Human Digital-Twin-Style Models for Early Deterioration Prediction in Austere Trauma Care: A Validation-Readiness Simulation Study

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Early prediction of physiologic deterioration in austere trauma care remains a major challenge in military and prehospital medicine, especially in prolonged field care scenarios where evacuation may be delayed and monitoring, laboratory access, and data continuity are limited. Although digital-twin-style models have potential to support individualized deterioration prediction, their performance under degraded field-like data conditions remains insufficiently validated. This study proposes a simulation-based validation framework to test whether a dynamic digital-twin-style model maintains predictive reliability as data availability progressively worsens, and to compare its performance with that of a static baseline model.

Synthetic patient agents are modeled using two complementary clinical scoring frameworks: NEWS2 for vital-sign-based deterioration under sparse monitoring conditions and SOFA for organ dysfunction under fuller hospital-quality data. This dual-framework structure is used to approximate the transition from data-rich to data-limited assessment in austere trauma environments. Two model types are evaluated across five simulation conditions: full hospital-quality data, sparse vital-sign collection, delayed laboratory availability, missing data, and a combined austere-data condition intended to approximate prolonged field care. The static model

estimates deterioration risk from an initial patient snapshot, whereas the dynamic digital-twin-style model updates risk as new patient data become available.

Performance will be assessed using AUROC, AUPRC, sensitivity, specificity, calibration, Brier score, and lead time to deterioration prediction. We hypothesize that the dynamic model will outperform the static baseline when full data are available but will show declining performance as data degradation increases. This pattern would identify both the promise and the current validation limits of digital-twin-style deterioration models for operational use.

This work contributes to modeling and simulation by introducing a replicable validation framework for testing deterioration models under progressive data degradation, by computationally approximating the shift from hospital-quality to austere assessment conditions, and by defining validation-readiness benchmarks for digital-twin-style models before deployment in military trauma care, disaster response, and other resource-limited environments.