CLAIMS

1. A comprehensive adaptive cytokine regulation system for immune cell expansion comprising: (a) a closed-loop bioreactor configured to expand immune cells ex vivo; (b) multiple cytokine reservoirs containing one or more cytokines selected from IL-2, IL-7, IL-15, IL-21, IL-12, IFN-gamma, and GM-CSF; (c) real-time cytokine concentration sensors integrated within the bioreactor; (d) immune phenotype detection modules for real-time detection of markers including CD25, PD-1, CD127, and CD45RA; (e) a programmable software-controlled system that dynamically modulates cytokine infusion rates based on sensor inputs and pre-defined immune logic algorithms; (f) safety controls to maintain cytokine levels within predetermined safe ranges; and (g) a data analytics module configured to log, analyze, and optimize cytokine usage and immune phenotype evolution.
2. The system of claim 1, further comprising modules to prime immune cells ex vivo using patient-derived autologous tumor lysates, enhancing tumor-specific immune cell education and memory cell induction.
3. The system of claim 1, wherein cytokine infusion rates are automatically adjusted based on real-time IL-2 and IL-7 concentration feedback to maintain cell viability and minimize T cell exhaustion.
4. The system of claim 1, wherein cytokine delivery transitions dynamically from IL-2 dominant infusion to IL-15 and IL-21 based on changes in immune cell phenotypes detected by surface markers.
5. The system of claim 1, wherein IL-12 is administered as a controlled pulse based on immune viability thresholds, PD-1 expression, and IFN-gamma response readiness.
6. The system of claim 1, wherein cytokine feedback algorithms utilize longitudinal cytokine consumption data, patient-specific immune phenotypes, and real-time metabolic indicators.
7. The system of claim 1, integrated within a GMP-compliant manufacturing process, supporting closed-system immune cell expansion without manual interventions.
8. A method of producing a personalized, tumor-specific immune cell therapy comprising: (a) isolating immune cells from a patient; (b) incubating the immune cells ex vivo with autologous tumor lysates in a cytokine-conditioned medium within a closed-loop bioreactor; (c) monitoring cytokine concentrations and immune phenotype markers in real-time; (d) dynamically modulating cytokine concentrations to optimize immune cell expansion and tumor-specific immune education; (e) harvesting a memory-enriched, tumor-specific immune cell product optimized for therapeutic efficacy.
9. The method of claim 8, wherein the harvested cell product demonstrates enhanced CD45RO+CCR7+ memory cell populations, reduced PD-1 expression, and elevated IFN-gamma secretion relative to conventional static cytokine protocols.
10. The method of claim 8, further comprising adaptive re-dosing of expanded immune cells based on longitudinal patient-specific responses to therapy.
11. A computer-readable medium containing executable instructions that, when executed by a processor, perform: (a) real-time collection and analysis of cytokine and immune phenotype sensor data; (b) dynamic cytokine infusion adjustments based on adaptive feedback control algorithms; (c) predictive optimization of cytokine delivery regimens based on historical patient response data.