

From bench to bedside: translational research integrating polymer substrate experimental data with PM&R clinical outcomes via AI

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Editorial

I have been given the opportunity to feature my work in an editorial in the first issue of the International Physical Medicine & Rehabilitation Journal of for 2026. The field of Physical Medicine and Rehabilitation (PM&R) is undergoing a critical transformation, moving from generalized interventions toward a model of precision rehabilitation. This shift is particularly urgent in the burgeoning sub-specialty of cancer rehabilitation, where managing the complex sequelae of cancer and its treatments—including debilitating fatigue, functional decline, and the constant threat of recurrence—demands highly personalized strategies. To achieve true precision, PM&R must bridge the existing gap between molecular and cellular insights and patient-level functional outcomes. A compelling frontier in this translational effort is the integration of advanced *in vitro* data, such as that derived from polymer substrate-based cancer models, with real-world PM&R clinical data, unified by the power of Artificial Intelligence (AI).

Current cancer rehabilitation practice often operates on an empirical basis, relying on standardized protocols adapted for general oncological guidelines. However, the biological drivers of disability and recurrence are intrinsically linked to the unique tumor biology of the individual patient, notably the presence and activity of Cancer Stem Cells (CSCs). CSCs are a small population within a tumor responsible for metastasis, therapeutic resistance, and eventual recurrence, acting as the ultimate determinant of long-term prognosis. Our research, focusing on the breast cancer microenvironment using polymer substrates, has demonstrated the profound influence of the Extracellular Matrix (ECM) stiffness and composition on CSC phenotype, survival, and metastatic potential. These findings are also related to polymer nanoparticle research targeting cancer stem cells.¹ These sophisticated polymer platforms offer a high-fidelity, high-throughput environment to model the *in vivo* metastatic niche, providing an environment as a biocompatible platform also used in the management of brain tumors,² and yielding rich datasets on cell migration, differentiation, and gene expression in response to various stimuli.

The core challenge lies in making this sophisticated “Bench Data” clinically meaningful for the PM&R specialist. This is where AI and Machine Learning (ML) become indispensable translational tools. The polymer substrate data provides an intricate, causal understanding of how a tumor’s microenvironment influences its most aggressive cells (CSCs). Conversely, PM&R clinical data—which includes Patient-Reported Outcomes (PROs), gait analysis, muscle strength measurements, fatigue scores, and long-term functional status—represents the *phenotypic* manifestation of the patient’s

underlying biological state. Integrating these disparate data types requires a structured, multi-modal AI approach. ML algorithms can be trained to identify correlations and predictive patterns invisible to the human eye, and AI-designed proteins are also being explored for personalized cancer treatment.³ For instance, a model can use the specific biophysical properties of a patient’s tumor (as simulated on a polymer substrate) to predict their likelihood of experiencing severe post-treatment fatigue or functional decline. A new approach utilizing AI to identify treatments that reprogram and destroy CSCs is also under development,⁴ suggesting the clinical potential of this integration. AI can then couple this biological risk profile with clinical outcomes to generate a personalized “Rehabilitation Risk Score” that informs the intensity, type, and timing of PM&R intervention. The translational pathway is as follows: Polymer Substrate Data (CSCs, cell mechanics, molecular profiles) → Feature Engineering and Integration with Clinical Data (Functional scores, imaging, treatment history) → AI/ML Modeling (Predictive analytics) → Precision PM&R Intervention. This integration would allow PM&R to move beyond general management to become a proactive, predictive field. For example, if the *in vitro* data suggests that a particular chemotherapeutic agent, combined with low mechanical strain (mimicking prolonged rest), enhances the aggressive properties of a patient’s CSCs, the AI model could signal an urgent need for an aggressive, targeted exercise regimen to counteract this effect. Conversely, if the model predicts a high risk of musculoskeletal complications based on clinical data, but low CSC activity based on the *in vitro* model, the focus of the rehabilitation might shift to function preservation with less emphasis on anti-recurrence strategies.

In conclusion, the convergence of advanced biomaterial science (polymer substrates), cancer biology (CSCs), and PM&R clinical practice, facilitated by AI, marks a powerful paradigm shift. It empowers PM&R physicians to utilize molecular-level insights to drive clinical decision-making, offering cancer survivors not just functional recovery, but strategies that potentially impact long-term prognosis by targeting the roots of recurrence and disability. The future of cancer rehabilitation is one where the fundamental discoveries made on engineered substrates translate directly into life-changing,

personalized care protocols for patients worldwide, fundamentally redefining the scope and impact of the specialty.

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None.

Conflicts of interest

The author declares that there are no conflicts of interest.

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