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STUDY ON NEW TRENDS IN DRUG DELIVERY SYSTEMS

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Abstract

Background: Drug delivery science has advanced far beyond conventional tablets and injections, introducing innovative technologies that enhance therapeutic precision, patient comfort, and safety.
Objective: To evaluate the awareness, perception, and adoption of emerging drug delivery technologies amongparticipants, including healthcare professionals, pharmacists, and patients.
Methodology: This descriptive cross-sectional study was conducted at Navodaya Medical College Raichur, India. Data were collected using a pretested structured questionnaire assessing knowledge, attitudes, and usage patterns of advanced delivery systems such as nanocarriers, transdermal patches, microneedles, and implantable devices.
Results: Among 255 participants, 55.7% were female and 49.8% held a university-level education. Awareness was highest for transdermal (82.0%) and inhalation systems (87.5%), while only 46.3% were aware of implantable or controlled-release systems. Most respondents (83.1%) agreed that new drug delivery technologies improve treatment precision, and 77.6% believed they reduce side effects. However, 65.5% perceived them as expensive, and only 38.8% felt adequately trained to use them. Adoption was higher for transdermal and inhalation systems, while microneedle and implantable devices showed limited usage.
Conclusion: It is concluded that awareness and acceptance of advanced drug delivery systems are increasing, but their clinical application remains restricted by cost, limited training, and insufficient availability.

Keywords: Drug delivery systems, nanocarriers, transdermal patches, microneedle technology, controlled-release formulations

Introduction

The field of drug delivery has undergone a remarkable transformation over the last few decades. What was once limited to simple formulations such as tablets, capsules, and injections has now evolved into a sophisticated science focused on precision, control, and personalization [1]. The primary goal of any drug delivery system is to ensure that the therapeutic agent reaches its target site at the right concentration, for the right duration, and with minimal side effects. However, traditional delivery routes often face significant limitations, including poor bioavailability, fluctuating plasma drug levels, systemic toxicity, and reduced patient adherence [2]. These shortcomings have fueled a continuous search for more efficient and patient-friendly systems that can optimize the therapeutic response.Advances in material science, biotechnology, and nanotechnology have played a major role in reshaping the landscape of drug delivery [3]. Modern approaches now emphasize controlling

not only how drugs are administered but also when and where they act in the body. This has led to the emergence of innovative platforms such as nanoparticles, liposomes, dendrimers, micelles, and polymeric systems [4]. These carriers offer targeted and sustained delivery, protecting drugs from premature degradation while ensuring that therapeutic agents are released at the desired site of action. For example, nanocarrier-based systems can be engineered to recognize specific receptors or respond to biological cues like pH, temperature, or enzyme levels, enabling site-specific drug release and reducing collateral damage to healthy tissues [5].

Beyond nanocarriers, alternative routes of administration have become increasingly popular. Transdermal patches, inhalers, ocular inserts, and nasal sprays are transforming how drugs are delivered to the body. These non-invasive methods bypass the challenges associated with oral and parenteral administration, such as first-pass metabolism and injection pain [6]. Transdermal microneedle systems, for instance, allow painless and controlled drug delivery through the skin, while intranasal delivery systems have shown potential for rapidly transporting drugs to the brain. Such approaches are not only more efficient but also improve patient compliance, especially for chronic diseases that require long-term therapy.A major focus of current research is on controlled and sustained release systems [7]. By employing biodegradable polymers, osmotic pumps, and implantable devices, researchers aim to maintain stable drug levels over prolonged periods. These systems minimize the need for frequent dosing, reduce fluctuations in drug concentration, and enhance therapeutic outcomes [8]. Long-acting injectable formulations, for instance, have revolutionized treatments for diabetes, contraception, and psychiatric disorders by ensuring consistent drug availability with minimal patient intervention [9]. Biodegradable implants and depot injections represent another step forward, allowing drug release for weeks or even months after a single administration.Nanotechnology continues to dominate the discussion of new trends in drug delivery. The small size and large surface area of nanoparticles enhance drug solubility, stability, and tissue penetration [10]. Moreover, the advent of smart nanocarrierscapable of releasing their contents in response to specific physiological or external triggershas enabled more precise therapeutic control. These systems can be tuned to respond to changes in temperature, pH, or even magnetic and ultrasonic stimuli, leading to on-demand drug release [11]. This approach not only maximizes efficacy but also minimizes toxicity by delivering the drug only where it is needed.The emergence of biologicssuch as proteins, peptides, and nucleic acidshas further expanded the need for advanced delivery systems [12]. These macromolecules are often unstable and easily degraded in the body, making their effective delivery a major challenge [13]. The success of lipid nanoparticles in mRNA vaccine development demonstrated the transformative potential of modern delivery technologies. Similar strategies are now being explored for gene editing, cancer therapy, and regenerative medicine, highlighting the growing intersection between pharmaceutical science and molecular biology [14].Another exciting direction is the integration of digital health and personalized medicine into drug delivery. Smart drug delivery devices, wearable sensors, and implantable pumps are capable of adjusting drug release based on real-time physiological data [15].

Objective

To evaluate the awareness, perception, and adoption of emerging drug delivery technologies amongparticipants, including healthcare professionals, pharmacists, and patients.

Methodology

This was a descriptive cross-sectional study conducted at Navodaya Medical College Raichur, India. The study was conducted at tertiary care hospitals, retail pharmacies, and community health centers. These sites were selected to ensure diversity in participants' professional backgrounds and exposure to various drug delivery systems.A total of 255 participants were included in the study.Non-probability convenience sampling was employed to recruit participants who met the inclusion criteria and were willing to participate in the study.

Inclusion Criteria:
- Adults aged 18 years and above.
- Healthcare professionals (doctors, pharmacists, nurses) and patients familiar with the use of therapeutic drugs.
- Individuals willing to provide informed consent.

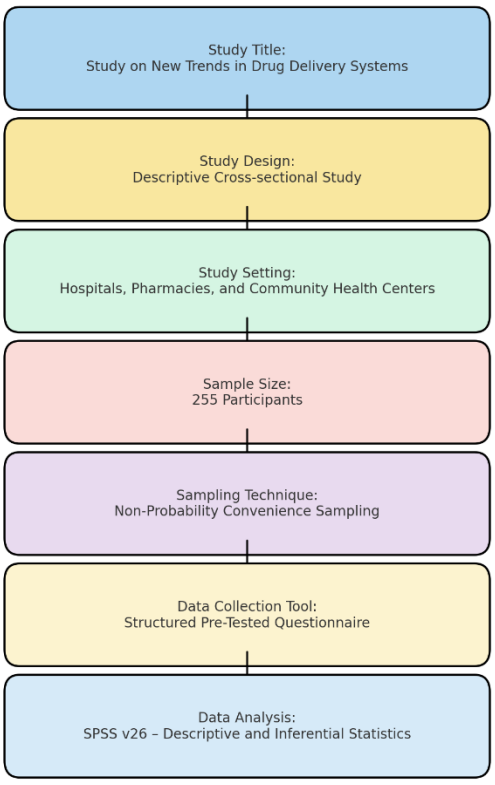
Exclusion Criteria:
- Participants below 18 years of age.
- Individuals unwilling to participate or unable to comprehend the questionnaire.
- Those with incomplete or invalid responses were excluded from analysis.

Data Collection

Data were collected using a structured, pre-tested questionnaire. The tool was designed to capture demographic data, awareness of modern drug delivery systems, perceptions of their safety and efficacy, and preferences for traditional versus advanced systems. The questionnaire consisted of both closed-ended and Likert-scale questions to assess attitudes and awareness levels.Participants were approached in person and briefed on the purpose of the study. After obtaining informed consent, the questionnaire was self-administered. For participants who required assistance, trained data collectors provided guidance without influencing responses. Confidentiality and anonymity were strictly maintained.The key variables analyzed included age, gender, profession, level of education, awareness of advanced drug delivery systems (e.g., nanocarriers, liposomes, transdermal patches, implants), perceived benefits and risks, frequency of use, and factors influencing preference for innovative systems.

Data Analysis

Collected data were entered and analyzed using the Statistical Package for the Social Sciences (SPSS) version 26. Descriptive statistics, including means, standard deviations, frequencies, and percentages, were used to summarize the data. Associations between categorical variables were tested using the Chi-square test, while t-tests were applied for continuous variables where appropriate. A p-value of <0.05 was considered statistically significant.



Results

A total of 255 participants were included in this study, consisting of healthcare professionals, pharmacists, and adult patients. Among the 255 participants, the majority were aged between 31 and 45 years (42.0%), followed by 18–30 years (36.1%) and over 45 years (21.9%). There was a slightly higher proportion of females (55.7%) compared to males (44.3%). In terms of education, nearly half of the respondents (49.8%) held a university or higher-level qualification, while 33.7% had completed high school, and 16.5% were below high school level. Regarding professional background, 40.0% were healthcare professionals, 26.7% were pharmacists, and 33.3% represented the general patient population. Most participants resided in urban areas (65.9%), whereas 34.1% were from rural regions.

Table 1. Demographic Characteristics of Participants (N = 255)

Variable	Categories	n (%)
Age (years)	18–30	92 (36.1)
	31–45	107 (42.0)
	>45	56 (21.9)
Gender	Male	113 (44.3)
	Female	142 (55.7)
Educational Status	Below High School	42 (16.5)
	High School	86 (33.7)
	University and Above	127 (49.8)
Profession	Healthcare Professional	102 (40.0)
	Pharmacist	68 (26.7)
	Patient (General Public)	85 (33.3)
Residence	Urban	168 (65.9)
	Rural	87 (34.1)

The findings indicated a generally high level of awareness about contemporary drug delivery technologies. Awareness was greatest for inhalation or nasal systems (87.5%) and transdermal patches (82.0%), followed by nanoparticle-based systems (75.3%) and liposomal formulations (69.4%). Awareness declined notably for microneedle systems (51.4%) and implantable or controlled-release systems (46.3%).

Table 2. Awareness and Understanding of Modern Drug Delivery Systems

Awareness Aspect	Aware n (%)	Not Aware n (%)
Nanoparticle-based delivery	192 (75.3)	63 (24.7)
Liposomal formulations	177 (69.4)	78 (30.6)
Transdermal patches	209 (82.0)	46 (18.0)
Microneedle systems	131 (51.4)	124 (48.6)
Inhalation or nasal delivery systems	223 (87.5)	32 (12.5)
Implantable/controlled-release systems	118 (46.3)	137 (53.7)

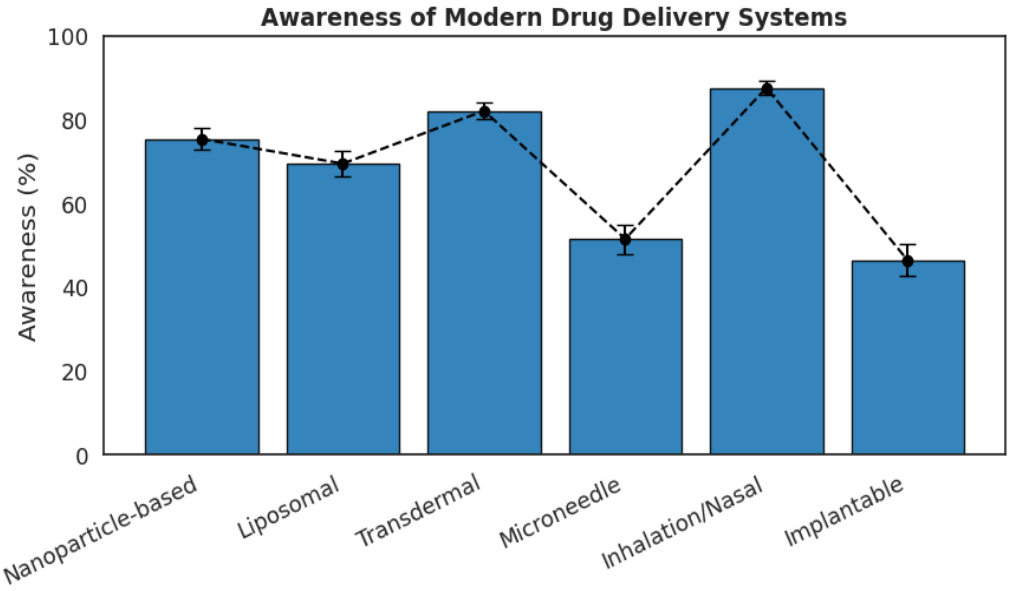


Figure 1: Awareness and Adoption of New Drug Delivery Systems Among Participants

Most participants expressed strong agreement that new drug delivery systems improve treatment precision (83.1%) and reduce side effects compared to conventional drugs (77.6%). However, a considerable number (65.5%) believed that these systems remain too expensive for routine use. Similarly, 74.1% agreed that lack of awareness among patients limits their use, and only 38.8% considered healthcare professionals adequately trained in the application of these technologies.

Table 3. Perception of Benefits and Limitations of New Drug Delivery Systems

Perception Item	Agree n (%)	Neutral n (%)	Disagree n (%)
New systems improve treatment precision	212 (83.1)	31 (12.2)	12 (4.7)
They reduce side effects compared to conventional drugs	198 (77.6)	39 (15.3)	18 (7.1)
These systems are too expensive for routine use	167 (65.5)	47 (18.4)	41 (16.1)
Lack of awareness limits their use in patients	189 (74.1)	51 (20.0)	15 (5.9)
Healthcare professionals are adequately trained in new systems	99 (38.8)	66 (25.9)	90 (35.3)

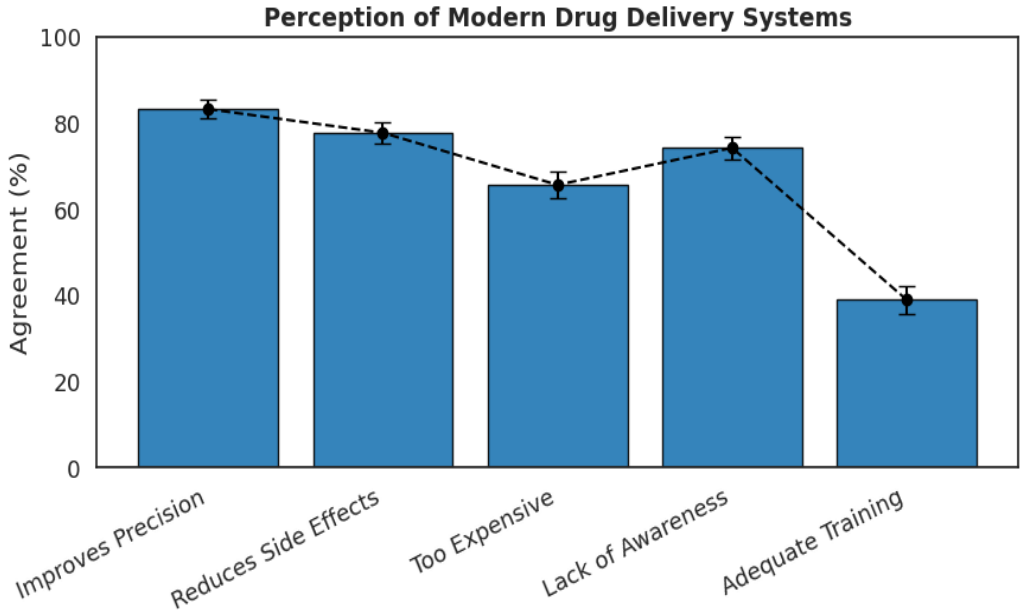


Figure 2: Perception of New Drug Delivery Systems Among Participants

With respect to actual usage, inhalation or nasal delivery systems (n = 158, 62.0%) and transdermal patches (n = 126, 49.4%) were the most commonly used modalities. Meanwhile, nanoparticle-based formulations (n = 82, 32.2%) and microneedle or implant systems (n = 41, 16.1%) had significantly lower current usage rates. Nearly 99 participants (38.8%) reported plans to adopt nanoparticle-based systems in the future, while 96 (37.6%) expressed similar intent for microneedle or implant technologies. Nonetheless, a large fraction (n = 118, 46.3%) indicated no plans to use microneedle or implantable systems, highlighting the presence of both curiosity and caution toward highly advanced drug delivery options. For transdermal patches, 67 (26.3%) planned future use and 62 (24.3%) had no plans to adopt, while for inhalation systems, 59 (23.1%) planned future use and 38 (14.9%) reported no plans.

Table 4. Adoption and Usage Pattern of Advanced Drug Delivery Systems

Type of System	Currently Using n (%)	Plan to Use n (%)	No Plan to Use n (%)
Transdermal patches	126 (49.4)	67 (26.3)	62 (24.3)
Inhalation/nasal delivery	158 (62.0)	59 (23.1)	38 (14.9)
Nanoparticle-based formulations	82 (32.2)	99 (38.8)	74 (29.0)
Microneedle or implant systems	41 (16.1)	96 (37.6)	118 (46.3)

Discussion

The findings of this study highlight a growing awareness and interest in modern drug delivery systems among healthcare professionals and patients, though certain knowledge and adoption gaps persist. Out of 255 participants, the majority demonstrated a good understanding of newer modalities such as transdermal patches, inhalation systems, and nanoparticle-based formulations. However, awareness of advanced technologies like microneedle arrays, liposomal systems, and implantable devices was comparatively limited. This uneven distribution of knowledge reflects how most individuals are familiar only with systems already commercialized, while emerging innovations remain confined to specialized fields or research environments.A significant proportion of participants perceived modern drug delivery systems as more effective and precise compared to conventional methods. This perception aligns with the well-established advantages of these technologies, including improved bioavailability, controlled drug release, and targeted action. The positive attitude toward precision and reduced side effects suggests that both practitioners and patients are open to adopting novel systems once their safety and efficacy are validated. However, the belief among many participants that these systems are “too expensive for routine use” underscores a major barrier to implementation, particularly in developing healthcare economies. High production and research costs, complex regulatory pathways, and limited local manufacturing capabilities continue to restrict widespread accessibility [16].

Despite strong theoretical awareness, the practical adoption of advanced delivery systems remains moderate. While inhalation and transdermal systems were frequently used, nanoparticle-based and implantable systems showed lower uptake. This may be attributed to limited availability in local markets, lack of specialized training among clinicians, and minimal patient education. The observation that only about one-third of participants believed healthcare professionals are adequately trained in these technologies highlights a systemic need for continuing professional development. Integration of new drug delivery concepts into medical, pharmaceutical, and nursing curricula could help bridge this gap and improve real-world competency [17].Another notable observation is the enthusiasm for patient-centric and non-invasive approaches. The growing acceptance of patches, sprays, and microneedle systems reflects a shift in healthcare culture toward comfort, convenience, and compliance. This trend also mirrors the broader movement toward personalized medicine, where drug delivery is tailored to individual patient needs rather than a one-size-fits-all approach. Such preferences are encouraging for pharmaceutical developers focusing on wearable and smart devices, which can monitor drug levels and adjust dosing automatically [18].Economic and logistical challenges, however, continue to limit the adoption of high-end technologies like nanocarriers, liposomes, and controlled-release implants. These systems require

stringent quality control, specialized storage, and trained personnel [19]. For low- and middle-income countries, the cost of production and maintenance often outweighs the perceived benefits. To overcome this, there is a need for local research collaborations, public-private partnerships, and government-supported innovation programs that can make advanced systems more affordable and scalable [20,21].

The study also revealed that a considerable proportion of the general public still depends on conventional oral and injectable routes, largely due to habit and familiarity. This highlights the importance of awareness campaigns emphasizing the safety, reliability, and long-term advantages of newer technologies. Educating patients about how these systems improve adherence and minimize side effects can significantly influence acceptance and compliance.Overall, the findings suggest a transitional phase in the field of drug delivery. The knowledge base is expanding, acceptance is improving, and the scientific community is progressively moving toward more sophisticated systems that integrate nanotechnology, biotechnology, and digital monitoring. However, the gap between innovation and implementation remains wide. Efforts must be directed toward improving education, reducing costs, simplifying manufacturing, and ensuring that regulatory frameworks are adaptive enough to accommodate rapid scientific advances.

Conclusion

It is concluded that awareness and acceptance of new drug delivery systems are steadily increasing, reflecting a significant transformation in modern therapeutics. Most participants in this study recognized that advanced systemssuch as transdermal patches, inhalation devices, and nanoparticle-based formulationsoffer improved precision, enhanced patient comfort, and reduced side effects compared to conventional methods. However, despite this positive perception, practical adoption remains limited due to barriers such as high cost, lack of technical training, and limited availability in clinical settings.

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