

Acute myocardial interstitial edema from pathophysiology to therapeutic considerations in critical care: a narrative review

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Abstract

The excess accumulation of fluid in the extracellular space of the heart determines a condition of “myocardial interstitial edema.” Myocardial edema is present in multiple pathological conditions observed in the intensive care setting: fulminant myocarditis, sepsis-induced cardiomyopathy, cardiac arrest, capillary leak syndrome, and extracorporeal circulation. Fluid accumulation in the interstitium can occur rapidly, leading to severe heart failure and potentially progressing to cardiogenic shock. Early diagnosis and prompt therapy are crucial. Understanding the factors and diseases that can disrupt myocardial fluid homeostasis and contribute to the development of interstitial edema allows for a targeted therapeutic approach, aimed at reducing fluid accumulation and clinical detrimental effects.

Keywords: Cardiac arrest, Cardiogenic shock, Fulminant myocarditis, Myocardial fluid balance, Myocardial interstitial edema, Sepsis-induced cardiomyopathy, Systemic capillary leak syndrome

Introduction

The excess accumulation of fluid in the extracellular space of the heart determines a condition of “myocardial interstitial edema” (MIE). Myocardial edema is present in a large number of acute and chronic cardiac pathologies (ischemia, myocardial infarction, myocarditis, cardiac sarcoidosis, cardiomyopathy, and arterial hypertension).^[1] However, in multiple pathological conditions observed in the intensive care setting (fulminant myocarditis [FM], sepsis-induced cardiomyopathy, cardiac arrest, capillary leak syndrome, and extracorporeal circulation), interstitial fluid accumulation can occur rapidly: acute MIE may cause marked myocardial wall thickening, reduction in ventricular cavity size, and severe impairment of both systolic and diastolic function. When a low cardiac output state begins to develop and tends to progress toward cardiogenic shock, early diagnosis and prompt therapy are crucial.^[2–5]

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

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Understanding the factors and diseases that can disrupt myocardial fluid homeostasis and contribute to the development of interstitial edema allows for a targeted therapeutic approach, aimed at reducing fluid accumulation and clinical detrimental effects.

Methods

This narrative review was informed by searches of Ovid MEDLINE, Embase, the Cochrane Library, and APA PsycInfo conducted up to 30 June 2025. We searched for case reports and series, nonrandomized and randomized trials, and systematic reviews and meta-analyses by using combinations of subject headings and keyword terms for “myocardial interstitial edema,” “myocardial edema AND myocarditis,” “myocardial interstitium AND cardiac arrest,” and “myocardial interstitium anatomy.” More keywords were selected on the basis of the literature found in the initial search. No restrictions on publication date, type, or status were applied. Findings were organized and discussed narratively according to the major physiological and clinical themes of the review. This approach enabled the identification, comparison, and organization of recurring themes across the literature, allowing for a comprehensive interpretation of the evidence. Nevertheless, with this synthesis process, the findings are dependent on the methodological quality and heterogeneity of the included studies without involving statistical aggregation of data.

Results

Myocardial interstitium: anatomy, function, and fluid balance

Myocardial interstitium represents one-third of the total myocardial volume (the remaining two-thirds are taken up by cardiomyocytes). It is located between cardiac myofibers and contains endothelial and smooth muscle cells of coronary vessels, lymphatic vessels, macrophages, fibroblasts (the main

nonmyocyte cell type in the heart), and extracellular matrix rich in collagen, elastin, and proteoglycans. The myofiber, typically consisting of 2 to 4 cardiomyocytes, represents the fundamental structural unit of the myocardium. Myocardial interstitium forms a 3-dimensional network that surrounds and connects myofibers, a scaffold that maintains the alignment of myocytes, transmits the force of contraction between myocytes, ensures mechanical strength and elasticity, and helps maintain ventricular shape and function.^[6, 7] Myocardial fibers have a variable orientation across the myocardial wall, and each fiber is stretched by the interaction with the shortening of adjacent fibers due to the presence of connective tissue within the interstitium. This “cross-fiber shortening” mechanism, via a multiplicative effect and a coordinated reorganization of myofiber bundle orientation, results in the inward displacement of the endocardial border, ultimately leading to myocardial wall thickening. Myocardial wall thickening contributes to maintaining adequate systolic function and may serve as a compensatory mechanism in the setting of impaired longitudinal or circumferential fiber shortening.

Interstitial collagen contributes to maintaining myocardial structural architecture even during the diastolic relaxation phase. The interaction between cardiomyocytes and interstitial myocardial collagen can be conceptualized as a parallel spring system, in which each component exhibits distinct mechanical characteristics, contributing differently to overall myocardial stiffness and elasticity: the collagen spring limits the extension of the muscle spring, preventing excessive stretching and misalignment of the fibers.

Proper interstitial function requires precise fluid homeostasis. In normal conditions, the rate of filtration from capillary vessels into the interstitium is perfectly balanced by its removal, according to Starling's law^[8-10]:

$$J_v = L_m \times A \times [(P_c - P_i) - \sigma(\pi_c - \pi_i)]$$

J_v is the rate of fluid leaving the vessel (mL/min/g),

L_m is the myocardial microvascular hydraulic conductivity (mL/min/mm Hg/cm),

A is the microvascular exchange vessel surface area (cm²/g).

P_{cap} is the hydrostatic “capillary” pressure at end-diastole. P_{cap} is the main factor promoting filtration: it has been estimated determining coronary sinus pressure, almost 25–30 mm Hg at the end-diastole.^[11]

P_{int} is the hydrostatic “interstitial” pressure at end-diastole, a force opposing to filtration. The interstitial fluid pressure ranges between 15 and 120 mm Hg, from end-diastolic to end-systolic phase. During systole, myocardial contraction compresses the interstitium, so that P_{int} rises, while during diastole the interstitium is released and P_{int} decreases, allowing fluid filtration.^[11]

The protein reflection coefficient (σ) ranges from 0 to 1. A value approaching 1 indicates near-complete reflection of macromolecules and low protein permeability, whereas a value approaching 0 indicates relatively free passage of macromolecules across the barrier. In normal conditions, in the myocardium, it is 0.51–0.67 for total plasma protein (0.41–0.59 for albumin).

π_{cap} is the plasma colloid osmotic pressure. It represents the osmotic force generated by plasma protein (>30 kDa) that does not cross capillary membrane and it is the main filtration antagonist whose normal value is 21–24 mm Hg.

π_{int} is the interstitial colloid osmotic pressure. It has been measured at about 14 mm Hg, resulting an oncotic gradient of almost 3–5 mm Hg that opposes filtration.

The rate of fluid (J_v) leaving the myocardial vessel is 10 times greater than other tissues^[12]; the high capillary density (4×10^3 capillaries per mm² cross section), results in an exchange surface of 500 cm²/g of myocardium. In normal conditions heart interstitium does not store fluid. Myocardium is abundantly supplied with a network of lymphatic capillaries: each lymphatic capillary drains 1300 surrounding blood capillaries. The excess of fluid flows from the endocardium to the epicardium through intramyocardial channels, then into left and right coronary lymphatic trunks and into cardiac lymph nodes to reach thoracic lymph duct.^[13-15]

The major determinant of myocardial lymph propulsion remains the rhythmic contraction and relaxation of the heart which squeezes the interstitium so that interstitial pressure rises and moves lymph into the lymphatic capillaries (Fig. 1). Contraction and relaxation of the cardiac muscle enhance the outflow of lymph from the heart through 2 efferent pathways probably in a continuous stream: the first mechanism, during systole, is the shortening of the heart axis from apex to base (with consequent augmentation in volume content of lymph channels) and the second, in diastole, is the pericardium stretching during filling of the chambers.

Pathogenesis of acute myocardial interstitial edema

MIE derives from an imbalance between filtration rate and reabsorption: in normal conditions, a chronic rise in filtration is balanced by an increase in lymphatic flow that acts as an antiedema safety mechanism. However, in an abrupt increase in filtration or every time lymphatic protection is not enough, MIE occurs, mainly due to 4 essential mechanisms deriving from the Starling equation^[16]: (1) increased microvascular permeability, (2) reduced colloid osmotic gradient ($\pi_{cap} - \pi_{int}$), (3) reduced lymph flow rate, and (4) increased hydrostatic gradient ($P_{cap} - P_{int}$).

Any condition that increases capillary filtration or decreases lymphatic drainage will increase fluid content in the interstitium. Capillary filtration will be increased in case of increased hydrostatic pressure, decreased intravascular oncotic pressure or increased interstitial oncotic pressure, and an increase in the microvascular filtration coefficient. Despite the predominance of one in the different disorders, the mechanisms are often overlapped and all result in a certain amount of heart dysfunction.

FM and sepsis-induced cardiomyopathy are the pathological conditions most commonly associated with significant acute MIE among critically ill patients.^[17, 18] Bacterial, viral, or autoimmune injury activates immune cells (T-lymphocytes and macrophages), which release cytokines (alpha-Tumor Necrosis Factor [alpha-TNF], Interleukin [IL]-1, and IL-6). These increase capillary permeability, allowing fluid and proteins to leak into the interstitial space. Damage to the capillary endothelium and loss of tight junction integrity contribute to fluid extravasation. Simultaneously, microbial products like lipopolysaccharides exacerbate this permeability, further impairing endothelial integrity. Moreover, bradykinins, upregulated by inflammatory cytokines, bind to the beta-1 receptor on endothelial cells, stimulating nitric oxide (NO) production. NO disrupts endothelial tight junctions and the glycocalyx, increasing vascular permeability. Concurrently, matrix metalloproteinases alter the composition of structural proteins, causing lymphatic vessels to collapse and impeding fluid drainage. The leakage of albumin into the interstitium lowers capillary osmotic pressure, exacerbating fluid filtration.

Acute MIE causes a sudden impairment of systolic cardiac function: interstitial squeezing is reduced so that lymphatic

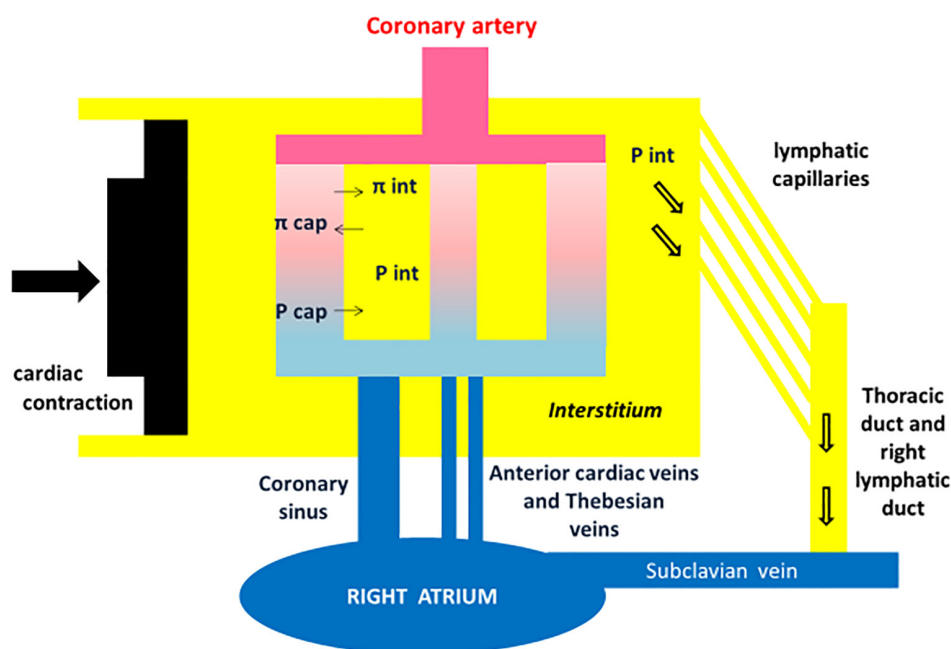


Figure 1. The determinants of fluid balance. Myocardial contraction (represented as the black piston on the left) squeezes the interstitium (yellow field) and rises P_{int} (the hydrostatic “interstitial” pressure) increasing flow through lymphatic vessel and thoracic duct. Opposite forces balance the rate of filtration from capillary vessels into the interstitium: P_{cap} (the hydrostatic “capillary” pressure) and P_{int} (the hydrostatic “interstitial” pressure), π_{cap} (the plasma colloid osmotic pressure) and π_{int} (the interstitial colloid osmotic pressure). Blood from myocardial capillary vessels drains into the coronary sinus, the anterior cardiac veins, and the Thebesian veins. Interstitial fluid, collected by the cardiac lymphatic system, drains into the subclavian vein via the thoracic duct and the right lymphatic duct.

outflow is not enough to preserve interstitial structure.^[19] Progressive interstitial edema contributes to impaired myocardial contractility, thereby initiating a vicious cycle of worsening cardiac function up to a condition of cardiogenic shock. The increase in interstitial fluid increases microvascular resistance, thus reducing coronary perfusion. The increased diffusion distance to myofibril causes inadequate oxygen supply, leading to relative ischemia and worsening of cardiac dysfunction.^[20]

Diastolic function also depends on the integrity of interstitial structure: acute MIE increases the interstitial volume and displaces the collagen fibers, uncoupling collagen struts, which lose their anchoring points on fibroblasts leading to acute increased

stiffness. The degree of MIE should correlate, despite not linearly, with the severity of both diastolic and systolic dysfunction, in terms of myocardial stiffness and impaired contractility.^[21] Increased myocardial stiffness and pressures impede ventricular filling, shifting the heart to a detrimental position on the Starling curve. Furthermore, central venous pressure (CVP) augmentation increases hydrostatic gradient ($P_{cap} - P_{int}$) because of the rise of coronary sinus pressure: this enhances microvascular filtration and impedes fluid removal from cardiac interstitium through myocardial lymphatic vessels, worsening MIE in a detrimental ring.^[22]

Echocardiography is a practical bedside tool for detecting rapid changes in myocardial wall thickness and ventricular function in

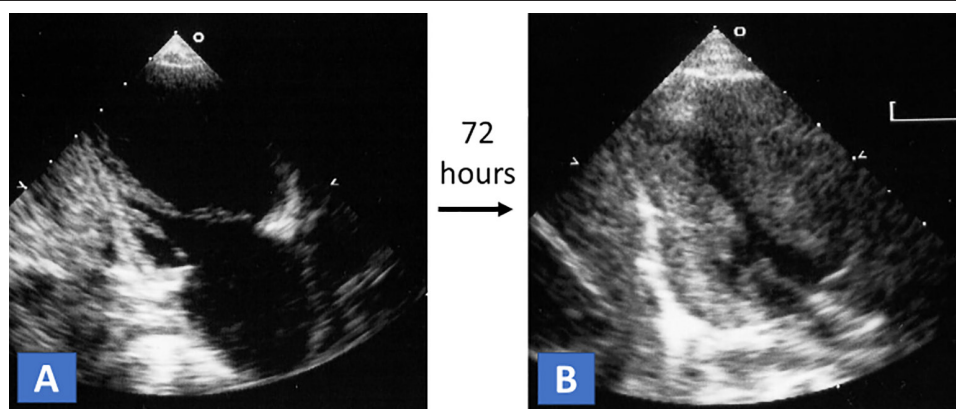


Figure 2. The increase in myocardial wall thickness in a patient with fulminant myocarditis. (A) bidimensional transthoracic echocardiography (apical-2-chamber view) shows the normal myocardial wall thickness in a 3-year-old patient with fulminant myocarditis at presentation in the emergency department. (B) bidimensional transthoracic echocardiography (apical-2-chamber view) shows the severely increased myocardial wall thickness in the same patient after 72 hours.

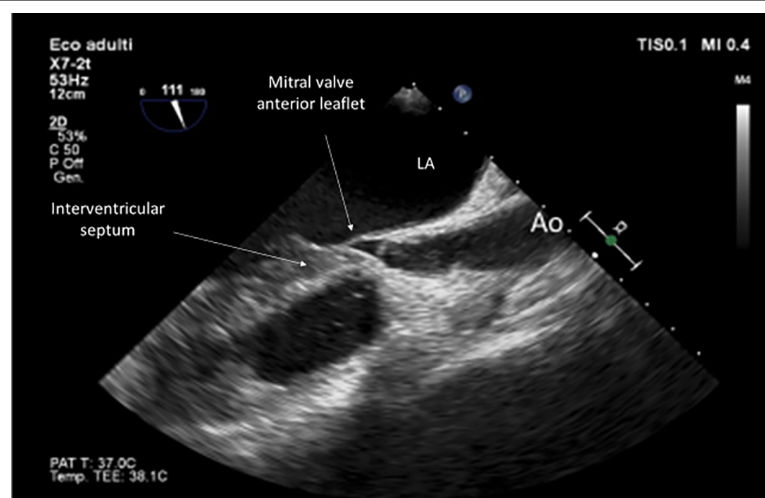


Figure 3. LVOT obstruction after cardiac arrest. Bidimensional transesophageal echocardiography (long axis view at 110 degrees) shows left ventricular outflow tract obstruction following the mitral valve anterior leaflet contact to edematous interventricular septum, blocking blood flow into aortic root. LA, left atrium; LVOT, left ventricular outflow tract.

critically ill patients, but these findings are not specific for interstitial edema. Cardiac magnetic resonance, particularly T2-weighted imaging and T2 mapping, provides more specific tissue characterization when clinically feasible. The increase of myocardial wall thickness in a short time (hours) is the characteristic feature of MIE.^[18, 23] Figure 2 shows the increase in myocardial wall thickness, as visualized by transthoracic echocardiography, in a 3-year-old patient with FM. The myocardial wall thickness, which was normal at the onset (Fig. 2A), progressively increased, resulting in complete obliteration of the left ventricular cavity within 72 hours (Fig. 2B) with severe functional impairment. After 15 days of mechanical circulatory support (venous-arterial extracorporeal membrane oxygenation [ECMO]), the inflammatory process resolved, the wall thickening due to myocardial edema began to decrease, and the ventricular function progressively improved. Echocardiography allows monitoring not only of the increase in myocardial wall thickness, but also the progression through successive stages of diastolic dysfunction.^[24]

Other pathological conditions may lead to the onset of interstitial myocardial edema and the sudden increase in myocardial wall thickness.

In cardiac arrest, during “no-flow” time, vascular capillary permeability increases and lymphatic flow is interrupted.^[25, 26] MIE would have a key prognostic role during cardiopulmonary resuscitation: the anterior mitral leaflet contact to edematous interventricular septum may result to left ventricular outflow tract obstruction, which blocks blood flow into aortic root (Fig. 3); this is a sign of ineffective cardiopulmonary resuscitation and is associated to no survival after cardiac arrest.^[27] During cardioplegic arrest and cardiopulmonary bypass for cardiac surgery, the heart remains in a prolonged diastolic phase, without any cardiac contraction, condition that not only stops lymphatic flow, but also promotes microvascular filtration.^[16, 28] Moreover, the use of crystalloid cardioplegia solution reduces π_{cap} and CBP circuit activates humoral and cellular inflammatory mediators, factors increasing myocardial permeability.^[29]

Systemic capillary leak syndrome is a disorder characterized by a sudden increase in capillary permeability secondary to remodeling of endothelial cell-cell junctions.^[30] It produces extravascular leakage of fluid and plasmatic proteins into the myocardial interstitial area and peripheral tissues with oncotic

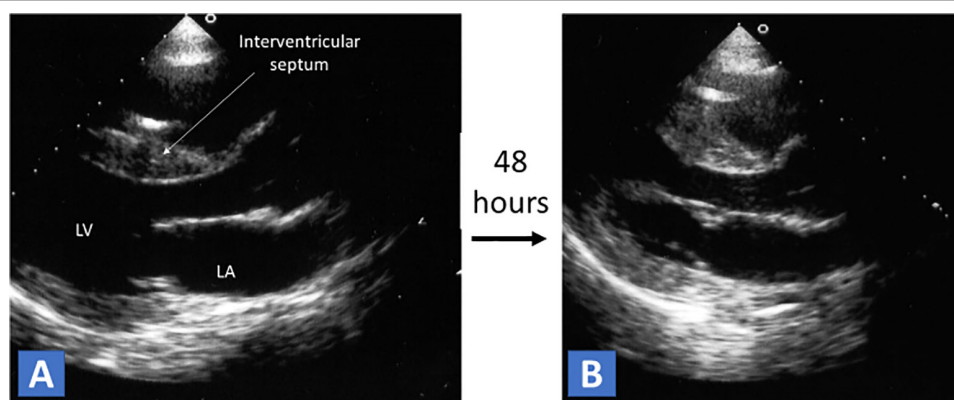


Figure 4. The increased myocardial wall thickness in a patient with idiopathic capillary leak syndrome. (A) transthoracic echocardiography (parasternal long axis view) shows the normal myocardial wall thickness in a 50-year-old patient with idiopathic capillary leak syndrome at presentation in the emergency department. (B) transthoracic echocardiography (parasternal long axis view) shows the increased myocardial wall thickness in the same patient after 48 hours. LA, left atrium; LV, left ventricular.

gradient reduction.^[31] The prodromal phase consists of flu-like symptoms, quickly followed (3–48 hours) by the peculiar “leak-phase” with severe hemoconcentration (often hematocrit >60%), hypoalbuminemia, oligo-anuria, and arterial hypotension, leading to typically hypovolemic shock. Heart failure and the need for mechanical circulatory support depend on the degree of MIE and the extent of myocardial dysfunction.^[32] Figure 4 shows the acute increase in myocardial wall thickness during the leak phase in a 50-year-old patient. Clinical conditions start to improve when the capillary leakage begins to decrease and the intravascular compartment is restored.

Discussion

Therapeutic challenges for acute myocardial interstitial edema

The treatment should be targeted both to support vital function and to avoid MIE worsening. Figure 5 summarizes the therapeutic strategies required to counteract the phenomenon.

Modulation of $\beta 1$ adrenergic receptors

Echocardiography is a practical bedside tool for detecting rapid changes in myocardial wall thickness and ventricular function in critically ill patients, but these findings are not specific for interstitial edema. Cardiac magnetic resonance, particularly T2-weighted imaging and T2 mapping, provides more specific tissue characterization when clinically feasible. Norepinephrine has a stronger alpha-adrenergic profile compared with beta-1, which results in increased afterload more than increased myocardial function. While this is essential for the treatment of low systemic resistances, increasing afterload without any beta-1 will drop cardiac output and could result in the worsening of cardiac dysfunction. Dobutamine may improve cardiac output in selected patients with low-output

states. Whether increased contractility directly enhances myocardial lymphatic clearance or reduces interstitial edema has not been established clinically. However, dobutamine shows an associated arterial vasodilatory effect, particularly evident at low infusion rate (2–5 mcg/kg/min). In the presence of severe ventricular wall thickening, a marked vasodilation may lead to the development of an intraventricular pressure gradient or subvalvular aortic obstruction. Levosimendan is an inodilator drug that causes a positive inotropic effect through a calcium sensitization action on troponin C and vasodilation as an ATP-dependent potassium channel opener in vascular smooth muscle. Levosimendan, due to its long half-time, is probably not the ideal drug in the very acute phase, where a rapid-onset drug could be the preferred choice. However, levosimendan can be a useful drug to support weaning from other inotropes after the very acute phase.^[33]

Mechanical circulatory support

MIE can reach such a degree of severity that it significantly reduces left ventricular filling and stroke volume. Mechanical circulatory support (veno-arterial ECMO) becomes essential to maintain circulation and organ perfusion.^[18] During veno-arterial ECMO support, a combined strategy involving low-dose inotropic agents (epinephrine 0.03–0.05 mcg/kg/min) and peripheral resistance modulation, may prove beneficial to preserve residual myocardial function and limit the development of interstitial edema. Landiolol is a pure S-enantiomer that effectively controls heart rate without significantly affecting inotropism and with minimal impact on blood pressure.^[34]

Selection of inotropes, beta-blockade, VA-ECMO, Impella, or intra-aortic balloon counterpulsation should be individualized according to shock phenotype, ventricular geometry, loading conditions, arrhythmia, and device feasibility. Current evidence does not support general recommendations based specifically on myocardial interstitial edema.

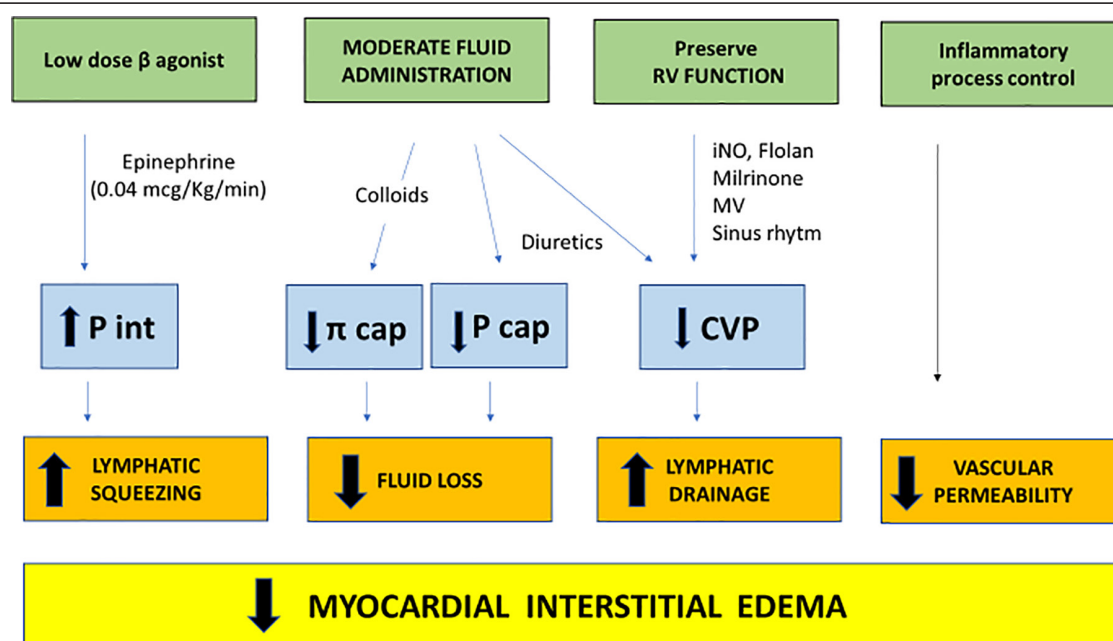


Figure 5. Therapeutic strategies to counteract the acute myocardial interstitial edema. The Figure summarizes the 4 therapeutic strategies required (green field) to counteract the acute myocardial interstitial edema and avoid worsening. π_{cap} , the plasma colloid osmotic pressure; π_{int} , the interstitial colloid osmotic pressure; CVP, central venous pressure; P_{cap} , the hydrostatic “capillary” pressure; P_{int} , the hydrostatic “interstitial” pressure.

Prevention of right ventricular failure

Lymphatic drainage can be achieved and facilitated by lowering CVP, maintaining it below 8–10 mm Hg. High CVP values not only reduce lymphatic drainage through the coronary sinus outflow into the right atrium, but also lead to elevated capillary pressures and enhanced microvascular fluid filtration.^[35]

Meticulous attention to optimizing preload, afterload, and contractility is crucial to prevent right ventricular (RV) failure. Simple measures include maintenance of normal sinus rhythm at a heart rate of 80–100 bpm, adequate temperature, oxygenation, and acid-base balance. Mechanical ventilation should be carefully adjusted to avoid excessive positive pressures and detrimental effects on RV function. Aggressive diuretic therapy and, if ineffective, continuous venovenous hemodialysis are effective measures to control CVP. Supporting RV with inotropes that allow some pulmonary vasodilatation (dobutamine or milrinone) may be necessary. Specific pulmonary vasodilators (iNO and Flolan) may be required to reduce pulmonary vascular resistance and manage RV failure.

Fluid management

Overfluid resuscitation can have detrimental effects. It is necessary to be judicious with fluid management after the initial resuscitation phase. When assessing fluid resuscitation, it is essential to ensure an adequate preload to maintain circulatory stability while avoiding volume overload. The capacity to ensure sufficient preload is independent to the amount of volume administered because MIE increases myocardial stiffness. The assessment of fluid responsiveness based on invasive arterial pressure parameters (pulse pressure variation and stroke volume variation) loses clinical relevance. A more effective strategy involves the use of echocardiography, applying a dynamic functional approach during maneuvers of preload variation (leg rising), allowing direct evaluation of diastolic reserve capacity.^[24] Fluid administration should also be guided by clinical suspicion and overall patient assessment: an aggressive volume administration in idiopathic capillary leak syndrome leak phase is dangerous because crystalloid solutions and albumin pools extravasate from vessels in the third space, worsening general edema and MIE.^[32] Albumin or other colloids may also extravasate when capillary permeability is markedly increased; fluid choice should therefore be individualized and guided by hemodynamic response rather than an assumed reduction in edema. Immunosuppression in fulminant myocarditis should be considered only for selected etiologies and clinical contexts supported by diagnostic evidence and guideline-based multidisciplinary assessment.

Inflammatory process control

In all cases of MIE, an inflammatory process exists and leads to an increase in vascular permeability.

Steroid treatment must be balanced against the risk of immunosuppression. In FM, it is recommended to stop the process^[36]; in idiopathic capillary leak syndrome, aggressive steroid therapy exposes only to detrimental effects (in particular, predisposition to infections), without any hypothetical advantage, because the main mechanism underlying MIE is not immune cells infiltrations but endothelial junctions' disruption.^[32] Experimental approaches include Tie2 receptor agonist, which enhances endothelial barrier function and reduces vascular leakage in preclinical models. High-dose intravenous immunoglobulin may have benefits by modulating immune responses. Furthermore, artificial surfaces of extracorporeal supports are involved in a further inflammation burden: it remains to be demonstrated the possible

benefit of cytokine absorbers' application can reduce inflammation and its role in promoting increased permeability.^[37]

Conclusion

Myocardial interstitial edema is a dynamic feature of several critical cardiac conditions. Bedside echocardiography may support serial assessment, whereas cardiac magnetic resonance provides more specific tissue characterization when feasible. Management should target the underlying cause and the patient's hemodynamic phenotype. Proposed edema-directed strategies are based mainly on physiological reasoning and require prospective clinical evaluation.

Conflict of interest statement

The authors declare no conflict of interest.

Author contributions

All authors assisted in study conceptualization and design, analysis, interpretation, drafted, and critically revised the manuscript. The final manuscript was approved by all authors.

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Ethical approval of studies and informed consent

Ethics approval was not applicable, written informed consent was obtained from the patient.

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References

- [1] Kiseleva DG, Kirichenko T, Markina YV, Cherednichenko VR, Gueva EA, Markin AM. Mechanism of myocardial edema development in CVD pathophysiology. *Biomedicines*. 2024;12(2):465. doi:10.3390/biomedicines12020465
- [2] Stiermaier T, Thiele H, Eitel I. Early myocardial edema after acute myocardial infarction is stable and not bimodal in humans: evidence from a large CMR multicenter study. *Int J Cardiol*. 2017;246:87–89. doi:10.1016/j.ijcard.2017.05.064
- [3] Ammirati E, Veronese G, Bottiroli M, Wen D. Update on acute myocarditis. *Trends Cardiovasc Med*. 2021;31(6):370–379. doi:10.1016/j.tcm.2020.05.008
- [4] Wu MA, Catena E, Cogliati C, et al. Myocardial edema in paroxysmal permeability disorders: the paradigm of Clarkson's disease. *J Crit Care*. 2020;57:13–18. doi:10.1016/j.jccrc.2020.01.014
- [5] Bowers SLK, Banerjee I, Baudino TA. The extracellular matrix: at the center of it all. *J Mol Cell Cardiol*. 2010;48(3):474–482. doi:10.1016/j.yjmcc.2009.08.024
- [6] Schelbert EB, Fonarow GC, Bonow RO, Butler J, Gheorghiade M. Therapeutic targets in heart failure: refocusing on the myocardial interstitium. *J Am Coll Cardiol*. 2014;63(21):2188–2198. doi:10.1016/j.jacc.2014.01.068
- [7] Villari B, Campbell SE, Hess OM, et al. Influence of collagen network on left ventricular systolic and diastolic function in aortic valve disease. *J Am Coll Cardiol*. 1993;22(5):1477–1484. doi:10.1016/0735-1097(93)90560-n
- [8] Starling EH. On the absorption of fluids from the connective tissue spaces. *J Physiol*. 1896;19(4):312–326. doi:10.1113/jphysiol.1896.sp000596

- [9] Laine GA, Granger HJ. Microvascular, interstitial, and lymphatic interactions in normal heart. *Am J Physiol*. 1985;249(4 Pt 2):H834–H842. doi:10.1152/ajpheart.1985.249.4.H834
- [10] Koyama T, Kikuchi Y, Kakiuchi Y, Nagashima C. An analysis of water movement between myocardial tissue and capillary blood during reactive hyperemia. *Jpn J Physiol*. 1979;29(1):1–13. doi:10.2170/jjphysiol.29.1
- [11] Stein PD, Marzilli M, Sabbah HN, Lee T. Systolic and diastolic pressure gradients within the left ventricular wall. *Am J Physiol*. 1980;238(5):H625–H630. doi:10.1152/ajpheart.1980.238.5.H625
- [12] Chilian WM, Eastham CL, Layne SM, Marcus ML. Small vessel phenomena in the coronary microcirculation: phasic intramyocardial perfusion and coronary microvascular dynamics. *Prog Cardiovasc Dis*. 1988;31(1):17–38. doi:10.1016/0033-0620(88)90009-6
- [13] Norman S, Riley PR. Anatomy and development of the cardiac lymphatic vasculature: Its role in injury and disease. *Clin Anat*. 2016;29(3):305–315. doi:10.1002/ca.22638
- [14] Brakenhielm E, Alitalo K. Cardiac lymphatics in health and disease. *Nat Rev Cardiol*. 2019;16(1):56–68. doi:10.1038/s41569-018-0087-8
- [15] Klaourakis K, Vieira JM, Riley PR. The evolving cardiac lymphatic vasculature in development, repair and regeneration. *Nat Rev Cardiol*. 2021;18(5):368–379. doi:10.1038/s41569-020-00489-x
- [16] Mehlhorn U, Davis KL, Burke EJ, Adams D, Laine GA, Allen SJ. Impact of cardiopulmonary bypass and cardioplegic arrest on myocardial lymphatic function. *Am J Physiol*. 1995;268(1 Pt 2):H178–H183. doi:10.1152/ajpheart.1995.268.1.H178
- [17] Aissaoui N, Boissier F, Chew M, Singer M, Vignon P. Sepsis-induced cardiomyopathy. *Eur Heart J*. 2025;46(34):3339–3353. doi:10.1093/eurheartj/ehaf340
- [18] Catena E, Paino R, Milazzo R, et al. Mechanical circulatory support for patients with fulminant myocarditis: the role of echocardiography to address diagnosis, choice of device, management, and recovery. *J Cardiothorac Vasc Anesth*. 2009;23(1):87–94. doi:10.1053/j.jvca.2008.03.008
- [19] Mehlhorn U, Davis KL, Laine GA, Geissler HJ, Allen SJ. Myocardial fluid balance in acute hypertension. *Microcirculation*. 1996;3(4):371–378. doi:10.3109/10739689609148309
- [20] Zahara R, Santoso A, Barano AZ. Myocardial fluid balance and pathophysiology of myocardial edema in coronary artery bypass grafting. *Cardiol Res Pract*. 2020;2020:3979630. doi:10.1155/2020/3979630
- [21] Laine GA, Allen SJ. Left ventricular myocardial edema. lymph flow, interstitial fibrosis, and cardiac function. *Circ Res*. 1991;68(6):1713–1721. doi:10.1161/01.res.68.6.1713
- [22] Davis KL, Mehlhorn U, Laine GA, Allen SJ. Myocardial edema, left ventricular function, and pulmonary hypertension. *J Appl Physiol* (1985). 1995;78(1):132–137. doi:10.1152/jappl.1995.78.1.132
- [23] Ammirati E, Cipriani M, Lilliu M, et al. Survival and left ventricular function changes in fulminant versus nonfulminant acute myocarditis. *Circulation*. 2017;136(6):529–545. doi:10.1161/CIRCULATIONAHA.117.026386
- [24] Catena E, Volontè A, Rizzuto C, et al. The value of a dynamic echocardiographic approach to diastolic dysfunction in intensive care medicine. *J Clin Ultrasound*. 2024;52(1):95–102. doi:10.1002/jcu.23610
- [25] Bragadeesh T, Jayaweera AR, Pascotto M, et al. Post-ischaemic myocardial dysfunction (stunning) results from myofibrillar oedema. *Heart*. 2008;94(2):166–171. doi:10.1136/hrt.2006.102434
- [26] Klein A, Grand J, Meyer MAS, et al. Global myocardial oedema in resuscitated out-of-hospital cardiac arrest patients assessed by cardiac magnetic resonance: a pilot study. *Eur Heart J Acute Cardiovasc Care*. 2023;12(1):53–57. doi:10.1093/ehjacc/zuac159
- [27] Catena E, Ottolina D, Fossali T, et al. Association between left ventricular outflow tract opening and successful resuscitation after cardiac arrest. *Resuscitation*. 2019;138:8–14. doi:10.1016/j.resuscitation.2019.02.027
- [28] Heames RM, Gill RS, Ohri SK, Hett DA. Off-pump coronary artery surgery. *Anaesthesia*. 2002;57(7):676–685. doi:10.1046/j.1365-2044.2002.02613.x
- [29] Ashraf S. The inflammatory response to cardiopulmonary bypass. *Tech Extracorp Circ Fourth Ed*. 2004;112(3):117–132. doi:10.1378/chest.112.3.676
- [30] Druey KM, Arnaud L, Parikh SM. Systemic capillary leak syndrome. *Nat Rev Dis Primers*. 2024;10(1):86. doi:10.1038/s41572-024-00571-5
- [31] Houterman M, Ellenbroek D, Humalda JK, Van der Hoeven JG, Ramakers BP. Diagnostic and therapeutic considerations in idiopathic systemic capillary leak syndrome: a case report. *J Emerg Crit Care Med*. 2022;6(26):26–26. doi:10.21037/jecm-22-22
- [32] Wu MA, Colombo R, Podda GM, Cicardi M. Handling shock in idiopathic systemic capillary leak syndrome (Clarkson's disease): less is more. *Intern Emerg Med*. 2019;14(5):723–730. doi:10.1007/s11739-019-02113-4
- [33] Manca P, Matassini MV, Fazzini L, et al. Home inotropes in advanced heart failure: a practical review. *J Clin Med*. 2025;14(19):7018. doi:10.3390/jcm14197018
- [34] Rehberg S, Frank S, Cerny V, et al; LANDI-SEP Study Group. Landiolol for heart rate control in patients with septic shock and persistent tachycardia. a multicenter randomized clinical trial (Landi-SEP). *Intensive Care Med*. 2024;50(10):1622–1634. doi:10.1007/s00134-024-07587-1
- [35] Mahmood SS, Pinsky MR. Heart-lung interactions during mechanical ventilation: the basics. *Ann Transl Med*. 2018;6(18):349. doi:10.21037/atm.2018.04.29
- [36] Ammirati E, Veronese G, Cipriani M, et al. Acute and fulminant myocarditis: a pragmatic clinical approach to diagnosis and treatment. *Curr Cardiol Rep*. 2018;20(11):114. doi:10.1007/s11886-018-1054-z
- [37] Dogan G, Hanke J, Puntigam J, Haverich A, Schmitto JD. Hemoadsorption in cardiac shock with bi ventricular failure and giant-cell myocarditis: a case report. *Int J Artif Organs*. 2018;41(8):474–479. doi:10.1177/0391398818777362

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