# Transport of Nanoparticles in Targeted Drug Delivery System

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**Abstract:** *Nanoparticle-based drug delivery has emerged as a promising and evolving field in developing advanced diagnostics and therapeutics for blood flow-related disorders. A nanofluid consists of a colloidal suspension of nanoparticles, typically ranging from 10 to 100 nanometer (nm), dispersed in conventional carrier fluids such as water, oil, or even biological media like blood. Compared to conventional drug delivery systems, nanoparticles offer several advantages, including enhanced specificity, improved stability, superior drug-loading capacity, and the potential for controlled or sustained release. Both organic and inorganic nanoparticles have been widely investigated as drug carriers due to their excellent biocompatibility with tissues and cells, nanoscale size, reduced toxicity, and ability to achieve prolonged therapeutic effects. Moreover, using nanoparticles as drug delivery agents helps mitigate resistance and reduces the impact of blood flow obstruction or coagulation associated with stenosis. Targeted drug delivery aims to ensure that an appropriate amount of the therapeutic agent reaches its intended site of action. By carefully designing such delivery systems, it becomes possible to use lower doses while minimizing unwanted side effects, leading to better patient compliance. The main goal of focused drug transport is to achieve a safe and efficient interaction of the drug with the specific diseased tissue. Nanoparticle-based drug delivery plays a crucial role in treating complex conditions such as cancer, disorders involving the blood-brain barrier, and cardiovascular diseases, where precise targeting is essential to enhance therapeutic efficacy and minimize damage to healthy tissues. Mathematical modelling serves as a valuable tool for analyzing the intricate dynamics of blood flow in arterial stenosis, thereby contributing to the optimization of clinical treatments and advancements in biomedical engineering.*

**Keywords:** Nanoparticles; Blood Flow; Stenosis; Non-Newtonian Fluid; Targeted Drug Delivery; Cancer; Mathematical Modelling

## 1. Introduction

Nanoparticles [NPs] possess unique material properties due to their extremely small, sub-microscopic size. In recent years, NPs have emerged as rapidly expanding field, playing a vital role in drug delivery, microfluidics, bio-sensing, micro-arrays and tissue micro-engineering for the targeted and specialized treatment of various diseases (Afzal O. et al. 2022). Its characteristics ecompassing size, chemical composition and structure can be optimized to enhance their efficacy with in the biomedical industry. Considerable advancements have been made in the development of NPs for various biomedical applications, with several types demonstrating notable potential in the treatment and monitoring of several types demonstrating notable potential in the treatment and monitoring of capabilities of NPs for diagnostic and therapeutic purposes, thus facilitating ongoing progress in their biomedical utility (Suneetha S. et al. 2025). The shape factor of nanoparticles plays a vital role in defining the physical and chemical properties of nanofluids. It represents the geometry of the particles, which greatly affects their surface area, reactivity and interactions with rounding structures. In recent years, the importance of this factor has grown, particularly in field such as catalysis, imaging and drug delivery (Farooq U. et al. 2025). NPs such as bricks, cylindrical and platelets are considered as three district shape of particle forms (Akbar N. S. et al. 2023). The effects of various NPs focusing on spherical, cylindrical, platelets and blade like shapes are investigated by (Sharma B. et al. 2023). The emergence of nanotechnology drugs, resulting from the rapid progress in nanotechnology, present

tremendous potential to enhance cancer treatment methods. The versatility and innovative targeting strategies in nano-medicine products are becoming apparent. These particles have been assessed for various clinical applications including organic, lipid glycan and synthetic polymers have been utilized (Aghebati-Maleki A. et al. 2020).

Drug Delivery plays a vital role in modern medical treatments, especially in oncology (the study, diagnosis, treatment and prevention of cancer) where accurately directly therapeutic agents to malignant tissues are crucial for improving outcomes. Advances in delivery system such as NP carriers, convection-enhanced approaches and liposome-based encapsulation have shown significant potential in overcoming traditional various like tumor heterogeneity and blood brain barriers. Advanced types of nanocarriers includes dendrimers, liposomes, peptide-based NPs, carbon nanotubes, quantum dots, polymer- based NPs, inorganic carriers, lipid-based NPs, hybrid nanostructures and metallic NPs. As a cornerstone of pharmaceutical science, drug delivery is central to the development of targeted therapies that aim to maximize therapeutic benefits while reducing wide spread side effects (Abdellatif A. A. H. et al. 2021, Akhtar Y. et al. 2024). MHD mixed convective flow of Maxwell nanofluid in the presence of chemical reaction is investigated by (Dessie H. et al. 2020). They derived the expressions for skin friction, Nusselt number coefficient and Sherwood number coefficient.

NPs-based drug delivery systems are increasingly used in cancer therapy because they can carry therapeutic agents

directly to the target site in a controlled and efficient way (Singh M. et al. 2025). In this article, we focus on copper NPs, we analyzed how copper NPs are been recognised as a promising anticancer agent (Kang X. et al. 2023). Explored how copper may affect cancer cell viability through the excessive accumulation of reactive oxygen species and angiogenesis, as well as proteasome inhibition, due to the higher demand for copper and increased susceptibility to regulation. Given the versatile copper-based nanotubes can be used for both cancer detection and therapy intracellular copper has garnered significant attention (Aishajiang R. et al. 2023).

Nanofluids have become a topic of great interest because of their outstanding ability to conduct heat and their wide range possibilities in medical science. Researchers are exploring them as a way to improve the performance of traditional cooling and heating fluids. The presence of NPs not only increases the thermal conductivity of the base fluids but also enhances heat transfer efficiency by controlling factors such as nanoparticle concentration, type size and shape. Due to their high efficiency in heat transfer and remarkable stability, nanofluids are considered highly suitable for diverse application, including micro-electronics, solar energy systems, space exploration, medical diagnostics (e.g. blood and urine analysis), pharmaceutical manufacturing, nanomedicine, lithotripsy, cancer treatment and targeted drug delivery system (Zar P. M. et al. 2025). Nanofluids are formulated as stable suspension of metallic and non-metallic particles, ranging in size from 1 to 100 nm, evenly dispersed within a base fluid such as water, oils, polymer solutions, ethylene glycol or even biological fluids like blood. Further the numerical approach based on an artificial neural network to extract numerical solutions and the change in concentration of drug diffusion with the compartment of blood and tissue are analyzed by (Kumar R. et al. 2025). They compared the traditional methods and experimental results and efficacy of their proposed methodology.

The objective of our study is to explore that the transport of NPs in targeted drug delivery because of their double role. NPs are small enough to transported with the blood flow and may be attached to cells. If they are combined with drug, these particles may change the transcription process in cells. NPs are highly specific, efficient and rapidly internalized by the targeted cells.

## 1.1. Blood

Blood has a complex behaviour due to its properties and composition. The way blood flows through the body play a crucial role in how cardiovascular diseases (CVDs) develop and progress (Tripathi J. et al. 2021). Blood flow is not always steady. When a blood vessel narrows a condition called 'Stenosis'-the flow can slow down a lot. The narrowing often happens because plaque builds up in the arteries, called as Atherosclerosis (Athero stands for 'gruel' or 'paste' and sclerosis defines 'abnormal hardness'). Over time, the reduced and blocked flow may raise the risk of CVDs like a coronary artery disease, heart attacks, hypertension, stokes and hypotension etc (Akbar S. N. et al. 2024, Zaperi N. H. A. M. et al. 2024). Many mathematical models have been explored to study blood flow in arteries,

both in the presence and absence of stenosis. These models provide various perspective with in the field of arterial biomechanics, where blood vessels are mainly considered as cylindrical pipes with a uniform cross-sectional area along their length. As a result, numerous studies have investigated flow properties such as blood velocity, pressure and shear stress to better understand their importance in relation to stenosis and to assess the effectiveness of different treatment methods (Tripathi J. et al. 2021). It exhibits behaviour as both a Newtonian and Non-Newtonian fluid contingent upon the diameter of arterial vessels. In large arterial vessels where the shear rate exceeds $100s^{-1}$ blood behaves as a Newtonian fluid. Conversely, in smaller capillaries, where the strain rate is relatively low, blood displays Non-Newtonian fluid (Akbar S. N. et al. 2024).

## 1.2. Non-Newtonian fluid models

Blood is generally considered as Non-Newtonian fluid, although under specific conditions it can display near Newtonian behaviour. To represent its complex rheological nature, various generalized Non-Newtonian models such as Power Law, Casson Fluid, Herschel-Bulkley model, Ellis Fluid model etc. have been developed, along with viscoelastic fluid models that more accurately capture its flow characteristics. Extensive research has demonstrated that hemodynamic factors play a crucial role in the development of atherosclerotic lesions, leading to disruption in normal blood circulation. Several blood flow models and their corresponding constitutes equations are summarized below-

### Power Law Model
The power law model is one of the most widely used viscosity model to represent the Non-Newtonian behaviour of blood, offering significant practical importance. The constitutive equation has been employed by numerous researchers to describe blood flow characteristics effectively (Tripathi J. et al. 2021).

$$\tau = \eta_0 \left(\frac{\partial v}{\partial y}\right)^{m-1}, \qquad (1)$$

here, $\tau$ stands for shear stress, $(\partial v/\partial y)$ represents shear rate and 'm' is known as the power index. The power index is crucial in defining how the fluid flows: if m < 1, the fluid is shear-thinning and if m > 1, the fluid shear-thicking and if m=1, the fluid behaves like a Newtonian fluid.

### Carreau-Yasuda Fluid Model
The Carreau-Yasuda Non-Newtonian fluid model is recommended for determining viscosity across both high and low shear rate conditions.

$$\tau = \left[\eta_\infty + (\eta_0 - \eta_\infty)\{1 + (\lambda\dot{\gamma})^2\}^{\frac{n-1}{2}}\right]\dot{\gamma}, \quad (2)$$

here, $\tau$ stands for stress tensor, $\eta_0$-represents for zero (low) shear rate viscosity, $\eta_\infty$- represents infinite (high) shear rate viscosity, n define as power index and $\dot{\gamma}$ is given by (Fanelli C. et al. 2022).

$$\dot{\gamma} = \sqrt{\frac{1}{2}\sum_i \sum_j \dot{\gamma}_{ij}\dot{\gamma}_{ji}}, \qquad (3)$$

## Casson Fluid Model

This model was first introduced by Casson in 1959, to study rheological behavior of printing inks, has since found wide application in describing Non-Newtonian fluids like blood. This model is particularly useful for understanding how blood behaves under low shear rates and in small vessels, where the fluid exhibits viscous behaviour (Tripathi J. et al. 2021). The constitutive equation of this fluid is

$$\tau = 2 \begin{cases} (\mu_B + p_y/\sqrt{2\pi})e_{ij} \, , \, \pi > \pi_c \\ (\mu_B + p_y/\sqrt{2\pi_c})e_{ij} \, , \, \pi < \pi_c \end{cases} \quad (4)$$

where, $p\_y$- yield stress of fluid, $\mu\_B$ − dynamic viscosity, $e\_{ij} = (i,j)^{th}$ − component of deformation $\pi = e\_{ij}.e\_{ij}$ represents the self- product of the components of the deformation rate and $\pi\_c$ − critical value. At extremely high shear rates, this fluid shows shear-thinning characteristics, possesses an infinite yield stress, and approaches zero viscosity.

## Sisko Model

This model's, rheological equation is given as-

$$\bar{\tau} = \left[ a + b \left| \sqrt{\frac{1}{2}(\bar{\Delta}.\bar{\Delta})} \right|^{m-1} \right] \bar{\Delta} \, , \quad (5)$$

here $\bar{\Delta}$ = the rate of deformation tensor; $\bar{\tau}$ = the rate of deformation stress tensor; $a, b$ and $m$ are different material constants corresponding to different fluids.

## Herschel-Bulkley Model

This model was first described by Herschel and Bulkley in 1926. This fluid model explains the relationship between three parameters: flow index, yield stress and consistency index. The constitutive equation for this fluid is define as (Tripathi J. et al. 2021).

$$\tau = \tau_0 + k\gamma^n \, , \quad (6)$$

here, $\tau$ = shear stress, $\tau_0$ = stands yield stress, $k$ = consistency index, $\dot{\gamma}$ = shear rate, '$n$'represents the flow index.

## Ellis Fluid Model

The Ellis fluid model was first introduced by R. Ellis in 1958. It is rheological with three parameters that effectively characterize shear-thinning Non-Newtonian fluids that do not exhibit yield stress. The constitutive equation is given as (Ashkenazi A. et al. (2025).

$$\eta(\tau) = \eta_0 \left[ 1 + (\tau/\tau_{1/2})^{n_e - 1} \right]^{-1} \quad (7)$$

here, $\eta_0$ stands zero shear rate viscosity, $n_e$ represents ellis exponent, $\tau_{1/2}$ represents shear stress at $\eta_0/2$.

## 2. Transport of NPs

Solid colloidal NPs typically range in size from 10 to 1000 nms, although nanomedicine applications often prioritize particles smaller than 200 nms for therapeutic use. Due to their diminutive size, these NPs are capable of traversing the smallest capillary networks and can efficiently penetrate cellular membranes and interstitial spaces. This property enables them to reach target tissues and organs, including sites such as the liver and spinal cord, thus serving as highly effective carriers for target drug delivery (Gupta N. et al. 2022). Dispersing NPs within a suspension has been shown to enhance both the heat transfer properties and pressure drop characteristics of fluids. Notably, critical parameters such as particle size, geometric configuration, and surface features significantly influence the effectiveness of nanofluids in biological environments (Tripathi J. et al. 2021). This research investigates how NPs affect the movement of drugs within biological systems and influence biomarkers such as hydrogen peroxide, thereby contributing to the advancement of targeted drug delivery methods (Islam N. et al. 2024).

### 2.1 Characteristics of NPs

NPs are typically characterized on based their size, shape and surface charge using advanced microscopic techniques such as Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM) and Atomic Force Microscopy (AFM) (Gupta N. et al. 2022). These factors significantly influence the distribution of NPs throughout the body, their uptake of cells, the rate at which they are cleared, and their capacity to accurately targeted specific tissues or cells (Ly P.D. 2024).

#### 2.1.1 Effect of size

The size distribution and morphology of NPs play a key role in their characterization. These properties are especially important in drug delivery and targeting applications. Studies have revealed that smaller NPs provide a greater surface area, which promotes more efficient transport of drug molecules to the particles surface, resulting in faster drug release(Gupta N. et al. 2022). NPs such as polymers and liposomes ranging between 10 and 100 nm in diameter, are specifically developed for arterial drug delivery. This is because small spherical particles like liposomes tend to concentrate in a distinct area of blood vessels, known as the cell-free layer (Tripathi J. et al. 2021). Recent progress in nanotechnology is focusing on designing tiny engineered delivery system that can precisely transport medications to specific sites within the body (Suneetha S. et al. 2025).

#### 2.1.2 Effect of shape

NPs shape factor serves as key indicators of their heat transfer characteristics. Because NPs have extremely high surface area-to-volume ratios, their shape plays a crucial role in determining thermal behavior (Mahmood Z. et al. 2025). The behavior of blood flow through diverging, tapering arteries with the stenosis is investigated using NPs of different shapes (Akbar S. N. et al. 2024). The study investigates how NPs of various shapes behave within blood flow in covered arteries, aiming to generate insights that enhance the design and efficiency of NP based therapies particularly for targeting specific areas of arterial system (Asha K. N. et al. 2025). As the shape of stenosis changes, the velocity of brick- shaped, cylindrical and platelet particles decrease sharply. Elevated copper levels in the bloodstream promote greater arterial relaxation, which enhances blood flow efficiency. As a result, the velocity greater arterial relaxation, this enhances blood flow efficiency. As a result, the velocity fields of brick, cylinder and platelet-shaped particles gradually rise. Among all parameters, platelet- shaped particles exhibit higher shear-

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stress and impedance resistance values compared to brick and cylinder-shaped particles (Akbar S. N. et al. 2024).

### 2.1.3 Effect of surface charge

Refining the surface chemistry of NPs, particularly their charge characteristics plays a crucial role for enhancing biocompatibility and reducing their toxicity (Shen Z. et al.2016). Surface charge significantly NP behaviour during biological interactions. NPs with neutral or slight negative charges tend to circulate longer in the blood flow due to reduced clearance by the reticuloendothelial system and low liver uptake. In contrast, positively charged NPs are cleared faster but show improved transvascular movement. Thus, charge-switchable NPs hold strong potential for targeted drug delivery and enhance tissue penetration through cellular transport pathways (Souri M. et al. 2024).

## 3. Targeted Drug Delivery System (TDDS)

Targeted drug delivery (TDD) refers to a method that ensures a controlled amount of medication reaches is specific disease of organ over a sustained period (Ashique S. et al. 2021). TDD uses ligands or antibodies to direct nanocarriers specifically to cancer cells, enhancing the drugs effectiveness and reducing side effects on healthy tissues (Parvin N. et al. 2025). In a TDDS, drug carriers play a crucial role as they are designed to be biodegradable, non-toxic and easily cleared from the body. The main goal of these systems is to ensure that that drug reaches a specific target site, which enhances treatment effectiveness and helps sustain a stable level of drug in the bloodstream(Ashique S. et al. 2021). NPs improve the effectiveness of treatments by enabling both passive and active targeting strategies. These include ligand-based surface modifications and the enhanced permeability and retention (EPR) effect (Islam N. et al. 2025). There are two main approaches for directing bioactive compounds to specific tissues, cells, or organs within the body:

- Active Trageting Strategy
- Passive Targeting Strategy

### 3.1 Active targeting strategy

This form of targeting works on the principle of ligand – receptor interaction and relies on processes such as blood circulation and extravasation. The ligand is designed to specifically recognize receptors that are over expressed on the surface of the damaged or target cells. The binding between a ligand and its receptor occurs only when they are in close proximity typically within about 0.5 mm (Ashique S. et al. 2021). This targeting approach provides multiple benefits. It helps deliver a higher concentration of the drug directly to the target site, minimizes side effects and unwanted exposure to healthy tissues and improves the overall therapeutic outcome. Such a strategy shows great potential for improving treatment for diseases like infection and cancer (Tarighi P. et al. 2025).

### 3.2 Passive targeting strategy

Passive targeting works by using nanocarriers to transport drugs to tumor cells through processes like passive diffusion or convection, allowing them to pass through the gaps in tumor capillary walls. The main materials used in these drug delivery systems are liposomes, silica, metal oxides and polymeric based NPs. This strategy is widely preferred because it is simpler to apply and provides several benefits compared to active targeting techniques (Tarighi P. et al. 2025). Enhancing nanoparticle targeting can be achieved through precise control of their size and compositional properties. Such optimization extends their systematic circulation, facilitates preferential deposition within specific organs and consequently amplifiers their therapeutic efficacy (Oliveres R. et al. 2025).

## 4. Application of NPs for Drug Delivery in the Treatment of Diseases

### 4.1 Cancer

In recent years, cancer is acknowledged as one of the most susceptible categories of illness, characterized uncontrolled proliferation of cells and development of malignant tumor. Long term cardiovascular disorders may alter the body's internal environment in ways that increases susceptibility to cancer formation. A reduced blood supply can create a low oxygen (hypoxic) environment, which is turn may encourage tumor development and spread (Zaperi N. H. A. M. et al. 2024). Chemotherapy is among the most commonly employed therapeutic strategies for treating cancer like condition, initially showing a high susceptibility rate. However, over time, it leads to the evolution of drug resistance in cancer cells through various mechanisms. In recent year, the advancement of stable biocompatible core-shell nanomaterials has revealed numerous benefits for cancer therapy, including enhanced pharmacokinetics, minimizes side effects, targeted delivery to tumor cells, and overcoming drug resistance (Islam N. et al. 2024). Due to their nanoscale dimensions, capacity for tissue-specific targeting, and ability to traverse the blood–brain barrier, NPs represent a highly promising strategy for the treatment of brain cancer. Nanocarriers increase the effective solubility of hydrophobic anticancer drugs, enabling more precise and targeted delivery to cancer cells (Afzal O. et al. 2022).

### 4.2 Cardiovascular diseases

CVDs, includes various conditions that harm the heart and blood vessels, and it's still the leading cause of death worldwide. At the heart of most CVD cases is atherosclerosis, where fatty deposits slowly build up inside the arteries, forming plaques. These plaques make it harder for blood to flow properly, which can lead to serious problems like heart attacks, strokes, or issues with blood flow in the limbs (Kirla H. et al. 2023). Recent progress in biomimetic nanomaterials has opened new avenues for overcoming existing challenges in CVD therapy. Among these developments, nanocarriers coated with natural cell membranes have emerged as a versatile platform for cardiovascular applications, offering distinct advantages such as immune evasion, targeted delivery, and prolonged systemic circulation. In one notable example, researchers engineered a biomimetic heart valve by cross-linking erythrocyte membrane-coated, drug-loaded NPs onto an artificial valve scaffold, demonstrating the potential of such systems to combine structural functionality with therapeutic

capability (Zhao X. et al. 2025). Lipid based NPs have gained significant attention as advanced platforms for the precise diagnosis and therapy of CVDs. Their high biocompatibility, structural flexibility, and ability to carry a wide range of therapeutic agents make them exceptionally versatile. These NPs can efficiently encapsulate drugs, safeguard them from premature degradation, and facilitate targeted delivery to diseased tissues. Additionally, when integrated with multimodal imaging technologies, LNPs further improve both the sensitivity and accuracy of CVD detection and treatment monitoring (Gu Z. et al. 2024).

In summary, various nanoscale carriers like liposomes, silica NPs, dendrimers, cerium oxide particles, micelles, titanium dioxide NPs, nano-coated stents, microbubbles, and polymer–drug conjugates are being actively investigated to deliver medicines more effectively. Among these, magnetoliposomes stand out by combining the drug-carrying ability of liposomes with magnetic NPs, allowing drugs to be guided precisely within the body using magnetic fields. This approach helps target treatments better while minimizing side effects and improving the control of drug release (Afzal O. et al. 2022).

## 5. Mathematical Modelling

Mathematical modelling refers to the process of translating real-world issues into mathematical form, analyzing those mathematical problems, and interpreting the results in practical terms. This approach provides insights into key aspects of real-world situations and can often be used to predict future trends or outcomes. Every field of knowledge has two complementary sides one that focuses on theory, involving mathematics, statistics, and computational methods, and another that is grounded in practical inquiry through observation, experiments, and empirical evidence (Gupta N. et al. 2022). The study investigates blood flow by mathematically modelling it under the assumption that blood behaves as a Non-Newtonian fluid (Sarwar L. et al. 2024).
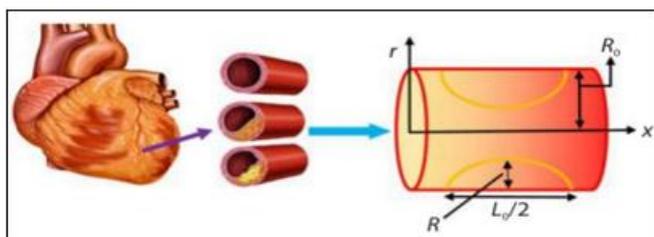


**Figure 4:** Physical Model of Stenosis Artery (Suneetha S. et al. 2025)

The model considers blood flow through a partially constricted arterial segment of $L_0/2$ , flow is treated as that of an incompressible, steady fluid moving through the restricted section. Here, $R_0$ denotes the width of the unblocked region, $R(x)$ represents the artery's radius at any axial position x, and 'h' corresponds to the maximum height of the constriction. In the presented coordinate system, the blood circulation is considered along the x-direction, while the r-direction denotes the perpendicular orientation, as depicted in the accompanying fig.4 (Suneetha S. et al. 2025).

In the schematic of the arterial flow model, the outline of the artery representing the stenosed region is illustrated as follows –

$$R(x) = R_0 - \frac{h}{2}\left[1 + \cos\left(\frac{4\pi x}{L_0}\right)\right] , -\frac{L_0}{4} < x < \frac{L_0}{4} = R_0$$

$$(8)$$

The mathematical formulation of the flow equation can be developed to regulate both circulation and heat transfer in Non-Newtonian nanofluids are defined as

$$\frac{\partial(r\bar{a})}{\partial x} + \frac{\partial(r\bar{b})}{\partial r} = 0 \qquad (9)$$

The continuity equation (9) is satisfied by the stream function$\psi$ for $\bar{a}$ and$\bar{b}$such is given that:

$$\bar{a} = \frac{1}{r}\frac{\partial\psi}{\partial r} , \quad \bar{b} = -\frac{1}{r}\frac{\partial\psi}{\partial x} , \quad (10)$$

The study examines blood flow in a narrow artery incorporating NPs, taking into account the Non-Newtonian behaviour of blood (Sarwar L. et al. 2024). This innovative approach enhances scientific understanding of blood flow complications related to stenosis while paving the way for more accurate medical interventions and personalized therapeutic strategies.

## 6. Results and Discussions

Nanoparticles (NPs) are stealing the spotlight in nanomedicine due to their remarkable physicochemical properties, paving the way for breakthroughs in targeted drug delivery, diagnostics, and nanofluid applications. By fine-tuning their size, shape, and composition, researchers can optimize how they interact with biological systems, leading to sharper therapeutic precision. Copper-based NPs shine in cancer therapy, generating reactive oxygen species and inhibiting proteasomes to attack tumors effectively. Meanwhile, NP-infused nanofluids boost heat transfer rates, which prove invaluable for biomedical tools and imaging. Blood's non-Newtonian nature and complex hemodynamics play a key role in vascular drug delivery, as fluid dynamics dictate NP transport and performance. These tiny particles ideally under 200 nmslip through capillaries and cell membranes with ease, enhancing tissue penetration and drug distribution. From polymeric and lipid-based to crystalline varieties, different NP types excel at encapsulating or conjugating drugs for tailored precision medicine. TDDS have revolutionized treatments by shuttling drugs straight to diseased sites like tumors or plaque-ridden arteries, slashing systemic side effects. They leverage passive strategies via the enhanced permeability and retention (EPR) effect, or active targeting with ligands and antibodies that lock onto specific receptors. In cancer, NPs dissolve hydrophobic drugs, bypass resistance, and breach barriers; in cardiovascular disease (CVD), biomimetic designs improve circulation and diagnostics.

Non-Newtonian blood flow models reveal important blood flow patterns tied to heart diseases and drug delivery. The Power Law model (m=0.6-0.8) captures blood's shear-thinning well in artery branches, where stress reaches 10-50 Pa at narrow spots- viscosity drops 70-90% from 0.056 Pa·s at low speeds to 0.0035 Pa·s over 100 s⁻¹. Newtonian

models overestimate wall stress by 20-30%. Carreau-Yasuda fits wide shear rates (0.1-10,000 s⁻¹), spotting oscillating shear index (OSI) of 0.2-0.4 in plaque-prone areas. Casson works best in tiny vessels with yield stress (0.003-0.005 Pa), showing 40% viscosity fall. Models like Herschel-Bulkley expand recirculation zones and suppress turbulence, improving nanoparticle targeting efficiency by 15–30%. Select models based on vessel scale: Carreau-Yasuda for large arteries, Casson for small vessels. Mathematical models of NP-laden Non-Newtonian blood flow offer critical insights into narrowed vessels, guiding smarter NP designs for real-world efficacy.

## 7. Conclusions

NPs have become vital tools in biomedical research and therapy, offering new possibilities for treating complex and previously untreatable diseases. However, their application also comes with certain challenges and potential drawbacks that need careful consideration. The article provides an in-depth overview of how NP-induced convective flows affect blood circulation within the human arterial system. Studies indicate that dispersing NPs in a fluid can enhance its heat transfer efficiency and modify pressure drop behavior. Key factors such as particle size, geometry, and surface texture play crucial roles in improving the overall performance of nanofluids in biological environments. The rheological behavior of nanofluids, whether Newtonian or Non-Newtonian, is influenced by several factors such as NP shape, size, shear rate range, and volumetric concentration. Studies have also identified certain inconsistencies related to particle shape and size effects on the overall flow characteristics of these nanofluids. The dynamics of blood flow through diverging, tapering arteries with stenosis are analyzed using nanoparticles of different shapes. Variations are observed in parameters such as velocity, temperature, flow resistance, impedance, and pressure gradient. These factors collectively determine the efficiency and effectiveness of NP-based drug delivery in clinical applications. The review also covered mathematical models that describe blood flow with NPs in stenotic regions. NPs possess nanoscale dimensions that enable the development of advanced drug delivery systems capable of reaching specific and confined regions within the body. Their intrinsic properties such as biodegradability, biocompatibility, wide availability, and minimal toxicity make them highly favourable candidates for future innovations in TDD applications.

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