* 2007; 26: 219–29
43. Dowling RD et al. Initial experience with the AbioCor implantable replacement heart system. *J Thorac Cardiovasc Surg* 2004; 127: 131–41
44. Pya Y et al. First human use of a wireless coplanar energy transfer coupled with a continuous-flow left ventricular assist device. *J Heart Lung Transplant* 2019; 38: 339–43
45. Escher A et al. A Cavopulmonary Assist Device for Long-Term Therapy of Fontan Patients. *Semin Thorac Cardiovasc Surg* 2021
46. Eid A et al. 5G as a wireless power grid. *Sci Rep* 2021; 11: 636
47. Kim YJ et al. NiCo<sub>2</sub>S<sub>4</sub> Bi-metal Sulfide Coating on LiNi<sub>0.6</sub>Co<sub>0.2</sub>Mn<sub>0.2</sub>O<sub>2</sub> Cathode for High-Performance All-Solid-State Lithium Batteries. *ACS Omega* 2021; 6: 6824–35
48. Tan DHSet al. Carbon-free high-loading silicon anodes enabled by sulfide solid electrolytes. *Science* 2021; 373: 1494–9

## **Indikationen zur Behandlung des kardiogenen Schocks mittels temporärer mechanischer Kreislaufunterstützung**

*G. Nersesian, P. Lanmüller, F. Spillmann, C. Starck, F. Schönrath, E. Potapov, S. Ott*

1. Chioncel O et al. Epidemiology, pathophysiology and contemporary management of cardiogenic shock – a position statement from the Heart Failure Association of the European Society of Cardiology. *Eur J Heart Fail* 2020; 22(8): 1315–41
2. Baran DA et al. SCAI clinical expert consensus statement on the classification of cardiogenic shock: This document was endorsed by the American College of Cardiology (ACC), the American Heart Association (AHA), the Society of Critical Care Medicine (SCCM), and the Society of Thoracic Surgeons (STS) in April 2019. *Catheter Cardiovasc Interv* 2019; 94(1): 29–37
3. Molina EJ et al. The Society of Thoracic Surgeons Intermacs 2020 Annual Report. *Ann Thorac Surg* 2021; 111(3): 778–92
4. McDonagh TA et al. 2021 ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure: Developed by the Task Force for the diagnosis and treatment of acute and chronic heart failure of the European Society of Cardiology (ESC) With the special contribution of the Heart Failure Association (HFA) of the ESC. *European Heart Journal* 2021; 42(36): 3599–726
5. Tehrani BN et al. Standardized Team-Based Care for Cardiogenic Shock. *J Am Coll Cardiol* 2019; 73(13): 1659–69
6. Basir MB et al. Improved Outcomes Associated with the use of Shock Protocols: Updates from the National Cardiogenic Shock Initiative. *Catheter Cardiovasc Interv* 2019; 93(7): 1173–83
7. Tehrani BN et al. A Standardized and Comprehensive Approach to the Management of Cardiogenic Shock. *JACC Heart Fail* 2020; 8(11): 879–91
8. Squiers JJ et al. Contemporary extracorporeal membrane oxygenation therapy in adults: Fundamental principles and systematic review of the evidence. *J Thorac Cardiovasc Surg* 2016; 152(1): 20–32
9. Lemor A et al. Impella Versus Extracorporeal Membrane Oxygenation for Acute Myocardial Infarction Cardiogenic Shock. *Cardiovasc Revasc Med* 2020; 21(12): 1465–71
10. Pozzi M et al. Extracorporeal life support in the multidisciplinary management of cardiogenic shock complicating acute myocardial infarction. *Catheter Cardiovasc Interv* 2020; 95(3): e71–e77
11. Muller G et al. The ENCOURAGE mortality risk score and analysis of long-term outcomes after VA-ECMO for acute myocardial infarction with cardiogenic shock. *Intensive Care Med* 2016; 42(3): 370–78
12. Weber DM et al. Principles of Impella Cardiac Support. 2009
13. Wernly B et al. Impella in Cardiogenic Shock: Is it Time to Hit the Break? *Shock* 2021; 55(5): 693–94
14. Seyfarth M et al. A randomized clinical trial to evaluate the safety and efficacy of a percutaneous left ventricular assist device versus intra-aortic balloon pumping for treatment of cardiogenic shock caused by myocardial infarction. *J Am Coll Cardiol* 2008; 52(19): 1584–8

15. Manzo-Silberman S et al. Percutaneous left ventricular assistance in post cardiac arrest shock: comparison of intra aortic blood pump and IMPELLA Recover LP2.5. *Resuscitation* 2013; 84(5): 609–15
16. Ouweneel DM et al. Percutaneous Mechanical Circulatory Support Versus Intra-Aortic Balloon Pump in Cardiogenic Shock After Acute Myocardial Infarction. *J Am Coll Cardiol* 2017; 69(3): 278–87
17. Pieri M et al. The role of different mechanical circulatory support devices and their timing of implantation on myocardial damage and mid-term recovery in acute myocardial infarction related cardiogenic shock. *J Interv Cardiol* 2018; 31(6): 717–24
18. Batsides G et al. Outcomes of Impella 5.0 in Cardiogenic Shock: A Systematic Review and Meta-analysis. *Innovations (Phila)* 2018; 13(4): 254–60
19. Nersesian G et al. Prediction of survival of patients in cardiogenic shock treated by surgically implanted Impella 5+ short-term left ventricular assist device. *Interact Cardiovasc Thorac Surg* 2020; 31(4): 475–82
20. Russo JJ et al. Left Ventricular Unloading During Extracorporeal Membrane Oxygenation in Patients With Cardiogenic Shock. *J Am Coll Cardiol* 2019; 73(6): 654–62
21. Al-Fares AA et al. Optimal Strategy and Timing of Left Ventricular Venting During Veno-Arterial Extracorporeal Life Support for Adults in Cardiogenic Shock: A Systematic Review and Meta-Analysis. *Circ Heart Fail* 2019; 12(11): e006486
22. Li Y et al. Effect of an intra-aortic balloon pump with venoarterial extracorporeal membrane oxygenation on mortality of patients with cardiogenic shock: a systematic review and meta-analysis†. *Eur J Cardiothorac Surg* 2019; 55(3): 395–404
23. Schrage B et al. Left Ventricular Unloading Is Associated With Lower Mortality in Patients With Cardiogenic Shock Treated With Venoarterial Extracorporeal Membrane Oxygenation: Results From an International, Multicenter Cohort Study. *Circulation* 2020; 142(22): 2095–106
24. Ott S et al. Management of increased systemic flow requirements in patients with left ventricular assist devices. *Ann Cardiothorac Surg* 2021; 10(3): 399–401
25. Eulert-Grehn JJ et al. ECMELLA 2.0 – Single arterial access technique for a staged approach in cardiogenic shock. *Ann Thorac Surg* 2020
26. Gaies MG et al. Vasoactive-inotropic score as a predictor of morbidity and mortality in infants after cardiopulmonary bypass. *Pediatr Crit Care Med* 2010; 11(2): 234–8
27. Abrams D et al. Extracorporeal membrane oxygenation in cardiopulmonary disease in adults. *J Am Coll Cardiol* 2014; 63(25 Pt A): 2769–78
28. Jayaraman AL et al. Cannulation strategies in adult veno-arterial and veno-venous extracorporeal membrane oxygenation: Techniques, limitations, and special considerations. *Ann Card Anaesth* 2017;20(Supplement):S11–s18

## Dauerhafte ventrikuläre Unterstützungstherapie – ventricular assist device therapy

I.A. Jäst, J. Mölzer, C. Hörmanninger, F. Schönrath

1. Braunwald E et al. The war against heart failure: the Lancet lecture. *Lancet* 2015; 385: 812–24

2. Mamas MA et al. Do patients have worse outcomes in heart failure than in cancer? A primary care-based cohort study with 10-year follow-up in Scotland. *Eur J Heart Fail* 2017; 19(9): 1095–104
3. De By TMMH et al. The European registry for patients with mechanical circulatory support (EUROMACS) of the European association for cardio-thoracic surgery (EACTS): Second report. *Eur J Cardiothorac Surg* 2018; 53: 309–16
4. McDonagh TA et al. 2021 ESC guidelines for the diagnosis and treatment of acute and chronic heart failure. *Eur Heart J* 2021; 42(36): 3599–726
5. Crespo-Leiro MG et al. Advanced heart failure: a position statement of the Heart Failure Association of the European Society of Cardiology. *Eur J Heart Fail* 2018; 20: 1505–35
6. Stevenson LW et al. INTERMACS profiles of advanced heart failure: the current picture. *J Heart Lung Transplant* 2009; 28(6): 535–41
7. Kirklin JK et al. Eighth annual intermacs report: special focus on framing the impact of adverse events. *J Heart Lung Transplant* 2017; 36: 1080–86
8. Boruah et al. Left ventricular assist device: what the internist needs to know. A review of the literature. *Cureus* 2019; 11: e4399
9. Rose EA et al. Randomized evaluation of mechanical assistance for the treatment of congestive heart failure (RE-MATCH) Study group. Long-term use of a left ventricular assist device for end-stage heart failure. *N Engl J Med* 2001; 345: 1435–43
10. Kirklin JK et al. Sixth INTERMACS annual report: a 10,000-patient database. *J Heart Lung Transplant* 2014; 33: 555
11. Jakovljevic DG et al. Left Ventricular Assist Device as a Bridge to Recovery for Patients With Advanced Heart Failure. *J Am Coll Cardiol* 2017; 69: 1924
12. Schnettler JK et al. Safety of contemporary heart failure therapy in patients with continuous-flow left ventricular assist devices. *J Card Fail* 2021; 27(12): 1328–36
13. Birks EJ et al. Reversal of severe heart failure with a continuous-flow left ventricular assist device and pharmacological therapy: a prospective study. *Circulation* 2011; 123: 381
14. Pae WE et al. Does total implantability reduce infection with the use of a left ventricular assist device? The LionHeart experience in Europe. *J Heart Lung Transplant* 2007; 26(3): 219–29
15. Rogers JG et al. Chronic mechanical circulatory support for inotrope-dependent heart failure patients who are not transplant candidates: results of the INTREPID trial. *J Am Coll Cardiol* 2007; 50(8): 741–7
16. Slaughter et al. Advanced heart failure treated with continuous-flow left ventricular assist devices. *N Engl J Med* 2009; 361: 2241–51
17. Estep JD et al. Risk Assessment and comparative effectiveness of left ventricular assist device and medical management in ambulatory heart failure patients: results from the ROADMAP study. *J Am Coll Cardiol* 2015; 66(16): 1747–61
18. Starling RC et al. Risk assessment and comparative effectiveness of left ventricular assist device and medical management in ambulatory heart failure patients: the ROADMAP study 2-year results. *JACC Heart Fail* 2017; 5(7): 518–27
19. Aaronson KD et al. Use of an intrapericardial, continuous-flow, centrifugal pump in patients awaiting heart transplantation. *Circulation* 2012; 125: 3191–200
20. Rogers JG et al. Intrapericardial left ventricular assist device for advanced heart failure. *N Engl J Med* 2017; 376: 451–60

21. Mehra MR et al. Primary results of long-term outcomes in the MOMENTUM-3 pivotal trial and continued access protocol study phase: a study of 2200 HeartMate 3 left ventricular assist device implants. *Eur J Heart Fail* 221; 23(8): 1392–400
22. Khush KK et al. The International Thoracic Organ Transplant Registry of the International Society of Heart and Lung Transplantation: 37<sup>th</sup> adult heart transplantation report-2020; focus on deceased donor characteristics. *J Heart Lung Transplant* 2020; 39(10): 1003–15
23. Molina EJ et al. The society of thoracic surgeons Intermacs 2020 annual report. *Ann Thorac Surg* 2021; 111(3): 778–92
24. Kormos RL et al. Right ventricular failure in patients with the HeartMate II continuous-flow left ventricular assist device: incidence, risk factors, and effect on outcomes. *J Thorac Cardiovasc Surg* 2010; 139: 1316–24

## **Patienten mit einem linksventrikulären Unterstützungssystem – Besonderheiten in der Patientenversorgung und im Alltag**

*J. Mäßlzer, I. A. Jäst, F. Schönrath*

1. Willemsen et al. Rehabilitation standards for the Anschlussheilbehandlung und allgemeine Rehabilitation von Patienten mit einem Herzunterstützungssystem (VAD - ventricular assist device). *Clinical research in cardiology* 2016; 11(Suppl1): 2–49
2. Bobenko A et al. Exercise training in patients with a left ventricular assist device (Ex-VAD): rationale and design of a multicentre, prospective, assessor-blinded, randomized, controlled trial. *Eur J Heart Fail* 2019; (9): 1152–59
3. Cho SM et al. Understanding risk factors and predictors for stroke subtypes in the ENDURANCE trials. *J Heart Lung Transplant* 2020; 39(7): 639–47
4. Feldman D et al. The 2013 International Society for Heart and Lung Transplantation Guidelines for mechanical circulatory support: executive summary. *J Heart Lung Transplant: Off Publ Int Soc Heart Transplant* 2013; 32(2): 157–87
5. Li, Song et al. “Accuracy of Doppler blood pressure measurement in continuous-flow left ventricular assist device patients.” *ESC heart failure* 2019; (6,4): 793–98
6. Schläglhofer T et al. International Normalized Ratio Test Frequency in Left Ventricular Assist Device Patients Affects Anticoagulation Quality and Adverse Events. *ASAIO J* 2021 ; 67(2): 157–62
7. Gummert, Jan F et al. Permanent implantierbare Herzunterstützungssysteme. Permanent implantable cardiac support systems. *Dtsch Arztebl Int* 2019; 116: 843–8
8. Stainback RF et al. American Society of Echocardiography. Echocardiography in the Management of Patients with Left Ventricular Assist Devices: Recommendations from the American Society of Echocardiography. *J Am Soc Echocardiogr* 2015; 28(8): 853–909
9. Knierim J et al. Outcomes from a recovery protocol for patients with continuous-flow left ventricular assist devices. *J Heart Lung Transplant* 2019; 38(4): 440–48

10. Vakil K et al. Implantable Cardioverter-Defibrillator Use in Patients With Left Ventricular Assist Devices: A Systematic Review and Meta-Analysis. *JACC Heart Fail* 2016; 4(10): 772–79
11. Alvarez PA et al. Implantable Cardioverter Defibrillators in Patients With Continuous Flow Left Ventricular Assist Devices: Utilization Patterns, Related Procedures, and Complications. *J Am Heart Assoc* 2019; 8(14): e011813
12. Tehrani DM et al. Unclear Benefit of Cardiac Resynchronization Therapy in Patients with Implanted Left Ventricular Assist Devices. *ASAIO J* 2019; 65(4): e43
13. Veenis JF & Brugts JJ. Remote monitoring for better management of LVAD patients: the potential benefits of CardioMEMS. *Gen Thorac Cardiovasc Surg* 2020; 68(3): 209–18
14. Kusne S et al. An ISHLT consensus document for prevention and management strategies for mechanical circulatory support infection. *J Heart Lung Transplant* 2017; 36(10): 1137–53
15. Bernhardt AM et al. Driveline Expert STagINg and care DESTINE study group, a Ventricular Assist Device Driveline Infection Study Group. Prevention and early treatment of driveline infections in ventricular assist device patients – The DESTINE staging proposal and the first standard of care protocol. *J Crit Care* 2020; 56: 106–12
16. Hanke JS et al. Driving After Left Ventricular Assist Device Implantation. *Artif Organs* 2018; 42(7): 695–99
17. Hanke JS et al. Flying after left ventricular assist device implantation. *Artif Organs* 2021; 45(3): 230–35
18. Mehra MR et al. MOMENTUM 3 Investigators. A Fully Magnetically Levitated Left Ventricular Assist Device – Final Report. *N Engl J Med* 2019; 380(17): 1618–27
19. Brouwers C et al. Psychological distress in patients with a left ventricular assist device and their partners: an exploratory study. *Eur J Cardiovasc Nurs* 2015; 14(1): 53–62
20. Strangl F et al. Assessing palliative care need in left ventricular assist device patients and heart transplant recipients. *Interact Cardiovasc Thorac Surg* 2020; 31(6): 874–80
21. Fendler TJ et al. Team-based Palliative and End-of-life Care for Heart Failure. *Heart Fail Clin* 2015; 11(3): 479–98
22. Pak ES et al. Ethical Challenges in Care of Patients on Mechanical Circulatory Support at End-of-Life. *Curr Heart Fail Rep* 2020; 17(4): 153–60

## **Temporäre mechanische Kreislaufunterstützung auf der Intensivstation – Management, Komplikationen und Weaning (CME)**

*S. Ott, G. Nersesian, F. Spillmann, C. Starck, F. Schönrath, E. Potapov, P. Lanmüller*

1. Crespo-Leiro MG et al. Advanced heart failure: a position statement of the Heart Failure Association of the European Society of Cardiology. *Eur J Heart Fail* 2018; 20(11): 1505–35
2. Subramaniam AV et al. Complications of Temporary Percutaneous Mechanical Circulatory Support for Cardiogenic Shock: An Appraisal of Contemporary Literature. *Cardiol Ther* 2019; 8(2): 211–28
3. Moghaddam N et al. Cardiogenic shock teams and centres: a contemporary review of multidisciplinary care for cardiogenic shock. *ESC Heart Fail* 2021; 8(2): 988–98

4. Kim DH. Mechanical Circulatory Support in Cardiogenic Shock: Shock Team or Bust? *Can J Cardiol* 2020; 36(2): 197–204
5. Debrunner M et al. Proinflammatory cytokines in acute myocardial infarction with and without cardiogenic shock. *Clin Res Cardiol* 2008; 97(5): 298–305
6. Pudil R et al. Inflammatory response to acute myocardial infarction complicated by cardiogenic shock. *Acta Medica (Hradec Kralove)* 2001; 44(4): 149–51
7. Shpektor A. Cardiogenic shock: the role of inflammation. *Acute Card Care* 2010; 12(4): 115–8
8. Millar JE et al. The inflammatory response to extracorporeal membrane oxygenation (ECMO): a review of the pathophysiology. *Crit Care* 2016; 20(1): 387
9. Notarianni A et al. Mechanical Cardiac Circulatory Support: an Overview of the Challenges for the Anesthetist. *Curr Anesthesiol Rep* 2021: 1–8
10. Tanaka D et al. What Is the Optimal Blood Pressure on Veno-Arterial Extracorporeal Membrane Oxygenation? Impact of Mean Arterial Pressure on Survival. *Asaio j* 2019; 65(4): 336–41
11. Lackermair K et al. Outcome of patients treated with extracorporeal life support in cardiogenic shock complicating acute myocardial infarction: 1-year result from the ECLS-Shock study. *Clin Res Cardiol* 2020
12. Lüsebrink E et al. Prevention and treatment of pulmonary congestion in patients undergoing venoarterial extracorporeal membrane oxygenation for cardiogenic shock. *Eur Heart J* 2020; 41(38): 3753–61
13. Abrams D et al. Extracorporeal membrane oxygenation in cardiopulmonary disease in adults. *J Am Coll Cardiol* 2014; 63(25 Pt A): 2769–78
14. Douflé G & Ferguson ND. Monitoring during extracorporeal membrane oxygenation. *Curr Opin Crit Care* 2016; 22(3): 230–8
15. Douflé G et al. Echocardiography for adult patients supported with extracorporeal membrane oxygenation. *Crit Care* 2015; 19: 326
16. Taylor M & Taylor B. Cardiac ultrasound and extracorporeal life support: the two go together. *J Am Soc Echocardiogr* 2015; 28(4): A18–9
17. Shaaban-Ali M et al. Clinical and Technical Limitations of Cerebral and Somatic Near-Infrared Spectroscopy as an Oxygenation Monitor. *Journal of Cardiothoracic and Vascular Anesthesia* 2021; 35(3): 763–79
18. Bembea MM et al. Neuromonitoring During Extracorporeal Membrane Oxygenation: A Systematic Review of the Literature. *Pediatr Crit Care Med* 2015; 16(6): 558–64
19. Vranken NPA et al. Cerebral and Limb Tissue Oxygenation During Peripheral Venoarterial Extracorporeal Life Support. *J Intensive Care Med* 2020; 35(2): 179–86
20. Moynihan K et al. Coagulation monitoring correlation with heparin dose in pediatric extracorporeal life support. *Perfusion* 2017; 32(8): 675–85
21. Beckmann A et al. Position article for the use of extracorporeal life support in adult patients. *Eur J Cardiothorac Surg* 2011; 40(3): 676–80
22. Burzotta F et al. Impella ventricular support in clinical practice: Collaborative viewpoint from a European expert user group. *Int J Cardiol* 2015; 201: 684–91
23. Tamura T et al. Acquired von Willebrand syndrome in patients treated with veno-arterial extracorporeal membrane oxygenation. *Cardiovasc Interv Ther* 2019; 34(4): 358–63
24. Rougé A et al. Argatroban for an alternative anticoagulant in HIT during ECMO. *J Intensive Care* 2017; 5: 39

25. Sanfilippo F et al. Bivalirudin for Alternative Anticoagulation in Extracorporeal Membrane Oxygenation: A Systematic Review. *J Intensive Care Med* 2017; 32(5): 312–19
26. Abbasciano RG et al. Blood Transfusion Threshold in Patients Receiving Extracorporeal Membrane Oxygenation Support for Cardiac and Respiratory Failure-A Systematic Review and Meta-Analysis. *J Cardiothorac Vasc Anesth* 2021; 35(4): 1192–202
27. Jiritano F et al. Platelets and extra-corporeal membrane oxygenation in adult patients: a systematic review and meta-analysis. *Intensive Care Med* 2020; 46(6): 1154–69
28. S3-Leitlinie 011/021: Einsatz der extrakorporalen Zirkulation (ECLS / ECMO) bei Herz- und Kreislaufversagen. ([https://www.awmf.org/uploads/tx\\_szleitlinien/011-021\\_S3\\_Einsatz-der-extrakorporalen-Zirkulation-ECLS-ECMO-bei-Herz-Kreislaufversagen\\_2021-02.pdf](https://www.awmf.org/uploads/tx_szleitlinien/011-021_S3_Einsatz-der-extrakorporalen-Zirkulation-ECLS-ECMO-bei-Herz-Kreislaufversagen_2021-02.pdf)).
29. ELSO Guidelines for Adult Respiratory Failure. Extracorporeal Life Support Organization, Version 1.4 August 2017. Ann Arbor, MI, USA. [www.elso.org](http://www.elso.org)
30. Abrams D et al. Thrombocytopenia and extracorporeal membrane oxygenation in adults with acute respiratory failure: a cohort study. *Intensive care medicine* 2016; 42(5): 844–52
31. Pichler P et al. [Use of ECMO in adult patients with cardiogenic shock: a position paper of the Austrian Society of Cardiology]. *Med Klin Intensivmed Notfmed* 2015; 110(6): 407–20
32. Bolliger D et al. Point-of-care coagulation management algorithms during ECMO support: are we there yet? *Minerva Anestesiol* 2016; 82(9): 1000–9
33. Kasirajan V et al. Risk factors for intracranial hemorrhage in adults on extracorporeal membrane oxygenation. *Eur J Cardiothorac Surg* 1999; 15(4): 508–14
34. Cheng R et al. Complications of extracorporeal membrane oxygenation for treatment of cardiogenic shock and cardiac arrest: a meta-analysis of 1,866 adult patients. *Ann Thorac Surg* 2014; 97(2): 610–6
35. Lorusso R et al. In-Hospital Neurologic Complications in Adult Patients Undergoing Venoarterial Extracorporeal Membrane Oxygenation: Results From the Extracorporeal Life Support Organization Registry. *Crit Care Med* 2016; 44(10): e964–72
36. Barbone A et al. Left ventricle unloading by percutaneous pigtail during extracorporeal membrane oxygenation. *Interactive CardioVascular and Thoracic Surgery* 2011; 13(3): 293–95
37. Bavaria JE et al. Changes in left ventricular systolic wall stress during biventricular circulatory assistance. *Ann Thorac Surg* 1988; 45(5): 526–32
38. Lucas SK et al. The harmful effects of ventricular distention during postischemic reperfusion. *Ann Thorac Surg* 1981; 32(5): 486–94
39. Jayaraman AL et al. Cannulation strategies in adult veno-arterial and veno-venous extracorporeal membrane oxygenation: Techniques, limitations, and special considerations. *Ann Card Anaesth* 2017; 20(Supplement): S11–s18
40. Murphy DA et al. Extracorporeal membrane oxygenation-hemostatic complications. *Transfus Med Rev* 2015; 29(2): 90–101
41. Pan KC et al. The meaning of a high plasma free haemoglobin: retrospective review of the prevalence of haemolysis and circuit thrombosis in an adult ECMO centre over 5 years. *Perfusion* 2016; 31(3): 223–31
42. Rother RP et al. The clinical sequelae of intravascular hemolysis and extracellular plasma hemoglobin: a novel mechanism of human disease. *Jama* 2005; 293(13): 1653–62
43. Lubnow M et al. Technical complications during veno-venous extracorporeal membrane oxygenation and their relevance predicting a system-exchange--retrospective analysis of 265 cases. *PLoS One* 2014; 9(12): e112316

44. Lou S et al. Hemolysis in pediatric patients receiving centrifugal-pump extracorporeal membrane oxygenation: prevalence, risk factors, and outcomes. *Crit Care Med* 2014; 42(5): 1213–20
45. Lyu L et al. Plasma Free Hemoglobin Is a Predictor of Acute Renal Failure During Adult Venous-Arterial Extracorporeal Membrane Oxygenation Support. *J Cardiothorac Vasc Anesth* 2016; 30(4): 891–5
46. Appelt H et al. Factors associated with hemolysis during extracorporeal membrane oxygenation (ECMO)-Comparison of VA- versus VV ECMO. *PLoS One* 2020; 15(1): e0227793
47. Magliato KE et al. Biventricular support in patients with profound cardiogenic shock: a single center experience. *Asaio j* 2003; 49(4): 475–9
48. O'Neill JM et al. Nosocomial infections during extracorporeal membrane oxygenation. *Intensive Care Med* 2001; 27(8): 1247–53
49. Burkett JS et al. Nosocomial infections in adult patients undergoing extracorporeal membrane oxygenation. *Clin Infect Dis* 1999; 28(4): 828–33
50. Foley PJ et al. Limb ischemia during femoral cannulation for cardiopulmonary support. *J Vasc Surg* 2010; 52(4): 850–3
51. Yoshimura N et al. A simple technique for the prevention of lower limb ischemia during femoral veno-arterial cardiopulmonary support. *J Cardiovasc Surg (Torino)* 1996; 37(6): 557–9
52. Basra SS et al. Current status of percutaneous ventricular assist devices for cardiogenic shock. *Curr Opin Cardiol* 2011; 26(6): 548–54
53. Kim D et al. Echocardiographic Predictors of Successful Extracorporeal Membrane Oxygenation Weaning After Refractory Cardiogenic Shock. *J Am Soc Echocardiogr* 2021; 34(4): 414–422.e4
54. Aissaoui N et al. Predictors of successful extracorporeal membrane oxygenation (ECMO) weaning after assistance for refractory cardiogenic shock. *Intensive Care Med* 2011; 37(11): 1738–45
55. Eulert-Grehn JJ et al. ECMELLA 2.0 - Single arterial access technique for a staged approach in cardiogenic shock. *Ann Thorac Surg* 2020