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Patient microcirculation in trauma anesthesia: artificial intelligence as the missing translational link?

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ABSTRACT

Traumatic hemorrhage is a major cause of preventable death, where a critical challenge remains the dissociation between systemic hemodynamics and microcirculatory function. While macrocirculatory variables may be normalized during resuscitation, this does not necessarily ensure adequate tissue perfusion, leading to "hemodynamic coherence" loss and subsequent organ failure. Handheld vital microscopy (HVM) allows for bedside visualization of microcirculation, but clinical adoption is hindered by technical complexities in image acquisition and the time-consuming nature of manual analysis. Artificial intelligence (AI) is proposed as the missing translational link to make this monitoring clinically actionable. AI-based systems can enable automated video quality assessment and quantification of perfusion indices, reducing interobserver variability. Furthermore, AI could integrate microcirculatory data with macrocirculatory and biochemical streams to support individualized decisions regarding fluid and vasopressor therapy. However, several limitations persist. AI cannot compensate for poor primary data acquisition, and the clinical impact of microcirculatory-guided interventions remains unproven in interventional studies. Additionally, the integration of AI raises concerns regarding system robustness and cybersecurity. In conclusion, while AI-augmented monitoring is a promising step toward precise trauma resuscitation, it is not yet practice-changing and requires further validation through outcome-driven research.

KEY WORDS: Trauma, artificial intelligence, monitoring, resuscitation, microcirculation, trauma anesthesia.

LETTER TO THE EDITOR

Traumatic hemorrhage remains one of the leading causes of preventable death following injury, particularly during the early phases of trauma care [1]. While rapid hemorrhage control and restoration of systemic hemodynamics are central components of modern trauma resuscitation, normalization of macrocirculatory variables does not necessarily equate to adequate tissue perfusion. This persistent dissociation between systemic hemodynamics and microcirculatory function represents a critical and unresolved challenge in trauma anesthesia and critical care [2,3]. Artificial intelligence (AI) may represent the missing translational link required to make microcirculatory monitoring clinically actionable in this context.

The microcirculation constitutes the final pathway for oxygen and substrate delivery to tissues. In hemorrhagic shock, endothelial dysfunction, inflammation, glycocalyx degradation, and coagulation disturbances lead to profound alterations in capillary perfusion [4]. Importantly, this results in a loss of hemodynamic coherence, characterized by increased flow heterogeneity, functional shunting, and impaired capillary recruitment. These alterations may persist despite restoration of arterial pressure and cardiac output, contributing to ongoing tissue hypoxia and organ dysfunction. Clinical studies have consistently demonstrated that microcirculatory impairment is associated with adverse outcomes and the development of multiple organ failure following traumatic hemorrhagic shock [2,3].

Handheld vital microscopy (HVM) has enabled direct bedside visualization of the microcirculation, most commonly in the sublingual region [5]. This technique has proven feasible in emergency and trauma settings, including both civilian and military populations [6]. However, despite its physiological relevance, microcirculatory monitoring has not been widely adopted in routine clinical practice. A major limitation lies in the technical complexity of image acquisition, as high-quality video sequences are difficult to obtain in unstable trauma environments due to motion artefacts, pressure artefacts, and challenging imaging conditions [7].

Equally important are the limitations of image analysis. Traditional approaches rely on manual or semi-automated methods, which are time-consuming, require significant expertise, and are subject to considerable interobserver variability [5,8]. Even validated software platforms often necessitate extensive manual correction and have demonstrated inconsistent performance across studies [9]. As a result, microcirculatory assessment remains largely confined to research settings, limiting its clinical applicability.

In this context, artificial intelligence offers a potential solution. Recent advances in AI within anesthesia and critical care have primarily focused on monitoring, prediction, and decision support [10]. Applied to microcirculatory imaging, AI-based systems may enable automated video quality assessment, vessel detection and segmentation, flow classification, and quantification of parameters such as vessel density and perfusion indices. By reducing reliance on manual interpretation, these approaches have the potential to improve reproducibility and minimize observer-dependent variability.

A useful parallel can be drawn from the evolution of AI in point-of-care ultrasound (POCUS). Similar to microcirculatory imaging, POCUS has historically been limited by operator dependency, variable image quality, and challenges in real-time interpretation. Recent advances in AI have enabled automated guidance for image acquisition, quality assessment, and pattern recognition. In selected applications, performance approaches expert-level interpretation. Importantly, these developments have facilitated early clinical integration of AI-augmented ultrasound as a decision-support tool. However, persistent challenges remain, including limited generalizability, dataset bias, and uncertain impact on patient outcomes [11]. This trajectory may provide a relevant translational framework for the development of AI-assisted microcirculatory monitoring.

Emerging data supports the feasibility of AI-driven microcirculatory analysis. Automated tools have been developed to quantify microvascular parameters with limited manual input and have been successfully applied in critically ill populations [12-14]. For example, AI-assisted analysis has identified clinically relevant microcirculatory alterations in both COVID-19 and perioperative settings [14,15]. However, these systems are not yet fully validated for routine clinical use, and discrepancies between automated and manual measurements persist [12].

Beyond image analysis, the most promising application of AI may lie in the integration of microcirculatory data with systemic perfusion parameters. In current practice, anesthesiologists rely on variables such as arterial pressure, heart rate, lactate concentration, hemoglobin levels, vasopressor requirements, and venous oxygen saturation. AI-based models could integrate these macrocirculatory and biochemical data streams with microcirculatory metrics to provide a more comprehensive and physiologically coherent assessment of tissue perfusion.This integrated multimodal monitoring could help identify occult shock states and support more individualized decisions regarding fluid therapy, transfusion strategies, and vasopressor use.

Nevertheless, several important limitations must be acknowledged. First, the quality of input data remains a fundamental constraint, as AI algorithms cannot compensate for poor image acquisition [7]. Second, the generalizability of AI models is uncertain, particularly when applied to heterogeneous trauma populations outside controlled research settings. Third, while automation may reduce variability, it does not eliminate the need for clinical interpretation and contextual judgment.

Crucially, the clinical impact of microcirculatory-guided interventions remains unproven [16]. To date, no interventional study has convincingly demonstrated that targeting microcirculatory endpoints improves patient-centered outcomes [2,8,17]. This has led to ongoing debate regarding whether microcirculation should be considered a therapeutic target or primarily a monitoring tool. Future research must therefore extend beyond technical validation and address whether AI-augmented microcirculatory monitoring can meaningfully influence clinical decision-making and improve outcomes.

Finally, the increasing integration of AI into critical care monitoring raises important considerations regarding system robustness and resilience. As digital infrastructures become more central to patient care, the attack surface for cyber-adversaries expands [18]. In the context of AI-driven microcirculatory imaging, "adversarial attacks", where small, imperceptible alterations are added to medical images, could lead to significant missegmentation or flow misclassification, potentially causing clinicians to misinterpret tissue perfusion states [19]. Beyond external threats, internal system resilience and specifically the AI's performance under "out-of-distribution" scenarios where sensor noise or clinical anomalies deviate from training data, must be rigorously validated to prevent algorithmic failure [20]. Addressing these cybersecurity and structural vulnerabilities is not merely a technical requirement but a fundamental ethical imperative to ensure a robust implementation of AI-driven technologies in high-stakes trauma environments.

In conclusion, microcirculatory dysfunction represents a key component of trauma pathophysiology that is not captured by conventional hemodynamic monitoring. While sublingual microcirculatory assessment offers unique physiological insight, its clinical adoption has been limited by technical and analytical challenges. AI has the potential to overcome several of these barriers by enabling automated analysis and facilitating integration with systemic monitoring. At present, this approach should be viewed as promising but not yet practice-changing. If validated in future outcome-driven studies, AI-augmented microcirculatory monitoring may represent an important step toward more precise and individualized trauma resuscitation.

SUPPLEMENTARY INFORMATION

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REFERENCES

[1] Eastridge BJ, Holcomb JB, Shackelford S. Outcomes of traumatic hemorrhagic shock and the epidemiology of preventable death from injury. Transfusion. 2019; 59(S2): 1423–1428.
doi: https://doi.org/10.1111/trf.15161

[2] Hutchings SD, Naumann DN, Hopkins P, Mellis C, Riozzi P, Sartini S, et al. Microcirculatory impairment is associated with multiple organ dysfunction following traumatic hemorrhagic shock: the MICROSHOCK study. Crit Care Med. 2018; 46(9): e889-e896
doi: https://doi.org/10.1097/CCM.0000000000003275

[3] Tachon G, Harrois A, Tanaka S, Kato H, Huet O, Pottecher J, et al. Microcirculatory alterations in traumatic hemorrhagic shock. Crit Care Med. 2014; 42(6): 1433–1441.
doi: https://doi.org/10.1097/CCM.0000000000000223

[4] Johansson PI, Stensballe J, Ostrowski SR. Shock induced endotheliopathy (SHINE) in acute critical illness - a unifying pathophysiologic mechanism. Crit Care. 2017; 21(1): 25.
doi: https://doi.org/10.1186/s13054-017-1605-5

[5] Ince C, Boerma EC, Cecconi M, De Backer D, Shapiro NI, Duranteau J, et al. Second consensus on the assessment of sublingual microcirculation in critically ill patients. Intensive Care Med. 2018; 44(3): 281–299. doi: https://doi.org/10.1007/s00134-018-5070-7

[6] Naumann DN, Mellis C, Smith IM, Mamuza J, Skene I, Harris T, et al. Safety and feasibility of sublingual microcirculation assessment in the emergency department for civilian and military patients with traumatic haemorrhagic shock: a prospective cohort study. BMJ Open. 2016; 6(12): e014162. doi: https://doi.org/10.1136/bmjopen-2016-014162

[7] Damiani E, Ince C, Scorcella C, Domizi R, Carsetti A, Mininno N, et al. Impact of microcirculatory video quality on evaluation of sublingual microcirculation. J Clin Monit Comput. 2017; 31(5): 981–988. doi: https://doi.org/10.1007/s10877-016-9924-7

[8] Dubin A, KanooreEdul VS, Caminos Eguillor JF, Ferrara G. Monitoring microcirculation: utility and barriers. Vasc Health Risk Manag. 2020; 16: 577–589. doi: https://doi.org/10.2147/VHRM.S242635

[9] Guay CS, Khebir M, Shiva Shahiri T, Szilagyi A, Cole EE, Simoneau G, et al. Evaluation of automated microvascular flow analysis software AVA 4. Intensive Care Med Exp. 2021; 9(1): 15. doi: https://doi.org/10.1186/s40635-021-00380-0

[10] Montomoli J, Hilty MP, Ince C. Artificial intelligence in intensive care. Minerva Anestesiol. 2022; 88(12): 1066–1072. doi: https://doi.org/10.23736/S0375-9393.22.16739-8

[11] Puticiu M, Cimpoesu D, Pop F, Ciumanghel I, Rotaru LT, Oprita B, et al. AI-enhanced POCUS in emergency care. Diagnostics (Basel). 2026; 16(2): 353. doi: https://doi.org/10.23736/S0375-9393.22.16739-8

[12] Hilty MP, Guerci P, Ince Y, Toraman F, Ince C, et al. MicroTools enables automated quantification of capillary density. Commun Biol. 2019; 2: 217. doi: https://doi.org/10.1038/s42003-019-0473-8

[13] Hilty MP, Akin S, Boerma C, Donati A, Erdem Ö, Giaccaglia P, et al. Automated Algorithm Analysis of Sublingual Microcirculation in an International Multicentral Database Identifies Alterations Associated With Disease and Mechanism of Resuscitation. Crit Care Med. 2020; 48(10): e864-e875. doi: https://doi.org/10.1097/CCM.0000000000004491

[14] Hilty MP, Favaron E, Wendel Garcia PD, Ahiska Y, Uz Z, Akin S, et al. Microcirculatory alterations in critically ill COVID-19 patients analyzed using artificial intelligence. Crit Care. 2022; 26(1): 311. doi: https://doi.org/10.1186/s13054-022-04190-y

[15] Moazemi S, Vahdati S, Li J, Kalkhoff S, Castano LJV, Dewitz B, et al. Artificial intelligence for clinical decision support for monitoring patients in cardiovascular ICUs: A systematic review. Front Med (Lausanne). 2023;10: 1109411. doi: https://doi.org/10.3389/fmed.2023.1109411

[16] KanooreEdul VS, Dubin A. Pitfalls in use of microcirculation as a resuscitation goal. Intensive Care Med. 2023; 49: 1268-1269. doi: https://doi.org/10.1007/s00134-023-07191-9

[17] Hilty MP, Duranteau J, Montomoli J, Yu-Chang Yeh T, Ince C, et al. A microcirculation-guided trial doomed to fail. Intensive Care Med. 2023; 49(12): 1557-1558. doi: https://doi.org/10.1007/s00134-023-07223-4

[18] Granholm F, Tin D, Ciottone GR. Impact of hybrid warfare on emergency medicine. Am J Emerg Med. 2022; 62: 96-100. doi: https://doi.org/10.1016/j.ajem.2022.10.021

[19] Finlayson SG, Bowers JD, Ito J, Zittrain JL, Beam AL, Kohane IS. Adversarial attacks on medical machine learning. Science. 2019; 363(6433): 1287-1289. doi: https://doi.org/10.1126/science.aaw4399

[20] Amodei D, Olah C, Steinhardt J, Christiano P, Schulman J, Mané D. Concrete problems in AI safety. arXiv preprint. 2016; 1606.06565. doi: https://doi.org/10.48550/arXiv.1606.06565