Multimodal machine learning in chronic wound management: A bright future for biomaterials and soft materials

S. Melinte (1), J. Yunda (1), G. Torres (1), E. Eqlimi (2), D. Flandre (1), S. Szunerits (3), C. Varon (2,4), M. Op de Beeck (5), J. Vanfleteren (5), R. Speeckaert (6), S. Smet (6), and A. Nonclercq (2)

(1) ICTEAM, Université catholique de Louvain, 1348 Louvain-la-Neuve, Belgium
(2) BEAMS, Université Libre de Bruxelles, 1050 Brussels, Belgium
(3) Univ. Lille, CNRS, Centrale Lille, Univ. Polytechnique Hauts-de-France, UMR 8520 - IEMN, Lille, France
(4) Department of Electrical Engineering, KU Leuven, 3001 Leuven, Belgium
(5) Center for Microsystems Technology, IMEC and Ghent University, 9052 Ghent, Belgium
(6) Department of Dermatology, Ghent University Hospital, 9000 Ghent, Belgium

*Contact sorin.melinte@uclouvain.be

Wound management has been a challenge in healthcare, affecting the patient's quality of life and presenting a time-consuming task for healthcare professionals. Nowadays, assessing ulcer evolution and healing time is mainly performed by visual inspection, especially according to the TIME (Tissue, Infection, Moisture, and wound Edge) assessment guidelines; hence, the clinical protocol involves subjective decisions for the treatment. On the one hand, this hospital practice has been recently expanded to TIMERS (Tissue, Infection/Inflammation, Moisture, wound Edge, Repair/Regeneration, and Social) [1]. On the other hand, for ambulatory care, it is not common that the wound assessment proceeds through detailed quantitative analysis.

While decision-making remains demanding, emerging image-processing solutions that allow the segmentation and determination of the healing stage of the wound from images provide alternative pathways and unique support to clinical diagnostics. Interestingly, hyperspectral imaging, a paradigm in remote sensing, is becoming a key technique adopted in healthcare [2]. The question is whether other transformative technologies for diagnostics, like wearables, could significantly complement the multimodal assessment of wound healing through time-resolved recording of specific health parameters and edge computing.

Thanks to developments in nanoelectronics, two-dimensional (2D) biomaterials (*e.g.* graphene) and soft materials (*e.g.* hydrogels), biosensors can be integrated into smart bandages, allowing wound control without the need for qualified personnel. Here, we critically discuss the advancement of artificial intelligence methods and the handling of data from different sources, such as different wearables built with 2D materials, in conjunction with the use of hyperspectral imaging, for the (self-)management of venous leg ulcers and diabetic foot ulcers [3]. For each type of wound, we provide predictions of valuable biomaterials and soft materials for generating wearable data networks that employ computing work at the edge to minimize hospital admissions and reduce wound healing time. This discussion will directly benefit initiatives proposing smart patches for wound assessment and treatment [4], to help healthcare providers decide on the most appropriate diagnosis for complex wounds, leading to more efficient healthcare.

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[2] G. Saiko, *et al.* Hyperspectral imaging in wound care: A systematic review. *Int. Wound J.* 2020, 17, 1840.

[3] H. Ceren Ates *et al*. End-to-end design of wearable sensors. *Nat. Rev. Mater.* 2022, 7, 887. [4] AI-SWEEP “AI-enabling Smart Wound carE Electronics Patches”, supported by the Belgian State - Secretary of State for Digitalization (M. Michel) and GSkin “Growth factors-rich EVs-functionalized graphene-on-hydrogel based skin bioactive regeneration scaffolds“, under the umbrella of EuroNanoMed III.