Origin-Decoy-Extraction-System (ODES)

Concept Proposal for a Preclinical Research Project

1. Project Title

Origin-Decoy-Extraction-System (ODES):

Magnetic T-cell-mimetic Nanoparticles for Physical Capture and Ex-Vivo Removal of Free HIV Particles

2. Abstract

The ODES concept introduces a novel physical–technical strategy for reducing HIV viral load in the bloodstream.

Instead of relying on chemical suppression, the system uses:

1. T-cell-mimetic decoy nanoparticles that selectively bind HIV,
2. superparamagnetic cores enabling later magnetic separation,
3. an ex-vivo magnetic filtration device that removes virus–decoy complexes from circulating blood.

The goal is not to cure HIV but to physically reduce free viral particles, complementing existing therapies and lowering viral burden.

This proposal outlines a preclinical research framework to evaluate feasibility.

3. Background and Motivation

Despite highly effective antiretroviral therapy (ART), HIV remains incurable due to:

- persistent latent reservoirs,
- lifelong medication requirements,
- organ toxicity from long-term drug exposure,
- emerging drug resistance,
- high treatment costs in many regions.

ODES proposes an alternative paradigm:

capture the virus physically, bind it to engineered decoys, and remove it outside the body.

4. Project Objectives

This project aims to evaluate the technical feasibility of:

- synthesizing biocompatible, T-cell-mimetic magnetic nanoparticles,
- assessing their binding efficiency to HIV-like pseudoviruses,
- developing a microfluidic magnetic separation system,
- studying biocompatibility and clearance behavior in preclinical models.

The project is preclinical only and does not involve human application.

5. Concept Overview

5.1 Module A – Decoy Nanoparticles (“Ghost Cells”)

Design Features:

- Surface:
- Presentation of CD4-like structures (and optionally CCR5/CXCR4).
- Purpose: trick HIV into recognizing the nanoparticle as a target cell.
- Core:
- Superparamagnetic Fe_3O_4 nanoparticles embedded in a biocompatible matrix.
- Enables magnetic extraction.
- Shell:
- Polymer coating or cell-membrane-coated nanoparticle technology to minimize immune activation.

Function:

Free HIV particles bind to the decoy and become physically attached.

5.2 Module B – Viral Binding in the Bloodstream

- Decoy nanoparticles are administered intravenously.
- They circulate passively.
- HIV binds to the decoy instead of real T-cells.
- Virus–decoy complexes form and remain magnetically addressable.

Advantage:

The virus is intercepted before it can infect immune cells.

5.3 Module C – Ex-Vivo Magnetic Extraction

- After a defined circulation period, the patient's blood is passed through an external device (dialysis-like).
- A microfluidic chamber generates a focused magnetic field.
- Magnetic decoy–virus complexes are captured and removed.
- Purified blood is returned immediately.

Goal:

Physical reduction of circulating viral particles.

6. Theoretical Advantages

Feature	Conventional ART	ODES (Theoretical)
Mechanism	Chemical suppression	Physical capture & removal
Systemic burden	High	Minimal (ex-vivo)
Target	Viral replication	Free viral particles
Duration	Lifelong	Cyclical sessions
Resistance risk	Significant	Low (non-chemical)

7. Scientific and Technical Challenges

- Achieving high specificity of decoy binding
- Avoiding immune activation or nanoparticle accumulation
- Ensuring efficient magnetic separation
- Addressing latent reservoirs not present in blood
- Controlling nanoparticle distribution and clearance

8. Work Packages (WP)

WP1 – Synthesis & Characterization

- Fabrication of T-cell-mimetic magnetic nanoparticles
- Electron microscopy, DLS, zeta potential
- Surface functionalization optimization

WP2 – In-Vitro Binding Studies

- Use of HIV-like pseudoviruses
- Quantification of binding efficiency
- Comparison of different receptor configurations

WP3 – Magnetic Microfluidics

- Development of a microfluidic separation chamber
- Simulation of flow and magnetic field profiles
- Measurement of separation efficiency

WP4 – Biocompatibility Studies

- Cell culture assays
- Toxicity and immune activation analysis
- Clearance and biodistribution studies

WP5 – System Integration

- Conceptual design of a compact clinical prototype
- Evaluation of process stability and scalability

9. Expected Outcomes

- Technical feasibility assessment
- Binding and separation efficiency data
- Preliminary safety and compatibility data
- Risk analysis
- Foundation for future preclinical development

10. Summary

The Origin-Decoy-Extraction-System (ODES) proposes a new physical approach to HIV management.

By combining:

- biomimetic nanotechnology,
- magnetic separation,
- microfluidic engineering,

ODES aims to physically remove free HIV particles from the bloodstream.

This concept is intended as a research and development initiative, forming the basis for future preclinical studies.

Grant-Ready Proposal Summary

Origin-Decoy-Extraction-System (ODES)

Magnetic T-Cell-Mimetic Nanoparticles for Physical Capture and Ex-Vivo Removal of HIV Particles

1. Project Summary / Executive Overview

The Origin-Decoy-Extraction-System (ODES) proposes a novel, physics-based strategy for reducing circulating HIV particles by combining biomimetic nanotechnology with magnetic microfluidic separation.

Instead of suppressing viral replication chemically, ODES aims to capture free HIV particles using engineered T-cell-mimetic nanoparticles and subsequently remove them ex-vivo through a magnetic filtration device.

This project will evaluate the technical feasibility, biocompatibility, and separation efficiency of this approach in a preclinical research setting.

2. Scientific Rationale and Innovation

Unmet Need

Current antiretroviral therapy (ART) effectively suppresses HIV replication but requires lifelong adherence, causes cumulative organ toxicity, and does not eliminate latent reservoirs.

There is a critical need for complementary, non-chemical strategies that reduce viral burden without systemic toxicity.

Innovation

ODES introduces three innovations:

1. T-cell-mimetic decoy nanoparticles presenting CD4-like surface structures to selectively bind HIV.

2. Superparamagnetic nanoparticle cores enabling precise magnetic manipulation.

3. A microfluidic ex-vivo filtration system that physically removes virus–decoy complexes from circulating blood.

This represents a paradigm shift from biochemical suppression to physical extraction.

3. Objectives and Expected Impact

Primary Objective

To establish the feasibility of a nanoparticle-based, magnetically assisted system for capturing and removing free HIV particles from blood.

Secondary Objectives

- Develop and characterize T-cell-mimetic magnetic nanoparticles.
- Quantify binding efficiency to HIV-like pseudoviruses.
- Demonstrate magnetic separation in a microfluidic environment.
- Assess biocompatibility and clearance behavior in vitro.
- Provide a technical foundation for future preclinical studies.

Expected Impact

ODES could:

- reduce viral load without chemical toxicity,
- complement existing ART regimens,
- lower the risk of resistance development,
- provide a scalable, hardware-based therapeutic platform.

4. Methodology and Work Plan

WP1 – Nanoparticle Synthesis and Characterization

- Fabrication of CD4-mimetic magnetic nanoparticles
- Surface functionalization (CD4, CCR5/CXCR4 analogues)
- Structural and physicochemical analysis (TEM, DLS, zeta potential)

WP2 – In-Vitro Viral Binding Studies

- Use of HIV-like pseudoviruses
- Quantitative binding assays
- Optimization of receptor density and nanoparticle size

WP3 – Magnetic Microfluidic Separation

- Design of a microfluidic separation chamber
- Simulation of magnetic field gradients
- Measurement of capture efficiency under physiological flow conditions

WP4 – Biocompatibility and Safety Assessment

- Cytotoxicity assays
- Immune activation profiling
- Nanoparticle clearance and degradation studies

WP5 – System Integration and Prototype Design

- Integration of nanoparticle and microfluidic components
- Conceptual design of a compact ex-vivo filtration unit
- Evaluation of scalability and manufacturability

5. Feasibility and Preliminary Basis

ODES builds on established technologies:

- Cell-membrane-coated nanoparticles (widely studied in virology)
- Superparamagnetic iron oxide nanoparticles (SPIONs) (clinically used in imaging)
- Microfluidic magnetic separation (standard in diagnostics)
- Dialysis/Apheresis systems (clinically validated blood purification platforms)

The novelty lies in combining these technologies into a unified therapeutic concept.

6. Ethical and Safety Considerations

- All work is preclinical and limited to in-vitro and ex-vivo models.
- No human or animal application is proposed at this stage.
- Nanoparticle safety will be rigorously evaluated before any future translational steps.

7. Alignment with Funding Priorities

NIH / NIAID

- HIV/AIDS therapeutic innovation
- Nanotechnology for infectious diseases
- Non-pharmacological intervention strategies

NSF

- Convergence research (physics + nanotechnology + biology)
- High-risk, high-reward technological innovation

EU Horizon Europe

- Advanced nanomaterials for health
- Next-generation medical technologies
- Cross-disciplinary biomedical engineering

ODES fits directly into these priority areas.

8. Expected Deliverables

- A validated nanoparticle synthesis protocol
- Quantitative viral binding data
- A functional microfluidic magnetic separation prototype
- Biocompatibility and safety profile
- A complete feasibility report for follow-up funding

9. Long-Term Vision

ODES is envisioned as a modular therapeutic platform that could be adapted to:

- other viral pathogens,
- circulating toxins,
- immune complexes,
- or tumor-derived particles.

It represents a new class of physical, hardware-assisted biomedical interventions.

💉 1. Binding Affinity (Module A & B)

To ensure the "Ghost Cells" (Nanoparticles) capture the virus efficiently, we calculate the binding rate between the Nanoparticles (NP) and the free Virus particles (V):

$$R_{bind} = k_{on} \cdot [NP] \cdot [V] - k_{off} \cdot [NP - V]$$

- k_{on}/k_{off}: Rate constants for association and dissociation (optimized via the CD4-mimetic surface).
- $[NP]$: Concentration of magnetic nanoparticles in the blood.
- **Goal:** Maximize R_{bind} so the virus is "tricked" into binding with the decoys before it can reach real T-cells.

🧲 2. Magnetic Force (Module C - Extraction)

Once the complex enters the external device (filter), the magnetic force (F_m) must exceed the hydrodynamic drag force (F_d) of the flowing blood:

$$F_m = \frac{1}{\mu_0} \cdot \chi_{eff} \cdot V_p \cdot (B \cdot \nabla)B$$

- χ_{eff}: Effective magnetic susceptibility of the particle.
- V_p: Volume of the magnetic core.
- $(B \cdot \nabla)B$: The magnetic field gradient (the "pulling power" within the filter).

3. The Flow Condition (Drag Force)

To prevent the virus from simply washing through the filter, we calculate the resistance exerted by the blood (Stokes Drag):

$$F_d = 6 \cdot \pi \cdot \eta \cdot r \cdot \Delta v$$

- η: Dynamic viscosity of the blood.
- r: Radius of the nanoparticle-virus complex.
- Δv: Velocity difference between the particle and the blood flow.
- **Condition for Success:** $F_m > F_d$ (The magnetic force wins against the flow).

4. Clearance Efficiency (Total Output)

The reduction of the viral load (V_{red}) after an ODES session can be calculated as follows:

$$V_{red}(t) = V_0 \cdot e^{-(\frac{Q \cdot E}{V_{body}}) \cdot t}$$

- V_0: Initial viral load.
- Q: Blood flow rate through the ODES device.
- E: Extraction efficiency of the magnetic filter (targeted at >0.99 or 99%).
- V_{body}: Total blood volume of the patient.
- t: Duration of the treatment session.

Summary of "Auron-Parameters"

To operate the system safely, we must balance these factors:

1. **Probe Concentration:** High enough for 99% capture, low enough for biocompatibility.
2. **Field Gradient:** Strong enough for filtration, but localized to avoid heating the blood.
3. **Flow Rate (Q):** Carefully adjusted to the patient's blood pressure (Dialysis standard).

"Where there is a will, there is a way – but where there is a vision, we build the bridge. We don't just wait for a cure; we architect the solution."


We are physically
removing the
burden from
your system.
ODES