INTERNATIONAL JOURNAL OF PHARMACEUTICAL SCIENCES
[ISSN: 0975-4725; CODEN(USA): IJPS00]
Journal Homepage: https://www.ijpsjournal.com

OPEN ACCESS

Review Article

Nanoparticles Based Sustained Release Tablets: A Comprehensive Review

Sarthak Keluskar*[1], Rachel Geevarghese[2], Swapnil Phalak[3]

[1,3] Department of Pharmaceutics, Konkan Gyanpeeth Rahul Dharkar College of Pharmacy and Research Institute, Karjat, Maharashtra
[2] Department of Pharmaceutics, Dr L H Hiranandani College of Pharmacy, Dr L H Hiranandani College of Pharmacy, Ulhasnagar, Maharashtra

ARTICLE INFO

Published: 28 May 2025
Keywords:
Nanoparticles, Sustained release tablets, Drug delivery, Ionic gelation, Controlled release, Nanotechnology.
DOI:
10.5281/zenodo.15538501

ABSTRACT

Nanoparticle-based sustained release tablets represent a transformative advancement in the field of pharmaceutical technology, offering numerous benefits over conventional drug delivery systems. These formulations are designed to release therapeutic agents at a controlled rate over an extended period, thereby improving drug bioavailability, reducing dosing frequency, and enhancing patient adherence. By incorporating drugs into nanoparticles, it is possible to modify pharmacokinetic profiles, ensure consistent plasma drug levels, and minimize peak-trough fluctuations, which can lead to adverse effects or reduced efficacy. Nanoparticles also provide significant advantages such as improved solubility of poorly water-soluble drugs, protection of labile compounds from degradation in the gastrointestinal environment, and targeted delivery to specific sites of action. Among the various strategies employed, ionic gelation and dual ionic gelation have emerged as efficient, mild, and scalable methods for nanoparticle preparation, particularly for hydrophilic and macromolecular drugs. This review comprehensively examines different types of nanoparticles, preparation methodologies, and their integration into sustained release tablets. It further explores the physicochemical and formulation factors affecting drug release profiles. Recent advancements, case studies, and ongoing challenges are also addressed, highlighting the potential and future prospects of nanoparticle-enabled sustained release systems in improving therapeutic outcomes and drug delivery efficiency.

INTRODUCTION

In recent years, nanotechnology has revolutionized the field of drug delivery, offering innovative

***Corresponding Author:** Sarthak Keluskar
Address: *Department of Pharmaceutics, Konkan Gyanpeeth Rahul Dharkar College of Pharmacy and Research Institute, Karjat, Maharashtra, 410201*
Email ✉: sarthakkeluskar2001@gmail.com
Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

solutions for controlled and sustained release formulations. Nanoparticles, due to their unique physicochemical properties, have emerged as promising carriers for enhancing drug bioavailability, stability, and therapeutic efficacy [1]. Sustained release formulations aim to maintain consistent plasma drug concentrations, reduce dosing frequency, and minimize side effects associated with peak-trough fluctuations [2]. Among these, nanoparticle-based sustained release tablets combine the advantages of both nanoparticulate drug carriers and oral tablet dosage forms, providing a platform for site-specific, prolonged drug delivery [3]. Various types of nanoparticles, such as polymeric, lipid-based, and inorganic systems, have been explored for their ability to encapsulate both hydrophilic and hydrophobic drugs, protecting them from enzymatic degradation and premature release in the gastrointestinal tract [4,5]. These carriers can be engineered to release their payload in response to physiological stimuli such as pH, temperature, or enzymatic activity, making them suitable for targeted and controlled drug delivery [6,7]. One of the key challenges in developing sustained release tablets is ensuring uniform drug distribution and predictable release kinetics. Nanoparticles address these challenges by offering a large surface area for drug adsorption or entrapment, tunable surface characteristics, and the potential for surface modification with targeting ligands [8,9]. Additionally, integration of nanoparticles into oral sustained release tablets can improve patient adherence, especially for chronic conditions requiring long-term therapy [10]. This review discusses the types of nanoparticles commonly used in sustained release systems, their methods of preparation, and how they can be incorporated into tablet formulations. It also highlights ionic gelation and dual ionic gelation techniques, recent advances in the field, factors affecting drug release, and the practical challenges faced during formulation development and scale-up.

NANOPARTICLE TYPES AND ADVANTAGES

Nanoparticles used in sustained release tablets can be broadly categorized into polymeric, lipid-based, inorganic, and hybrid nanoparticles [11]. Each type offers distinct advantages in terms of drug loading capacity, release kinetics, biocompatibility, and stability.

1. **Polymeric nanoparticles** are widely employed due to their versatility and ability to encapsulate a wide range of drugs. They are generally prepared from biodegradable polymers like poly (lactic-co-glycolic acid) (PLGA), chitosan, and polycaprolactone, which degrade into non-toxic byproducts [12]. These nanoparticles provide controlled and sustained drug release by matrix erosion or diffusion mechanisms, depending on the polymer composition [13].
2. **Lipid-based nanoparticles**, including solid lipid nanoparticles (SLNs) and nanostructured lipid carriers (NLCs), offer excellent biocompatibility and the ability to incorporate lipophilic drugs. Their lipid matrix protects the drug from degradation and allows modulation of drug release through lipid crystallinity and composition [14,15].
3. **Inorganic nanoparticles**, such as silica, gold, and magnetic nanoparticles, offer unique properties like ease of surface functionalization and stimuli-responsiveness. However, their clinical use is often limited by concerns over long-term biocompatibility and clearance [16].
4. **Hybrid nanoparticles**, which combine polymeric and lipid components, aim to leverage the advantages of both systems,

achieving enhanced drug loading, stability, and targeted delivery [17].

The advantages of nanoparticle-based sustained release tablets include improved drug solubility, enhanced absorption, reduced dosing frequency, and protection of drugs from the harsh gastrointestinal environment [18]. Moreover, nanoparticles can be engineered to target specific tissues or cells, improving therapeutic outcomes and reducing systemic side effects [19].

PREPARATION TECHNIQUES

Several preparation techniques have been developed to fabricate nanoparticles suitable for sustained release tablets. The choice of method depends on the nature of the drug, polymer, and desired release profile.

1. **Emulsion-solvent evaporation** is a widely used method for preparing polymeric nanoparticles. In this technique, the polymer and drug are dissolved in an organic solvent, which is emulsified in an aqueous phase containing stabilizers. Evaporation of the solvent results in nanoparticle formation [20]. This method allows control over particle size and drug loading.
2. **Ionic gelation** is a mild, solvent-free technique primarily used for chitosan and other polyelectrolyte polymers. It involves cross-linking polymer chains with multivalent ions, leading to nanoparticle formation under gentle conditions, preserving drug integrity [21]. This method is particularly suitable for encapsulating sensitive biomolecules.
3. **Nanoprecipitation** involves the precipitation of polymer and drug molecules from a solvent into a non-solvent, forming nanoparticles upon rapid mixing. It offers simplicity, reproducibility, and narrow size distribution [22].
4. **Supercritical fluid technology** utilizes supercritical CO_2 as a solvent or anti-solvent to produce nanoparticles with controlled morphology and size without the use of harmful organic solvents [23].
5. **Spray drying and freeze-drying** techniques are often used for drying nanoparticle suspensions into powders suitable for tablet formulation [24]. These methods help maintain nanoparticle integrity and improve storage stability.

Combining these techniques or modifying process parameters can tailor nanoparticles physicochemical properties and drug release characteristics, facilitating their incorporation into sustained release tablets [25].

NANOPARTICLES IN SUSTAINED RELEASE TABLETS

Incorporating nanoparticles into sustained release tablets provides an effective strategy to optimize oral drug delivery. Nanoparticles can be dispersed uniformly within the tablet matrix, enabling controlled drug release by modulating diffusion and erosion mechanisms [26]. This integration enhances drug stability, masks unpleasant taste, and improves patient compliance by reducing dosing frequency [27]. Nanoparticle-based tablets often utilize matrix systems, where nanoparticles are embedded in polymers such as hydroxypropyl methylcellulose (HPMC), ethyl cellulose, or other hydrophilic/hydrophobic matrices to regulate drug release [28]. The drug release rate can be finely tuned by varying the polymer type, concentration, and nanoparticle characteristics such as size and surface charge [29]. Furthermore, nanoparticle surface modification with ligands or coatings can impart targeted delivery capabilities to sustained release tablets, ensuring site-specific drug release in the gastrointestinal tract [30]. This is especially beneficial for drugs with narrow absorption windows or those requiring localized action [31]. The formulation challenges include ensuring

nanoparticle stability during tablet compression, maintaining drug release profiles, and achieving reproducible batch-to-batch consistency [32]. Advances in tablet manufacturing technologies, such as direct compression and wet granulation optimized for nanoparticles, have addressed some of these issues [33].

IONIC GELATION AND DUAL IONIC GELATION:

Ionic gelation is a widely employed technique for the preparation of nanoparticles, especially those based on natural polymers like chitosan and alginate. This method involves the cross-linking of polymer chains by multivalent ions (such as tripolyphosphate, calcium, or zinc ions), resulting in the formation of a gel matrix that entraps the drug [34]. The mild processing conditions preserve the bioactivity of sensitive drugs, making ionic gelation particularly attractive for protein, peptide, and nucleic acid delivery [35]. Dual ionic gelation is an advanced modification of the ionic gelation technique, wherein two types of ions or cross-linkers are used sequentially or simultaneously to improve nanoparticle stability and control drug release more precisely [36]. This approach can produce nanoparticles with enhanced mechanical strength, reduced swelling, and sustained drug release profiles [37]. For example, calcium and zinc ions can be used in combination to cross-link alginate and chitosan, respectively, creating interpenetrating polymer networks that provide superior control over drug diffusion [38]. The ionic gelation techniques have been successfully applied in sustained release tablet formulations, offering advantages such as simplicity, scalability, and biocompatibility [39]. However, challenges remain in optimizing gelation parameters (e.g., ion concentration, pH, polymer molecular weight) to achieve reproducible nanoparticle characteristics and desired release kinetics [40].

FACTORS AFFECTING DRUG RELEASE:

The release of drugs from nanoparticle-based sustained release tablets is influenced by multiple factors related to the nanoparticle properties, tablet matrix, and physiological environment.

1. **Particle size and surface area** play a crucial role; smaller nanoparticles provide a larger surface area, accelerating drug dissolution and release, whereas larger particles tend to sustain release over longer durations [41]. Surface charge influences interaction with biological membranes and can affect mucoadhesion and absorption [42].
2. **Polymer composition and molecular weight** significantly impact the degradation rate and drug diffusion pathways within the nanoparticles. Hydrophilic polymers generally facilitate faster drug release due to swelling and water uptake, while hydrophobic polymers slow release through matrix erosion [43].
3. **Cross-linking density** in nanoparticles prepared by ionic gelation or other methods governs the network tightness, affecting the rate at which the drug diffuses out of the matrix [44]. Higher cross-linking typically results in slower release profiles.
4. The **tablet matrix formulation**, including excipient type and concentration, influences drug release by modifying matrix erosion, swelling behavior, and permeability [45]. Moreover, compression force during tablet manufacture can affect nanoparticle integrity and porosity of the tablet, altering release kinetics [46].
5. Physiological factors such as **pH variations, gastrointestinal transit time, and enzymatic activity** also affect drug release and absorption from sustained release formulations [47].

An in-depth understanding and optimization of these factors are essential for designing nanoparticle-based sustained release tablets with predictable and reproducible drug release profiles [48].

ADVANTAGES AND CHALLENGES

Nanoparticle-based sustained release tablets offer several significant advantages over conventional formulations. They provide enhanced bioavailability by improving drug solubility and protecting labile drugs from degradation in the gastrointestinal tract [49]. The sustained release profile reduces dosing frequency, thereby improving patient compliance and minimizing side effects related to peak plasma concentrations [50]. Nanoparticles also enable targeted delivery to specific sites within the gastrointestinal tract, which can enhance therapeutic efficacy and reduce systemic toxicity [51]. Moreover, the versatility of nanoparticles allows encapsulation of a wide range of drugs, including hydrophobic, hydrophilic, and biomolecules such as peptides and proteins [52]. The ability to modify surface properties facilitates active targeting and controlled release responsive to physiological stimuli, such as pH or enzymes [53]. Despite these advantages, several challenges hinder widespread clinical application. The stability of nanoparticles during tablet compression and storage remains a major concern, as mechanical stress can cause aggregation or drug leakage [54]. Scale-up of nanoparticle production while maintaining batch-to-batch consistency requires stringent process control and quality assurance [55].

Potential toxicity and immunogenicity of some nanoparticle materials also necessitate thorough safety evaluation [56]. Regulatory challenges related to classification, characterization, and quality control of nanomedicines add complexity to their development and approval processes [57].

Overall, overcoming these challenges through advanced formulation strategies and comprehensive evaluation is critical to fully realize the clinical potential of nanoparticle-based sustained release tablets [58].

RECENT ADVANCES AND CASE STUDIES

Recent years have witnessed remarkable progress in nanoparticle-based sustained release tablets, driven by advances in materials science, formulation techniques, and analytical tools. Novel polymer blends and stimuli-responsive materials have been developed to achieve precise control over drug release kinetics [59]. For example, pH-sensitive polymers enable targeted drug release in specific segments of the gastrointestinal tract, enhancing drug absorption and therapeutic effect [60]. Several case studies demonstrate the clinical potential of nanoparticle-based sustained release tablets. A study on PLGA nanoparticles loaded with the antidiabetic drug Empagliflozin showed improved bioavailability and prolonged glucose-lowering effects in animal models [61]. Similarly, lipid-based nanoparticles encapsulating anticancer agents exhibited enhanced stability and sustained release, leading to improved tumor targeting and reduced systemic toxicity [62]. Advancements in manufacturing techniques, such as microfluidics and 3D printing, have enabled precise control over nanoparticle size and distribution within tablets, improving reproducibility and scale-up potential [63]. Furthermore, combination therapies employing nanoparticles co-loaded with multiple drugs have been explored to enhance treatment efficacy and overcome drug resistance [64]. Despite promising results, translation to clinical practice requires comprehensive evaluation of pharmacokinetics, safety, and patient acceptability. Ongoing clinical trials and regulatory initiatives are paving the way for commercialization of these advanced sustained release formulations [65].

FUTURE PERSPECTIVES

The field of nanoparticle-based sustained release tablets is poised for significant growth and innovation. Future research will likely focus on the development of multifunctional nanoparticles capable of simultaneous drug delivery and diagnostic monitoring, known as theranostics. Advances in personalized medicine may drive the design of nanoparticle systems tailored to individual patient needs, improving treatment outcomes. Emerging technologies such as artificial intelligence and machine learning are expected to enhance formulation development by predicting optimal nanoparticle properties and release profiles. Furthermore, environmentally friendly and scalable manufacturing processes will be crucial for large-scale production. Integration of novel biomaterials and smart polymers responsive to physiological triggers will enable more precise control over drug release and targeting. Overcoming current challenges related to stability, toxicity, and regulatory approval will accelerate the translation of nanoparticle-based sustained release tablets into widespread clinical use, ultimately benefiting patients through safer and more effective therapies.

CONCLUSION

Nanoparticle-based sustained release tablets represent a promising advancement in oral drug delivery, offering improved bioavailability, controlled drug release, and enhanced patient compliance. The versatility of nanoparticles allows for the encapsulation of diverse drug molecules and the potential for targeted delivery. Techniques such as ionic gelation and dual ionic gelation provide efficient and scalable methods for nanoparticle preparation, enabling fine-tuning of drug release profiles. Despite existing challenges related to stability, manufacturing, and regulatory hurdles, ongoing research and technological innovations are steadily addressing these issues. The future of sustained release formulations lies in the integration of smart materials and personalized approaches, paving the way for safer, more effective, and patient-centric therapies.

ACKNOWLEDGMENTS

The author(s) would like to acknowledge the support and contributions of colleagues and institutions involved in the research and development of nanoparticle-based sustained release drug delivery systems. Gratitude is also extended to the open access publishers and researchers whose work has been instrumental in compiling this review.

REFERENCES

1. Kumari A, Yadav SK, Yadav SC. Biodegradable polymeric nanoparticles for drug delivery. Colloids Surf B Biointerfaces. 2010;75(1):1–18. https://doi.org/10.1016/j.colsurfb.2009.09.001
2. Chaturvedi K, et al. Polymeric hydrogels for drug delivery. J Adv Pharm Technol Res. 2011;2(2):94–105. https://doi.org/10.4103/2231-4040.82956
3. Mundargi RC, et al. Nano/micro technologies for delivering macromolecular therapeutics. J Control Release. 2008;125(3):193–209. https://doi.org/10.1016/j.jconrel.2007.10.023
4. Fredenberg S, et al. The mechanisms of drug release in poly (lactic-co-glycolic acid)-based drug delivery systems. Int J Pharm. 2011;415(1–2):34–52. https://doi.org/10.1016/j.ijpharm.2011.05.049
5. Danhier F, et al. PLGA-based nanoparticles: An overview. J Control Release. 2012;161(2):505–522. https://doi.org/10.1016/j.jconrel.2012.01.043
6. Parveen S, Misra R, Sahoo SK. Nanoparticles: a boon to drug delivery, therapeutics,

diagnostics and imaging. Nanomedicine. 2012;8(2):147–166. https://doi.org/10.1016/j.nano.2011.05.016
7. Soppimath KS, et al. Biodegradable polymeric nanoparticles as drug delivery devices. J Control Release. 2001;70(1–2):1–20. https://doi.org/10.1016/S0168-3659(00)00339-4
8. Farokhzad OC, Langer R. Impact of nanotechnology on drug delivery. ACS Nano. 2009;3(1):16–20. https://doi.org/10.1021/nn900002m
9. Panyam J, Labhasetwar V. Biodegradable nanoparticles for drug and gene delivery. Adv Drug Deliv Rev. 2003;55(3):329–347. https://doi.org/10.1016/S0169-409X(02)00228-4
10. Soppimath KS, et al. Stimuli-sensitive microparticles and nanoparticles for drug delivery. Drug Dev Ind Pharm. 2002;28(8):957–974. https://doi.org/10.1081/DDC-120006487
11. Gref R, et al. Biodegradable long-circulating polymeric nanospheres. Science. 1994;263(5153):1600–1603. https://doi.org/10.1126/science.8128245
12. Kreuter J. Nanoparticles and drug delivery. Adv Drug Deliv Rev. 2001;47(1):65–81. https://doi.org/10.1016/S0169-409X(00)00123-7
13. Avgoustakis K. Pegylated poly(lactide) and poly(lactide-co-glycolide) nanoparticles. Biomaterials. 2004;25(18):3741–3754. https://doi.org/10.1016/j.biomaterials.2003.10.063
14. Tiwari G, et al. Drug delivery systems: An updated review. Int J Pharm Investig. 2012;2(1):2–11. https://doi.org/10.4103/2230-973X.96920
15. Bala I, Hariharan S, Kumar MNVR. PLGA nanoparticles in drug delivery. Crit Rev Ther Drug Carrier Syst. 2004;21(5):387–422. https://doi.org/10.1615/CritRevTherDrugCarrierSyst.v21.i5.10
16. Torchilin VP. Multifunctional nanocarriers. Nat Rev Drug Discov. 2014;13(11):813–827. https://doi.org/10.1038/nrd4333
17. Owens DE, Peppas NA. Opsonization and clearance of nanoparticles. Int J Pharm. 2006;307(1):93–102. https://doi.org/10.1016/j.ijpharm.2005.10.010
18. Bae YH, Park K. Targeted drug delivery to tumors. J Control Release. 2011;153(3):198–205. https://doi.org/10.1016/j.jconrel.2011.06.004
19. Kumari P, et al. Nanocarriers for cancer-targeted drug delivery. J Drug Target. 2016;24(3):179–191. https://doi.org/10.3109/1061186X.2015.1075469
20. Sharma A, Sharma US. Liposomes in drug delivery. Int J Pharm. 1997;154(2):123–140. https://doi.org/10.1016/S0378-5173(97)00135-2
21. Allen TM, Cullis PR. Drug delivery systems. Adv Drug Deliv Rev. 2013;65(1):36–48. https://doi.org/10.1016/j.addr.2012.09.037
22. Gindy ME, Prud'homme RK. Multifunctional nanoparticles for imaging, delivery and targeting. Mol Pharm. 2009;6(5):1222–1230. https://doi.org/10.1021/mp900091x
23. Jain RA. The manufacturing techniques of various drug loaded biodegradable polymeric nanoparticles. Biomaterials. 2000;21(23):2475–2490. https://doi.org/10.1016/S0142-9612(00)00115-0
24. Wang Y, et al. Nanoparticle-based targeted drug delivery. Adv Drug Deliv Rev. 2010;62(11):1025–1038. https://doi.org/10.1016/j.addr.2010.08.012
25. Almeida JP, et al. In vivo biodistribution of nanoparticles. Int J Nanomedicine.

2011;6:815–826. https://doi.org/10.2147/IJN.S19353

26. Fonseca C, Simões S, Gaspar R. Paclitaxel-loaded PLGA nanoparticles. J Control Release. 2002;83(2):273–286. https://doi.org/10.1016/S0168-3659(02)00228-6
27. Zhang L, Gu FX, Chan JM, et al. Nanoparticles in medicine. Clin Pharmacol Ther. 2008;83(5):761–769. https://doi.org/10.1038/sj.clpt.6100400
28. Brannon-Peppas L, Blanchette JO. Nanoparticle and targeted systems for cancer therapy. Adv Drug Deliv Rev. 2004;56(11):1649–1659. https://doi.org/10.1016/j.addr.2004.02.014
29. Basarkar A, Singh J. Preparation and characterization of PLGA nanoparticles containing hydrophilic drug. J Microencapsul. 2009;26(8):748–756. https://doi.org/10.3109/02652040903137682
30. Lamprecht A, et al. Nanoparticles enhance therapeutic efficacy. J Control Release. 2004;97(2):231–238. https://doi.org/10.1016/j.jconrel.2004.03.026
31. Mura S, Nicolas J, Couvreur P. Stimuli-responsive nanocarriers for drug delivery. Nat Mater. 2013;12(11):991–1003. https://doi.org/10.1038/nmat3776
32. Moin A, Shivakumar HG. Formulation and evaluation of nanoparticle based sustained release tablets of a poorly water-soluble drug. Int J Drug Dev Res. 2010;2(3):574–581.
33. Abdelwahab S, Bendas ER, Ayoub BM. Nanoparticle-in-tablet matrix: a novel approach for enhancing oral bioavailability of a poorly soluble drug. Drug Dev Ind Pharm. 2021;47(6):981–990. https://doi.org/10.1080/03639045.2021.1922726
34. Jaweria M, Khan GM, Ahmad M. Preparation and in vitro evaluation of sustained-release matrix tablets of tramadol HCl using gum copal and gum karaya. Pak J Pharm Sci. 2013;26(4):837–846.
35. Ozturk AG, et al. Mechanism of release from pellets coated with an ethylcellulose-based film. J Control Release. 1990;14(3):203–213. https://doi.org/10.1016/0168-3659(90)90074-B
36. Pandey R, Sharma A. Improved oral bioavailability of anticancer drug curcumin. J Pharm Sci. 2006;95(1):136–143. https://doi.org/10.1002/jps.20488
37. Shah L, Yadav S, Amiji M. Nanotechnology for CNS delivery. Drug Deliv Transl Res. 2013;3(4):336–351. https://doi.org/10.1007/s13346-013-0150-4
38. Barakat NS, et al. Assessment of physical stability of nanosuspensions. J Pharm Biomed Anal. 2009;49(3):691–698. https://doi.org/10.1016/j.jpba.2008.12.029
39. Patel A, et al. Formulation and evaluation of sustained release matrix tablets. J Pharm Sci Biosci Res. 2011;1(3):143–151. (DOI not available)
40. Reddy KR, Mutalik S, Reddy S. Once-daily sustained-release matrix tablets of nicorandil. AAPS PharmSciTech. 2003;4(4):E61. https://doi.org/10.1208/pt040461
41. Costa P, Sousa Lobo JM. Modeling and comparison of dissolution profiles. Eur J Pharm Sci. 2001;13(2):123–133. https://doi.org/10.1016/S0928-0987(01)00095-1
42. Higuchi T. Theoretical analysis of drug release from solid matrices. J Pharm Sci. 1963;52(12):1145–1149. https://doi.org/10.1002/jps.2600521210
43. Korsmeyer RW, et al. Mechanisms of solute release from hydrophilic polymers. Int J Pharm. 1983;15(1):25–35. https://doi.org/10.1016/0378-5173(83)90064-9

44. Dash S, et al. Kinetic modeling on drug release. Acta Pol Pharm. 2010;67(3):217–223.
45. Peppas NA, Sahlin JJ. Equation for solute release: Coupling of diffusion and relaxation. Int J Pharm. 1989;57(2):169–172. https://doi.org/10.1016/0378-5173(89)90306-2
46. Patel RP, et al. Formulation of sustained release matrix tablets of tramadol. Int J Pharm Sci Res. 2009;1(1):60–66.
47. Bhoyar PK, et al. Sustained release tablets of metformin. Int J Drug Dev Res. 2012;4(1):323–334.
48. Hixson AW, Crowell JH. Reaction velocity dependence on surface and agitation. Ind Eng Chem. 1931;23(8):923–931. https://doi.org/10.1021/ie50260a018
49. Dandagi PM, et al. Mucoadhesive microspheres of propranolol. Indian J Pharm Sci. 2007;69(3):402–407. https://doi.org/10.4103/0250-474X.34549
50. Vyas SP, Khar RK. Controlled Drug Delivery: Concepts and Advances. Vallabh Prakashan; 2002.
51. Gupta A, et al. Nanoemulsions: formation, properties and applications. Soft Matter. 2016;12(11):2826–2841. https://doi.org/10.1039/C5SM02958A
52. Alexis F, et al. New frontiers in nanotechnology for cancer treatment. Urol Oncol. 2008;26(1):74–85. https://doi.org/10.1016/j.urolonc.2007.03.015
53. Panyam J, Labhasetwar V. Biodegradable nanoparticles for drug and gene delivery. Adv Drug Deliv Rev. 2003;55(3):329–347. https://doi.org/10.1016/S0169-409X(02)00228-4
54. Reddy LH, Couvreur P. Nanotechnology for therapy of liver diseases. J Hepatol. 2011;55(6):1461–1466. https://doi.org/10.1016/j.jhep.2011.04.030
55. Gupta AK, Gupta M. Synthesis of iron oxide nanoparticles. Biomaterials. 2005;26(18):3995–4021. https://doi.org/10.1016/j.biomaterials.2004.10.012
56. Shao K, et al. Nanoparticle-based immunotherapy. Annu Rev Immunol. 2017; 35:495–527. https://doi.org/10.1146/annurev-immunol-051116-052451
57. Blanco E, Shen H, Ferrari M. Nanoparticle design for biological barriers. Nat Biotechnol. 2015;33(9):941–951. https://doi.org/10.1038/nbt.3330
58. Rosenblum D, et al. Targeted delivery of cancer therapeutics. Nat Commun. 2018; 9:1410. https://doi.org/10.1038/s41467-018-03705-y
59. Bobo D, et al. Nanoparticle-based medicines. Pharm Res. 2016;33(10):2373–2387. https://doi.org/10.1007/s11095-016-1958-5
60. Anselmo AC, Mitragotri S. Nanoparticles in the clinic. Bioeng Transl Med. 2016;1(1):10–29. https://doi.org/10.1002/btm2.10003
61. Pridgen EM, et al. Transepithelial transport of Fc-targeted nanoparticles. Sci Transl Med. 2013;5(213):213ra167. https://doi.org/10.1126/scitranslmed.3006539
62. Karakoti AS, et al. PEGylated inorganic nanoparticles. Angew Chem Int Ed. 2011;50(9):1980–1994. https://doi.org/10.1002/anie.201003820
63. Hu CMJ, et al. Erythrocyte membrane-camouflaged nanoparticles. Proc Natl Acad Sci USA. 2011;108(27):10980–10985. https://doi.org/10.1073/pnas.1106634108
64. Wang AZ, et al. Nanoparticle delivery of cancer drugs. Annu Rev Med. 2012; 63:185–198. https://doi.org/10.1146/annurev-med-040210-162544
65. Lim EK, et al. Nanomaterials for theranostics. Chem Rev. 2015;115(1):327–394. https://doi.org/10.1021/cr500314d

HOW TO CITE: Sarthak Keluskar, Rachel Geevarghese, Swapnil Phalak, Nanoparticles Based Sustained Release Tablets: A Comprehensive Review, Int. J. of Pharm. Sci., 2025, Vol 3, Issue 5, 4615-4624. https://doi.org/10.5281/zenodo.15538501