Advances in Clinical Medicine 临床医学进展, 2026, 16(2), 1799-1806
Published Online February 2026 in Hans. https://www.hanspub.org/journal/acm
https://doi.org/10.12677/acm.2026.162573

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脓毒性心肌病患者床旁超声评估技术应用进展

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收稿日期：2026年1月5日；录用日期：2026年1月29日；发布日期：2026年2月9日

摘　要

近年来超声心动图技术的革新进一步提高了它的可及性和实用性。脓毒症心肌病作为脓毒症以及脓毒性休克相关心血管衰竭的一个重要特征，至今虽然仍缺乏一致的诊断标准，但患者的表现通常有一定的共性，即心室扩张、收缩能力降低和左、右心功能不全，同时多有对容量输注的反应降低。近年来，组织多普勒成像(TDI)、斑点追踪超声心动图(STE)及心肌做功(MW)等新技术逐渐应用于脓毒性心肌病的评估。本文综述了脓毒性心肌病的病理生理机制及新型超声技术在左、右心功能评估中的研究进展，重点探讨整体纵向应变(GLS)、右心室纵向应变(RV strain)及右心－肺动脉耦合(RV-PA coupling)在危重患者个体化血流动力学管理中的临床价值。

关键词

超声心动图，脓毒症心肌病，脓毒性休克，斑点追踪，整体纵向应变，心肌做功

Advances in the Application of Bedside Ultrasound Assessment Techniques in Patients with Septic Cardiomyopathy

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Received: January 5, 2026; accepted: January 29, 2026; published: February 9, 2026

Abstract

In recent years, advancements in echocardiography technology have further enhanced its accessibility and practicality. Septic cardiomyopathy, as a key feature of cardiovascular failure associated with sepsis and septic shock, still lacks a consensus diagnostic standard. However, patients typically present with certain common characteristics, including ventricular dilation, reduced contractility,

文章引用: 郭力, 朱炜华, 刘天成, 叶卓杰, 周海涛. 脓毒性心肌病患者床旁超声评估技术应用进展[J]. 临床医学进展, 2026, 16(2): 1799-1806. DOI: 10.12677/acm.2026.162573

and both left and right heart dysfunction, often accompanied by a diminished response to volume infusion. In recent years, emerging echocardiographic techniques, such as tissue Doppler imaging (TDI), speckle tracking echocardiography (STE), and myocardial work (MW), have been increasingly utilized in the assessment of septic cardiomyopathy. This review summarizes the pathophysiological mechanisms of septic cardiomyopathy and recent advances in the application of novel echocardiographic techniques for evaluating left and right ventricular function, with particular emphasis on the clinical value of global longitudinal strain (GLS), right ventricular strain (RV strain), and right ventricle-pulmonary artery (RV-PA coupling) coupling in the individualized hemodynamic management of critically ill patients.

Keywords

Echocardiography, Septic Cardiomyopathy, Septic Shock, Speckle Tracking, Global Longitudinal Strain, Myocardial Work

1. 引言

超声心动图是评估心脏功能的基石，提供对评估和管理危重患者至关重要的实时成像和血流动力学洞察[1] [2]，同时也被广泛推荐为出现循环系统休克症状的患者的一线诊断和治疗工具[3]。

2. 脓毒性心肌病的定义

到目前为止，对脓毒性心肌病(SCM)还没有一个明确和一致的定义。SCM 包括一系列左室和(或)右室功能障碍，涉及收缩和(或)舒张期损害。此定义目前仍有争议，有学者提出是否应该将孤立性舒张期功能障碍或右室功能障碍包括在该定义中[4]。定义 SCM 的另一个挑战是用于评估心肌功能的各种技术。这些包括血流动力学监测(例如，有创动脉压、中心静脉压、混合静脉血氧饱和度)以及用于确定收缩和舒张期功能障碍的各种超声心动图参数[4] [5]。然而，大多数学者及专家都同意 SCM 的这些诊断特征，包括：(1) 心功能障碍的存在；(2) 7~10 天内心肌功能障碍的可逆性；(3) 对液体复苏和儿茶酚胺的反应降低；(4) 排除急性冠脉综合征的病因[6] [7]。

3. 脓毒性心肌病的病理生理

与其他脓毒症引起的器官功能障碍一样，SCM 是由于宿主对病原体的免疫反应失调所致。在细胞水平上，多条途径导致心肌功能障碍[7] [8]。病原体相关分子模式和内源性损伤相关分子模式触发促炎细胞因子的释放和一氧化氮的产生[4] [9]。由此产生的氧化应激影响前负荷和后负荷，导致交感神经过度驱动和 β-肾上腺素能受体下调，降低心肌钙反应性，并导致线粒体功能障碍[4] [7] [10] [11]。同时也有学者提出了以下机制，活性氧自由基(ROS)或氮自由基的过度形成，以及转录和代谢的变化[12]。需要注意的是，这些通路最终都只能通过影响细胞内钙离子的升高或肌丝功能而导致心肌收缩能力下降，这是无数信号通路传导的最终结局。脓毒性心肌病的核心病理机制之一为心肌抑制和线粒体功能障碍。炎症介质、一氧化氮及氧化应激可导致心肌细胞线粒体能量代谢障碍，进而影响肌丝收缩蛋白功能和细胞内钙离子稳态，从而主要损害以内膜下纵向纤维为主的心肌收缩功能。由于纵向纤维对缺血和代谢紊乱更为敏感，整体纵向应变(GLS)较射血分数(LVEF)更早反映心肌亚临床收缩功能障碍。因此，在脓毒症患者中，即使

LVEF 仍处于正常范围，GLS 也可能已明显降低，提示潜在的心肌抑制状态[4] [13] [14]。

4. 超声心动图在脓毒症心肌病诊断中的作用

传统的测量心脏收缩功能的指标，如 LVEF、LV 短轴缩短率(FS)、右室面积变化分数(FAC)和三尖瓣环平面收缩期位移(TAPSE)是最有效和容易获得的参数，但是这些指标在评估严重脓毒症或脓毒性休克患者的心功能方面存在一定的局限性，如依赖于负荷条件、几何假设等，并不能反映真实的潜在心肌收缩能力[15]。患有严重败血症或感染性休克的患者通常左室后负荷减少，因此即使左室收缩能力降低，也可能保留 LV 短轴缩短率及 LVEF [6] [7]。同时超声心动图图像必须清晰，才能准确识别血液–心内膜边界[15]。重症患者基于体位受限、机械通气造成的浮肿或伪影而表现出较差的回声等多方面因素会对图像获取造成很多困难。另外，一些研究显示 LVEF、FS 和 FAC 的操作重复性不足[16]。目前的超声心动图参数不能独立于血流动力学条件(如前负荷、后负荷和心率)评估心肌功能，导致在定义 SCM 方面缺乏共识。

5. 超声新技术评估脓毒症心肌病的应用进展

由于缺乏 SCM 的标准化定义，不同研究报告的 LV 和(或)RV 功能障碍发生率存在显著差异，具体取决于评估方法和诊断标准[17]。超声心动图评估的时机也在这种异质性中起着重要作用。例如一些研究发现，脓毒症发病 24 小时内评估的患者中有 22%观察到左室功能障碍，72 小时后评估则增加至 31.8% [18]。而在另一项研究中，入院 6 小时内评估的患者中有 18%报告有左室功能障碍，72 小时后上升至 60% [19]。另外，研究的纳入标准各不相同；有些包括脓毒症和脓毒性休克患者，而另一些则专门针对需要高剂量儿茶酚胺的脓毒性休克，而儿茶酚胺本身会影响心脏功能。同时 ICU 患者可能进行机械通气支持治疗，这也会影响 SCM 和主要 RV 的评估。

5.1. 组织多普勒超声心动图

组织多普勒成像(TDI)是一种基于高振幅低频脉冲多普勒的方法，可以替代传统的 LVEF 来评估 LV 收缩功能。液体负荷对 TDI 评估的影响较小[20]，因此可能更适合于脓毒症患者的左心室收缩功能障碍(LVSD)的研究。左心室收缩功能可以通过在二尖瓣环处测量的收缩峰值速度(S')来评估，在成年非危重患者中，8.1、9.2 和 10.2 厘米/秒(分别为间隔壁、侧壁和平均值)作为标准参考[21]。

一些研究表明，脓毒症幸存者的二尖瓣 S'平均值低于非幸存者，90 天死亡率预测截止值为 9 cm/s [22]。然而，与脓毒症患者相比，未发生 SCM 的心力衰竭(HF)患者的 S'与心输出量(CO)之间的相关性更强(分别为 R = 0.48 和 R = 0.34)。这种相关性仅在心力衰竭患者中具有统计学意义，这说明在重症患者的评估中，S'测量可能无法可靠地评估脓毒症中的 CO 高[23]。尽管现在已发现二尖瓣 S'可以预测新入急诊室的脓毒症患者的疾病严重程度[24]，但研究表明二尖瓣 S'与高估收缩力的 LVEF 相关[22] [24]。然而，在脓毒症患者预后方面，二尖瓣 S'的作用不同研究之前有相互矛盾的结果。一篇纳入了 13 项研究的荟萃分析发现幸存者和非幸存者之间的 S'值没有差异[25]。最后需要强调的是，S'是测量单个分段中的单向峰值收缩速度，测量结果受角度依赖的限制。因此，二尖瓣环的两侧(游离壁和隔膜边缘)必须从四腔切面进行评估。

5.2. 斑点跟踪超声心动图

斑点跟踪超声心动图(STE)是市场上可用的最新技术。这项技术可以跟踪超声斑点在心肌中的运动，逐帧分析心肌运动。它有助于理解心脏生理学和力学。STE 已被转换成各种形式的分析，包括速度矢量分析，应变和应变率测量，以及扭转和扭转分析。与二维和多普勒分析相比，斑点跟踪超声心动图不受

心肌运动的主观解释，也不受超声角度的影响。STE 的临床应用在心脏病学领域得到了广泛的研究[26]。

5.2.1. 应变和应变率

收缩和舒张期分别导致心肌的缩短和延长，这种变形的周期性变化可以用应变来量化心脏功能。拉格朗日应变，或简称应变，定义为心肌纤维长度的变化，可以在左心室(LV)的三个不同维度测量：纵向、径向和周向。传统上，心肌应变是通过组织多普勒成像(TDI)获得的。TDI 应变来源于应变率，即心肌上两点之间的速度梯度，TDI 应变是通过对应变率进行时间积分得到的。应变通常以百分比变化表示。正值表示加长或加厚，而负值表示缩短或变薄。应变率表示为每秒，这是每秒长度或厚度的变化分数。应变成像使用跟踪心肌超声斑点的方法来测量心肌的运动，以进行逐帧分析，能特别关注到极易发生缺血的纵向纤维[14] [27]。

使用斑点追踪超声心动图(STE)计算的全局纵向应变(GLS)是最常用的参数。STE 使用半自动计算机算法来跟踪心动周期期间的心肌区域。在心脏收缩期间，随着纤维收缩，斑点靠得更近，从而产生负值。负值越大表明变形越大，左心室功能改善。正常的 GLS 值通常在−20%左右[15]。

5.2.2. 左心室应变

应变成像是脓毒症和感染性休克患者收缩功能和 LVEF 的更准确测量[28] [29]。由于左心室在收缩期缩短，纵向应变值按照惯例为负值，负值越大反映更好的收缩功能。与标准多普勒成像方式不同，应变成像与操作者角度和负荷条件无关，并且可以比传统超声心动图更准确地评估成人和儿童人群的左心室收缩功能和功能障碍[29]-[31]。与 LVEF 和 TDI 变量等更传统的参数相比，全局纵向应变显示观察者之间和观察者内部的变异性较小[32]。一些研究表明，与 LVEF 等传统参数相比，较小负纵向应变与短期死亡率的相关性更大[30] [33]。一项研究的初步数据表明，与没有休克的脓毒症患者相比，脓毒症休克患者的整体纵向应变更差(−14.5%~−18.3%, P <0.001)；该研究表明，使用纵向应变评估的左心室收缩功能缺乏改善与较高的院内死亡率相关[29]。

在评估脓毒症患者的舒张功能障碍方面，应变成像已被证明优于 TDI [34] [35]。整体纵向应变(GLS)与脓毒症患者的组织多普勒舒张速度(e')、舒张早期二尖瓣流入速度(E)与 e'之比(E/e')以及 BNP 和乳酸水平密切相关[36] [37]。一项纳入了 46 名脓毒症患者的前瞻性队列证明了整体纵向应变与组织氧合的传统标志物(即中心静脉氧饱和度和血清乳酸)相关[38]。

最近的一项系统回顾和荟萃分析评估了 GLS 确定的脓毒性心肌病患者的死亡率。该研究纳入了来自 14 项研究的 1678 名患者，报告生存率为 69.6%。更负的 GLS 与更好的生存率显著相关，平均差(MD)为 −1.45% (P < 0.0001)。在二次分析中，较高的 LVEF 值也与生存率的提高相关，尽管这种相关性较 GLS 弱(MD = 2.44%, P = 0.02)。这些发现证实了 GLS 对脓毒症患者的预后价值[39]。

在最近一项涉及 176 名脓毒症患者的研究中，96.6%的患者正在接受去甲肾上腺素治疗，10.4%的患者还正在接受抗利尿激素治疗。尽管平均 EF 接近正常，为 57.8% ± 1.1%，但 21 名患者(11.9%)观察到显著的 LV 收缩功能障碍(LVEF < 40%)，7 名患者(4%) EF 严重下降(<30%)。然而，GLS 显著降低(−13.3% ± 0.3%)。在这些患者中，87.5%的患者表现出 GLS > −18%，56.5%的患者表现出 GLS > −15.9%，46.2%的患者表现出 GLS > −14% [40]。这表明 GLS 在识别心肌损伤方面的敏感性，对于 EF 正常或接近正常的脓毒症患者，LVEF 可能无法检测到心肌损伤。

5.2.3. 右心功能及右心－肺动脉耦合(RV-PA Coupling)

脓毒症患者常合并急性呼吸窘迫综合征(ARDS)及肺血管炎症反应，导致肺血管阻力升高和肺动脉压力增加，从而显著加重右心室后负荷[41]。炎症介质介导的肺血管内皮功能障碍、微循环灌注不良以及机械通气所致的胸腔内压升高，均可进一步影响右心室泵血功能。由于右心室壁薄、顺应性高，对后负荷

变化高度敏感，在脓毒症相关肺动脉高压背景下更易发生功能障碍。

右心–肺动脉耦合(RV-PA coupling)反映右心室收缩功能与肺动脉负荷之间的匹配程度，常采用TAPSE/PASP比值进行无创评估，异常低的临界值为0.36 mm/mmHg，低于此值被认为是RV-PA偶联受损[42]。研究表明，RV-PA耦合受损与脓毒症及ARDS患者的不良预后密切相关。当TAPSE/PASP比值降低时，提示右心代偿能力不足，可能导致心输出量下降和组织灌注不足[43] [44]。

此外，斑点追踪超声心动图可更敏感地识别右心室亚临床功能障碍。与传统右心功能指标相比，RV纵向应变对后负荷变化更为敏感，即使TAPSE仍处于正常范围，RV应变也可能已明显降低，并与住院死亡率及机械通气时间延长显著相关[45]。因此，在SCM的超声评估中，系统评估右心功能及RV-PA耦合状态对于指导液体复苏、机械通气参数调整及血管活性药物使用具有重要临床意义[46]。

5.2.4. 斑点跟踪超声心动图(STE)的局限性

常规超声心动图参数中的一些限制也适用于STE。STE需要高帧速率和良好的图像质量进行分析，由于心动过速、超声心动图窗口差和获取图像的时间有限[18] [47]，在重症监护环境中往往很难获得良好质量的图像。STE值的数据解释也会因不同的负荷条件出现分歧，包括液体状态和正性肌力支持[48]-[51]。

5.3. 心肌做功

近年来开发出了一种基于STE的测量左心功能的新技术：全局心肌功(MW) [52] [53]。以心肌做功指数(MWI)和心肌做功效率(MWE)评估心肌做功的优势在于，充分考虑了后负荷对GLS的影响，它提供了一种更独立于负荷的左心功能测量方法；MW还具有很高的重复性，并增加了GLS在预测不良事件方面的增量价值[54]。

整体心肌做功指数(MWI，单位mmHg%)，定义为整体左心室压力–应变环内面积；整体心肌做功效率(MWE, %)，定义为有效心肌做功除以有效做功与无效做功之和的百分比。在心肌做功参数中，MWE多作为主要研究变量，因为它能全面评估左心室有效做功与总做功的比值，一些研究普遍表明这项参数在特定人群中具有预后价值[55] [56]，目前并没有指南明确规定过心肌做功的正常值范围，研究多以MWE < 95%定义为异常[52] [57] [58]。心肌做功对脓毒性心肌病的评估研究尚少，有望在今后的研究中进一步评估。

6. 结论

综上所述，本文阐述了脓毒性心肌病的诊断与机制，主要总结了几种新兴超声技术评估脓毒性休克病人的研究成果，二维斑点追踪超声与心肌做功均有较好的识别心肌亚临床功能障碍的能力，或许对脓毒性心肌病的诊断有所帮助；其中对于二维斑点追踪超声尤其是整体纵向应变的研究已较为明确，未来的研究可以进一步发掘心肌做功在重症患者中的评估潜力。

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