Quantum pressure and memory effects in cancer modeling: a fractional calculus neural network approach

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Abstract

This study presents a comparative analysis of an integer order and fractional order differential equation models describing the cancer immune system interactions. Incorporating quantum pressure and memory effects via Caputo fractional derivatives, the models represent tumor, immune, mutant, and suppressor cell populations. Fundamental properties including non-negativity, boundedness, and solution existence along with uniqueness are established for both formulations. The fractional model consistently predicts higher cell population levels. Immune cells show the largest deviation, with a 37.5% increase in maximum population and a 37.6% higher equilibrium compared to the integer model. Tumor and suppressor cells also exhibit increases of up to 18.5% and 25.4%, respectively. Both immune and suppressor cells exceed their respective carrying capacities K_2 and K_4 by 18.1% and 76.7% under the fractional model. Scenario-based comparison indicates a strong agreement under robust immune responses (differences below 0.5%), but in marked divergence tumor resistance conditions, the fractional model predicts 15.5% higher tumor equilibrium and 25.6% lower mutant cell populations. Two neural network validation studies support these findings. The first, comparing Caputo and integer models, shows significant performance gains, including a 72.6% reduction in RMSE. The second evaluates multiple fractional formulations, thereby identifying Hilfer derivatives as the most accurate (50.6% RMSE improvement), while Caputo derivatives demonstrate a superior robustness under parameter variation. These results highlight the value of memory-based modeling in capturing complex cancer immune dynamics and suggest potential applications in the personalized treatment optimization.

Author keywords

Fractional model; Memory effects; Neural netwroks; Quantum pressure; Tumor

Indexed keywords

Engineering controlled terms

Cell culture; Cell proliferation; Differential equations; Diseases; Immune system; Neural networks

Engineering uncontrolled terms

Cancer models; Cell populations; Comparative analyzes; Fractional calculus; Fractional model; Memory effects; Neural netwroks; Neural-networks; Quantum memory; Quantum pressure

Engineering main heading

Tumors

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