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Michaelis-Menten Kinetic Modification: The Space Pharmaceuticals Bioavailability Approaches Finasteride

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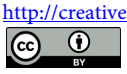

Abstract

This study explores the application of fundamental physics to evaluate the conclusion that, in a microgravity environment, the bioavailability of current pharmacy in space pharmaceuticals can potentially double by excluding substrate concentrations during pharmaceutical preparation. If validated through prioritized vivo experiments or clinical trials, these findings could significantly advance research and development in pharmaceutical sciences.

Keywords

Microgravity, Bioavailability, Space Pharmaceuticals, Substrates, Pharmaceutical Development

1. Introduction

In biophysics and biochemistry, the famous Michaelis-Menten kinetics is widely known [1]-[6]. Enzyme kinetics and inhibition are crucial concepts in understanding how enzymes work. Michaelis-Menten kinetics describes how enzyme reaction rates change with substrate concentration, using key parameters like $V_{\max}$ and K_M to characterize enzyme behaviors. Inhibitors can alter enzyme activity in different ways. The competitive inhibitors fight for the active site, non-competitive inhibitors bind elsewhere, and uncompetitive inhibitors only attach to enzyme-substrate complexes. These mechanisms affect $V_{\max}$ and K_M differently, helping scientists develop targeted drugs. The model is used in a variety of biochemical situations other than enzyme-substrate interaction, including antigen-antibody binding, DNA-DNA hybridization, and protein-protein interaction

[7] [8]. It can be used to characterize a generic biochemical reaction in the same way that the Langmuir equation can be used to model the generic adsorption of biomolecule species. In fields of pharmaceutical physics, it is widely recognized that most drugs follow first-order reaction kinetics. Secondary reactions, however, often describe the relationship between drug metabolism and excretion rates as proportional to the square of the drug concentration. This implies that as drug concentration increases, the metabolism and excretion rates rise more rapidly, while the drug's half-life is extended—for instance, as observed with aspirin administration.

Notably, the findings in *Space Pharmaceuticals* (2023) suggest that the concentration of pharmaceuticals in a microgravity environment tends to exhibit uniform reaction characteristics. Each reaction point adheres to the principles of parabolic equations and demonstrates second-order biochemical reaction dynamics, as well as the biophysical properties associated with SHO (simple harmonic oscillator) quantum tunneling [7] of drug molecules under specific conditions. This perspective is particularly significant because it highlights the potential for a substantial improvement in bioavailability within pharmacology. Our research on the application of physics to pharmaceutical reactions aims to address and overcome key quality control challenges faced in terrestrial pharmaceutical development.

2. Results and Discussion

2.1 Modification of Michaelis-Menten Kinetics in Microgravity Environments

To begin, let us clarify the notations used: **[S]** represents the concentration of substrates, which also corresponds to the pharmaceutical formulation during the production process. According to Michaelis-Menten kinetics, it is widely understood that

$$V_0 = V_{\max} \frac{[S]}{K_M + [S]} \tag{2.1}$$

In the first order reaction, $K_M = [S]$ [1]:

$$V_0 = \frac{V_{\max}}{2} \tag{2.2}$$

Above, [S] denotes the substrate concentration, while Km represents the Michaelis-Menten constant. In this study, we directly utilize the expression $V_0 = V_{\max}/2$, as the focus is on the dynamics of pharmaceutical processes during experimental production rather than on drug administration in vivo or general clinical trials. Our primary interest lies in scenarios involving microgravity conditions in outer space, specifically the behavior of uniformly concentrated pharmaceuticals in such environ-

[1]In a microgravity environment, such as during the manufacturing of drugs on a spacecraft in outer space, the concentration of drug molecules is evenly dispersed due to the absence of gravitational forces. As a result, the actual substrate concentration is significantly lower than the substrate-enzyme concentration. This distinction will be further explored in the subsequent sections.

ments. This unique context highlights the distinct properties of drug formulations under microgravity, which differ significantly from terrestrial conditions.

2.1.1. Remark 1

Advantages: Based on the principles of Michaelis-Menten kinetics, particularly in enzyme catalysis, the discussion in Eq. (2.2) highlights an important aspect: the "quantum tunneling effect" in biological systems.

Quantum tunneling appears to have limited contribution to enzymatic reactions alone, as it affects both enzymatic and non-enzymatic reactions occurring in solution. However, the tunneling effect—typically increasing reaction rates by a factor of 1000 compared to the classical "over-the-barrier" pathway—is critical for the viability of biological organisms. This underscores its particular importance to biological systems.

In the context of bioavailability, tunneling aligns with the stages of Liberation, Absorption, Distribution, Metabolism, and Excretion (LADME). At a constant concentration, LADME processes can be completed at half the maximum reaction rate (*i.e.*, consuming 1/2-time). The transition state dynamics, including quantum tunneling effects, are well-documented.

In the specific scenario of "spacecraft in microgravity fields" (*e.g.*, warp-driven spacecraft), the condition $K_M \gg [S]$ becomes a critical requirement for ensuring effective reaction dynamics and maintaining system stability. See Figure 1.

Figure 1. Manufacturing of rectangular tablets in microgravity within a spacecraft. In this environment, the pressure exerted by the liquid center is evenly distributed in all four directions. This uniform application of pressure ensures that the tablets exhibit consistent and uniform concentration throughout.

Based on these observations, it follows that:

$$\begin{aligned} &\frac{1}{V_0} = \frac{1}{V_{\max}} \frac{K_M + [S]}{[S]}, \; K_M \gg [S] \\ &V^2 = V_{\max} \frac{[S]^2}{K_M}, \; n = 2 \end{aligned} \tag{2.3}$$

It is evident that this is a second-order reaction, represented as a parabola (with a width of K_M, a slope of $(K_M / V_{\max})^{-1}$, and a peak at $(C_{\max}, V_{\max})$, as detailed in Eq. (A.5) later on). See Figure 2. This differs significantly from the expressions in Eqs. (2.1) and (2.2).

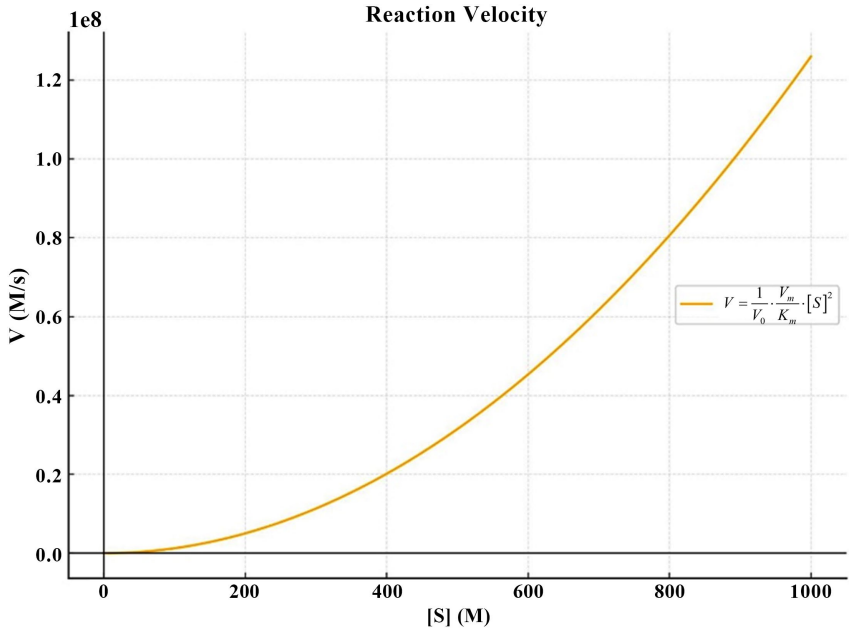

Figure 2. The parabola curve is partially shown. For convenience only the semi-curve is shown.

Based on this, we proceed to derive the formulation for space pharmaceuticals under specific conditions, characterized by a decay rate $t_{1/2} = \frac{1}{K_M [S_0]}$, where $[S_0]$ represents the initial concentration of the reactant at time t_0. If $[S_0] = 2[S]$, a scenario unique to microgravity environments aboard spacecraft—the decay rate is halved, leading to

$$t'_{1/2} = \left(\frac{1}{2}\right) \frac{1}{K_M [S]} \tag{2.4}$$

This represents the expected expression of decay rates for pharmaceuticals manufactured in a microgravity environment, as exemplified by initiatives such as "Space Manufacturing Startup Varda Space" (2023).

2.1.2. Remark 2

Under Earth's gravitational conditions: $[S] = [S_0]$

When manufacturing drugs in a gravity field, fluid molecules naturally accumulate at the bottom due to gravitational forces. Consequently, the concentration of material at the bottom becomes approximately twice that in a vacuum environment.

This phenomenon is further influenced by thermal convection, where fluid molecules move continuously in both upward and downward directions. During the cooling phase, the circulating flow and settling process result in uneven concentrations between the bottom and other parts of the fluid. Based on temperature gradient calculations, this disparity in concentration can be as high as twofold.

2.2. Pharmacokinetics: Area Under the Curve (AUC)

In pharmacology, the widely known calculation method for the Area Under the Curve $\left(\mathrm{AUC}_{\infty}\right)$ is represented as:

$$\mathrm{AUC}_{\infty} = \int_{t=0}^{\infty} \mathrm{C}\mathrm{d}t \tag{2.5}$$

Due to Eq. (2.4), the half-life is clearly reduced to half its original duration during the decay process. Consequently, the actual Area Under the Curve (AUC) can be expressed with the following updated formula:

$$\mathrm{AUC}_{\infty}^{'} = \frac{1}{2}\int_{t=0}^{\infty} \mathrm{C}\mathrm{d}t \tag{2.6}$$

Where $\left(C_{\max}, t_{\max}\right)$, and 1/e is observed on the *x*-axis at approximately 18 - 20 hours (*e.g.*, 18.75% of 100 hours). When utilizing spacecraft for the production of space pharmaceuticals, the substrate concentration [S] is significantly lower compared to other components of the formulation.

This implies that the condition $V_{\max}$ is rapidly achieved during the LADME process. By rearranging Eq. (2.3), we can express the updated relationship as follows:

$$[S] = \sqrt{K_M \frac{VV_0}{V_{\max}}} \tag{2.7}$$

Substituting Eq. (2.7) into Eq. (2.4), hence

$$t_{1/2}' = \left(\frac{1}{2}\right)\frac{1}{K_M\sqrt{K_M\dfrac{VV_0}{V_{\max}}}} \tag{2.7.1}$$

Since the pharmaceutical process is situated at the conclusion of all related processes, the dynamic parameters revert to their initial velocity, such that $V = V_0$. Therefore,

$$t_{1/2}' = \left(\frac{1}{2}\right)\frac{V_{\max}^{0.5}}{K_M^{1.5}V_0},\ 1/\mathrm{e} \tag{2.8}$$

Where 1/e represents the portion of time along the *x*-axis, the concentration of substrates is given by $C = [S]$. This result arises due to the singular nature of the enzyme involved in the reaction. In the case of pharmaceuticals produced in a microgravity environment using spacecraft, the substrate concentration corresponds to the overall uniform concentration achieved under these conditions. Consequently, we have AUC', such as:

$$\mathrm{AUC}_{\infty}^{'} = \frac{1}{2}\int_{t=0}^{t'1/2}\sqrt{K_M\frac{VV_0}{V_{\max}}}\mathrm{d}t \tag{2.9}$$

Since K_M and $\dfrac{V_0}{V_{\max}}$ are constant, it follows that:

$$\mathrm{AUC}_{\infty}^{'} = \frac{1}{2}\sqrt{\frac{V}{K_M^2 V_{\max}}} \tag{2.10}$$

Due to the properties of mathematical power terms $1/K_M^{1.5}$ (refer to Eq. (2.8)), it is evident that the area enclosed by Eq. (2.10) corresponds to scenarios ranging from $C = 50$ to $C = 12.50$. By incorporating the auxiliary coefficient 1/4 ($\mathrm{AUC}_\infty = \int_0^\infty \mathrm{Cdt} \times 1/4$, as shown in Figure 3), it can be deduced that the rate of metabolism of space pharmaceuticals in the body of a vivo is twice that of general pharmaceuticals.

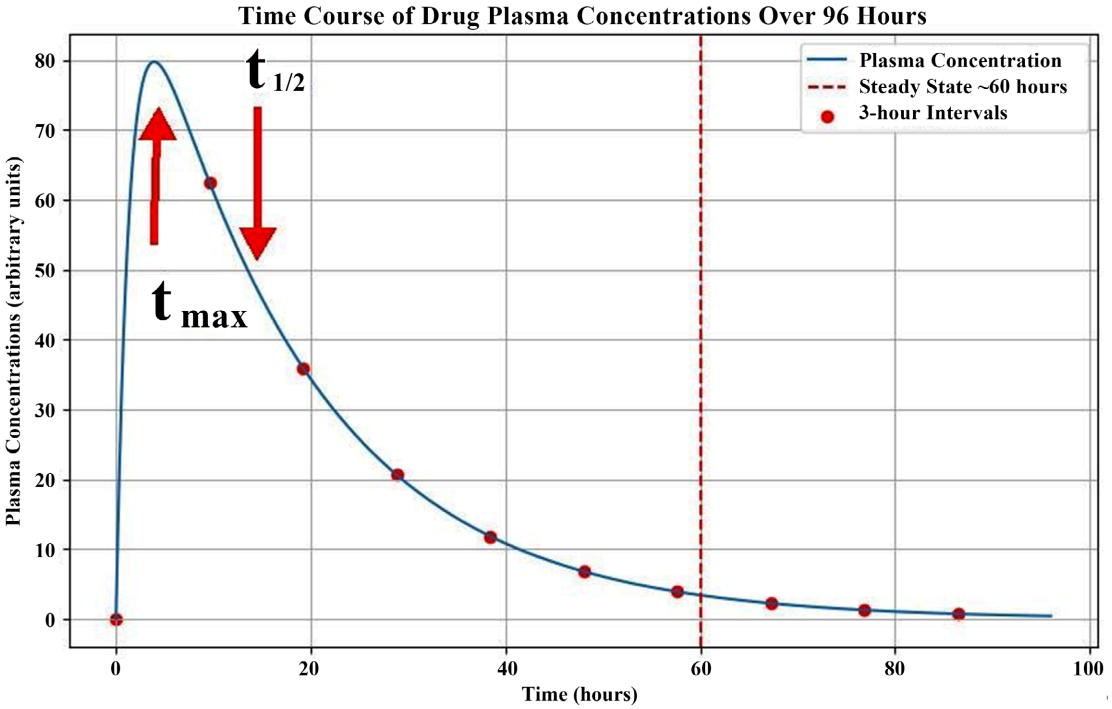

Figure 3. The well-known calculation of the Area Under the Curve (AUC): This plot represents plasma concentration versus time. It illustrates that, in the case of second-order reactions, the decay rate $\left(t'_{1/2}\right)$ is reduced to half of its original time duration, reflecting the faster consumption process.

2.3. The Space Pharmaceuticals Bioavailability, BA

Pharmacokinetics focuses on determining bioavailability [9]-[14] and enzymatic reactions, deriving physical deductions, and comparing these results with the earlier discussion sections. Using the pharmacokinetic formulas and the decay constant 1/e (refer to Eq. (2.8)), a preliminary estimate suggests that the bioavailability of space pharmaceuticals will approach:

$$1 - \frac{1}{\mathrm{e}} \approx 63.20\% \tag{2.11}$$

This is very close to the lower limit of 80% observed for aspirin and 63% observed for finasteride[2], and it is approximately equal to around 63.0% (therefore the area under the intravenous dose curve is set to be $[\mathrm{AUC}]_{\mathrm{IV}} \approx 39.50\%$ this is due to the reason of such is equivalent to the proportion 39% of amounts of the

[2] *i.e.*, International Nonproprietary Names (INN).

drug metabolized into urine by the liver in the organism). However, it is important to note that different types of space pharmaceuticals, depending on their molecular structures, may exhibit slightly varying levels of bioavailability. The detailed calculation is as follows:

By the formula of bioavailability (BA, the notation of F), therefore the detailed calculation is that,

$$F = \frac{[\mathrm{AUC}]_{\mathrm{po}}}{[\mathrm{AUC}]_{\mathrm{IV}}} \frac{D_{\mathrm{IV}}}{D_{\mathrm{po}}} = \frac{(1/4)}{(39.50\%)} \cdot \frac{1}{1} \approx 63.29\% \tag{2.12}$$

Where set $D_{\mathrm{IV}} = D_{\mathrm{po}} \equiv 1$. And due to the proportion of 63.29%, the "first pass effect" is essentially to be considered.

2.4. Other Explanations for Drug Manufacturing Efficiency and Comparisons with Earth-Based Analogues

When discussing the enhancement of drug bioavailability in space manufacturing, it is important to delve deeper into the drug manufacturing process on Earth and its efficiency. By comparing with Earth-based analogues, we can explain how the space environment impacts drug manufacturing efficiency. In terrestrial drug manufacturing, the commonly used processes (such as heat pressing, drying, and dissolution) are influenced by gravity and the Earth's physical environment. In contrast, microgravity in space might improve certain processes, particularly in terms of more uniform distribution of drug particles, improved solubility, and bioavailability. Furthermore, drug manufacturing in space is not only affected by microgravity but also by other factors such as space radiation, extreme temperature variations, and more. These environmental factors can alter the physical properties of the drugs, subsequently influencing their absorption and metabolism. Therefore, comparing with Earth-based drug manufacturing processes and their efficiency can help provide a comprehensive understanding of the advantages of space manufacturing.

2.5. Assumptions and Limitations in Microgravity Modeling

The microgravity modeling in this study is based on certain assumptions that may limit the generalizability of the results. For example, we assumed that drug absorption in microgravity would differ significantly from Earth-based conditions, without considering certain biological or physical factors, such as changes in blood flow in the gastrointestinal tract or the potential impact of microgravity on gut microbiota. These factors could influence drug absorption and metabolism in space, thereby affecting drug bioavailability. Additionally, the simulation assumes that drug dissolution and absorption in microgravity will be more uniform, but the actual situation may be more complex. Abnormal fluid dynamics in microgravity, such as uneven liquid distribution, could potentially affect the dissolution rate of the drug. Therefore, these assumptions and their impact on the simulation results should be further explored in order to understand more accurately the specific effects of microgravity on drug manufacturing efficiency.

2.6. Expanding the Discussion: Impact on Pharmaceutical Practices

In addition to the effects on drug bioavailability, we should broaden the discussion to consider how the microgravity environment may affect pharmaceutical practices, particularly in terms of drug manufacturing and clinical applications. The conditions in space might significantly influence drug formulation stability, release rates, particle size distribution, and more. These changes would directly impact the effectiveness of drugs in clinical applications, potentially requiring special clinical trials for space-manufactured products. For example, uniform distribution of drug particles or higher solubility of certain drugs might result in better therapeutic effects of space-manufactured formulations even on Earth. However, this may also present challenges, such as excessive absorption or changes in drug interactions, which would need to be addressed through further clinical research. From a manufacturing perspective, space conditions could also alter production parameters like temperature control and mixing times, potentially changing the stability and quality of pharmaceutical products. This has significant implications for large-scale production, and the widespread adoption of space manufacturing technology should be accompanied by further research into manufacturing processes, quality control, and regulatory compliance.

2.7. Conclusion and Future Research Directions

This study provides preliminary theoretical support for the potential of space drug manufacturing, but further research is needed to more thoroughly investigate drug behavior under microgravity conditions and overcome the assumptions and limitations in the current model. Future studies should focus on how to more accurately simulate drug manufacturing processes in space and the specific effects these changes may have on drug absorption, metabolism, and efficacy. Additionally, we should also consider the long-term impact of space drug manufacturing on Earth-based pharmaceutical practices, including drug quality control, production scalability, and clinical applicability.

3. Conclusion

This study focuses on the preparation of drugs in space under a microgravity environment. Due to the microgravity environment, the substrate concentration can be eliminated so that the concentration of the drug is evenly dispersed during the manufacturing process. We conclude that the half-life of space pharmaceuticals. It will be a half of the amount produced on Earth and its bioavailability will be doubled. Through rigorous physical demonstration, this paper modifies and generalizes famous the Michaelis-Menten kinetics. Ultimately we found that space-based pharmaceutical production can be double the reaction rate of the process of LADME in organisms, and the bioavailability is around 63.29%, which is very close to the lower limit of observed aspirin's bioavailability and is exactly equal to observed finasteride's 63%.

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Author Contributions

The authors contributed equally.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix

A. Calculation for second-order reactions

Under the direction of reaction is considered:

$$\frac{1}{V_0}=\frac{1}{V_{\max}}\frac{K_M+[S]}{[S]} \tag{A.1}$$

When represented on a double reciprocal plot, it becomes evident that:

$$\frac{1}{V}=\frac{1}{V_{\max}}\frac{K_M+[S]}{[S]} \tag{A.2}$$

During the LADME process, the velocity (V) varies with time; therefore:

$$\begin{aligned}&\left(\frac{1}{V}\right)'=\frac{1}{V_{\max}}\left(\frac{K_M+[S]}{[S]}\right)',\\&\frac{-1}{V^2}=\frac{1}{V_{\max}}\left(\frac{\left(K_M+[S]\right)'[S]-\left(K_M+[S]\right)}{[S]^2}\right),\\&\frac{-1}{V^2}=\frac{1}{V_{\max}}\frac{-K_M}{[S]^2},\\&V^2=V_{\max}\frac{[S]^2}{K_M},\ n=2\end{aligned} \tag{A.3}$$

This is a second-order reaction (n = 2). However, considering the low concentration of substrates (n = 1), it is necessary to separate one V term on the right-hand side (RHS) as follows[3]:

$$V=\frac{V_{\max}}{V_0}\frac{[S]^2}{K_M},\ n=2 \tag{A.4}$$

This mathematical approach is not unusual, as space pharmaceuticals exhibit a uniform molecular concentration within their formulations. Consequently, the majority of reactions are classified as n = 2, while the effect of n = 1 is sufficiently small to be considered negligible. In the double reciprocal plot, we obtain:

$$V=\frac{1}{V}\frac{[S]^2}{\left(K_M/V_{\max}\right)} \tag{A.5}$$

Where $K_M/V_{\max}$ represents the slope of the double reciprocal plot. By rearranging Eq. (A.5), we obtain:

$$\underbrace{\frac{1}{V}}_{y-axix}=\underbrace{\left(K_M/V_{\max}\right)}_{\text{slope}}\underbrace{\frac{1}{[S]}}_{x-axix}\frac{V}{[S]} \tag{A.6}$$

Since the space pharmaceuticals operates under the following conditions:

[3] Where k_{cat} (which means the catalytic constant or the turnover number and is in units: s^{-1}) is naturally included in Eq. (A.4), since that it is a biochemical dynamic problem in case of enzyme kinetics.

$K_M \gg [S]$, therefore,

$$\underbrace{\frac{1}{V}}_{y-axix} = \underbrace{\left(K_M / V_{\max}\right)}_{\text{slope}} \underbrace{\frac{1}{[S]}}_{x-axix} \left(\frac{V}{[S]}\right)^n, \; n = 1 \tag{A.7}$$

This is a first-order reaction ($n = 1$). Due to the extremely low concentration of substrates, it follows that:

$$\lim_{V \to [S]} \frac{1}{V} = \lim_{V \to [S]} \left(K_M / V_{\max}\right) \frac{1}{[S]} \frac{V}{[S]}\bigg|_{V=V_0}, \; n = 1 \tag{A.8}$$

Therefore,

$$\frac{1}{V} = \frac{K_M}{V_{\max}} \frac{1}{[S]}, \; n = 1 \tag{A.9}$$

This naturally leads back to the widely-known general representation, such as the double reciprocal plot. (Note: As mentioned above $V \to [S]$, this applies because the reaction occurs at low substrate concentrations, *i.e.*, $V = V_0 \propto [S]^1$.)

This regression strongly ensures the correctness from Eqs. (A.1) to (A.4). Namely the accurate of mathematical physical chemistry statements by second-order reaction (Modification of Michaelis-Menten Kinetics and still applies) is confirmed established.

B. Second-order reactions: quantum mechanics perspective (from a physics point of view)

In Sections 2.1 and 2.2, the discussion focuses on the quantum tunneling effect. Interestingly, this physical phenomenon significantly influences the probabilities associated with quantum tunneling, thereby impacting the decay rates of second-order reactions (a particular biochemical reaction reacts by the shorter path). As a result, the reaction time is effectively reduced by half under the condition of a fixed concentration. This observation aligns with and verifies the conclusions drawn in Sections 2.1 and 2.2.

C. **Experimental designs**

Objective: The goal is to simulate the bioavailability enhancement of oral drugs (with initial bioavailability ranging from 31.5% to 40%) in a space manufacturing environment, aiming to reach 63% or 80% bioavailability, which is 2 times the bioavailability of these drugs on Earth (which is 31.5% to 40%), thus approaching the bioavailability of Finasteride (which is 63% on Earth).

1. Drug selection

We selected finasteride as the study drug because its known bioavailability on Earth is 63%. Additionally, we will include some other commonly used oral drugs that have a bioavailability between 31.5% and 40% on Earth. These could include common over-the-counter drugs or prescription medications such as pain relievers or antihypertensive drugs.

2. Space simulation conditions

In this experiment, we simulate the behavior of the drug under space conditions

and set the following parameters:

- Microgravity Environment: Microgravity may change the dissolution and absorption rate of the drug. Studies have shown that microgravity can influence how drugs behave in the gastrointestinal tract, potentially enhancing their absorption rate and bioavailability.

- Space Radiation: The radiation environment in space can alter the chemical structure of drugs, which could affect their metabolism pathways and bioavailability. This factor will be simulated to analyze how space radiation affects drug stability and metabolism.

- Low Oxygen Environment: In a low-oxygen environment, the absorption and metabolism of drugs may differ, potentially influencing their bioavailability.

3. Simulating with idTarget drug target prediction platform

Using the idTarget platform, we will simulate the behavior of the drug, including absorption, metabolism, and bioavailability under space conditions. The specific steps include:

- Drug Absorption: Simulating the absorption rate of the drug in a microgravity environment. This involves changes in the drug's solubility, distribution, and absorption. Microgravity may cause the drug to distribute more evenly in the digestive system, thus improving absorption efficiency.

- Metabolism Simulation: Space radiation might affect the chemical structure of the drug, altering its metabolism pathways. The idTarget platform will help predict how the drug will metabolize in space and whether these changes lead to an enhanced bioavailability.

- Bioavailability Simulation: Using idTarget, we will predict the bioavailability of the drug. We will compare data from space and Earth environments to determine whether space conditions lead to the expected bioavailability enhancement.

4. Pharmacokinetics (PK) simulation

We will simulate the pharmacokinetics (PK) of the drug using idTarget, focusing on the following parameters:

- Absorption Rate (Ka): Whether the absorption rate of the drug is enhanced in the space environment, and compare this with Earth-based data.

- Maximum Plasma Concentration (Cmax): The change in the time to reach maximum plasma concentration between the space and Earth environments.

- Half-life (T1/2): The rate at which the drug is eliminated from the body.

Bioavailability enhancement model

I. Target Bioavailability: Set the target bioavailability to 63% (the bioavailability of Finasteride on Earth) or 80% and compare this to the bioavailability of the drug on Earth (ranging from 31.5% to 40%).

II. Result Validation: Using PK simulation results, we will analyze if the bioavailability of the drug can be enhanced from 31.5% or 40% to 63% or 80%.

5. Experimental setup design

Here are the necessary devices for simulating and measuring the drug's behavior in a space environment:

Experimental	Setup Description
Microgravity Simulation Platform	Simulates the microgravity environment in space, observing the solubility and absorption rate of the drug.
Radiation Exposure System	Simulates the effects of space radiation on the drug's structure, helping to predict the drug's stability and metabolism.
Pharmacokinetics Measurement System	Measures the concentration of the drug in the plasma over time to calculate bioavailability.
idTarget Drug Target Prediction Platform	Predicts how the drug will behave in microgravity, radiation, and other unique space conditions, focusing on absorption, distribution, metabolism, and excretion (ADME).

6. Data analysis and result validation

Based on the experimental data, the following analysis will be conducted:

- Bioavailability Enhancement: Assuming the starting bioavailability of the drug is in the range of 31.5% to 40%, and aiming to reach 63% or 80% bioavailability in the space environment.

- Pharmacokinetics Curves: Comparing the plasma concentration-time curves between Earth and space environments, and calculating the bioavailability improvement.

Expected results:

- Bioavailability Improvement: The bioavailability is expected to increase from 31.5% or 40% to 63% or 80%, meaning the absorption rate and/or stability of the drug will be significantly enhanced in the space environment.

- Evidence for Space Drug Manufacturing: The experimental results will provide evidence to support the potential for space manufacturing to enhance the bioavailability of drugs.

This experimental design aims to simulate and analyze the bioavailability enhancement of drugs in a space manufacturing environment using the idTarget Drug Target Prediction Platform. The goal is to improve the bioavailability from 31.5% or 40% to 63% or 80% (*i.e.*, 2 times the Earth bioavailability). This result will help advance space drug manufacturing technologies and provide valuable data for future drug development in space.