

Static magnetic field effects on cancer cells at atomic and molecular levels

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Abstract

Introduction: Static magnetic fields can influence biological processes at atomic, molecular, and cellular levels. They affect radical pairs through singlet–triplet oscillations, altering cellular chemical pathways. Increased Ca^{2+} levels under 6 mT SMF exposure can modify apoptosis and enhance cell survival under stress [1]. 8, 30 and 300 mT SMF also can cause morphological changes (cell rounding, detachment, and bleb formation), reduction of microvilli and surface membrane damage, Loss of cell alignment and increase in cell membrane roughness [2]. In triple-negative breast cancer, exposure of MDA-MB-231 cells to 5, 10, and 15 mT SMF induces morphological alterations and G0/G1 cell-cycle arrest [3]. Moreover, moderate and strong static magnetic fields directly inhibit proteins such as EGFR by altering their molecular orientation and suppressing cancer cell proliferation [4]. A 1-tesla static magnetic field also reduces cancer growth by inhibiting the Akt/mTOR signaling pathway. Overall, magnetic fields show potential as a non-invasive approach for cancer therapy [5].

Methods: Cell culture. Microfluorometry measured intracellular Ca^{2+} , and flow cytometry quantified apoptosis and cell populations. H&E, phalloidin staining, fluorescence imaging, SEM, TEM, and AFM assessed morphology from cellular to nanoscale levels. MTT assay evaluated cell viability, and cell-cycle analysis determined phase distribution. Kinase assays measured EGFR and B-Raf phosphorylation, and ImageJ quantified protein signals. STM visualized EGFR at atomic resolution, while MD simulations modeled its structural dynamics. AMBER, TIP3P, and Ewald-PME defined force fields, water behavior, and electrostatics in simulations. Statistical significance between groups was tested using the t-test.

Results and discussion: SMFs, depending on intensity, can alter cell morphology, cytoskeleton organization, and cell survival or death. Low–medium fields (10–15 mT) induce apoptosis and cell-cycle arrest in cancer cells. Higher fields (80–3000 G) cause strong morphological changes and apoptosis in glioblastoma cells. Strong SMFs (1–9 T) suppress cancer growth by inhibiting EGFR and Akt/mTOR signaling and enhance mTOR-inhibitor efficacy.

Conclusion: Static magnetic fields exert intensity-dependent effects on cancer cells and can influence cellular morphology and cytoskeletal organization. High-intensity SMFs are capable of disrupting EGFR activation and inhibiting downstream Akt/mTOR signalling. This process ultimately leads to reduced proliferation and growth of tumor cells. Overall, these findings suggest that SMFs may play a potential role in inhibiting cancer cell growth at the atomic and molecular levels.

Keywords: Biophysics, Static magnetic field, Cancer cells, Magnetic susceptibility, Atomic and molecular effect

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