Journal of Pharmaceutical Advanced Research
(An International Multidisciplinary Peer Review Open Access monthly Journal)
Available online at: www.jparonline.com

REVIEW ARTICLE JPAR 2025

Carbon Nanotubes: A Review

P.S. Patil[1*], S.V. Badgujar[2], N.G. Haswani[2], K.P. Rathod[1], M.R. Shirsath[1]

[1]R.C. Patel Institute of Pharmaceutical Education and Research, Shirpur, Dhule-425405, Maharashtra, India.
[2]R.C. Patel Institute of Pharmacy, Shirpur, Dhule-425405, Maharashtra, India.

Received: 11.02.2025 Revised: 18.01.2025 Accepted: 25.01.2025 Published: 28.01.2025

ABSTRACT: Carbon Nanotubes (CNTs) offer a promising prospect in drug delivery systems. Their unique structure and the ability to modify surface according to need make it a potential candidate for targeted drug delivery. CNTs can be conjugated with various biological molecules including drugs, proteins, and nucleic acid to afford bio-functionalities. The CNTs are valuable in the fields of drug delivery, blood cancer, breast cancer, brain cancer, liver cancer, cervical cancer, gene therapy, immune therapy, biomedical imaging, biosensors, and tissue engineering. The following review focuses on the method of development and applications of carbon nanotubes.

Corresponding author:
Mr. Pradeep S. Patil
Asst. Professor
R.C. Patel Institute of Pharmaceutical Education and Research,
Shirpur, Dhule-425405, Maharashtra, India.
Tel: +91-8149142956
E. Mail ID: patilpradeep19@yahoo.com

Keywords: Biomedical imaging, Biosensors, Drug delivery, Carbon nanotubes, Laser ablation, Tissue engineering.

INTRODUCTION:

Over the last few decades, the discovery and development of nanomaterials have been on a surge. Researchers are unraveling the benefits of various nanostructures in the field of drug delivery techniques. Carbon nanotubes are one of the recent developments in the field of nanomaterials. Carbon nanotubes are a class of carbon allotropes with unique properties that are of interest to the researchers. These nanostructures have a diameter of nanometers and their length can extend up to a millimeter range [1]. They also possess a wide range of electrical, thermal, and structural properties. They possess a very large surface area and have profound mechanical properties and tensile strength [2]. Studies suggested that the highest strength of carbon nanotubes was measured to be 63 GPa and even the weakest of the carbon nanotubes possessed strength of several GPa [3,4].

Historical background:

- In 1952 Radushkevich and Lukyanovich published clear images of 50 nanometer diameter tubes made of carbon in the Soviet Journal of Physical Chemistry [5,6].
- Oberlin *et al*. in their research work published in 1976 demonstrated hollow carbon fibers prepared by a vapor-growth technique using a mixture of benzene and hydrogen pyrolyzed at 1000 °C to have a diameter within 20-500 Å [7].
- In 1979, John Abrahamson at the 14th Biennial Conference of Carbon held at Penn State University presented evidence of carbon nanotubes [8].
- In 1987, a U.S. patent was issued to Howard G. Tennent for his work on cylindrical discrete carbon fibrils [9].
- In 1991, Sumio Iijima of Nippon Electric Company discovered nanotubes composed of graphite carbon [10].
- In 2006, Marc Monthioux and Vladimir Kuznetsov described the origin of Carbon nanotubes in their editorial for Carbon Journal [11].

Structure and morphology of Carbon nanotubes:

Carbon nanotubes are composed of sp^2 bonding where each atom is bound to 3 neighbouring atoms as observed in graphite. The tubes therefore are considered rolled-up graphene sheets. Such bonding provides the nanotubes with unique strength [12]. The structure of carbon nanotubes is given in Fig 1 [13].

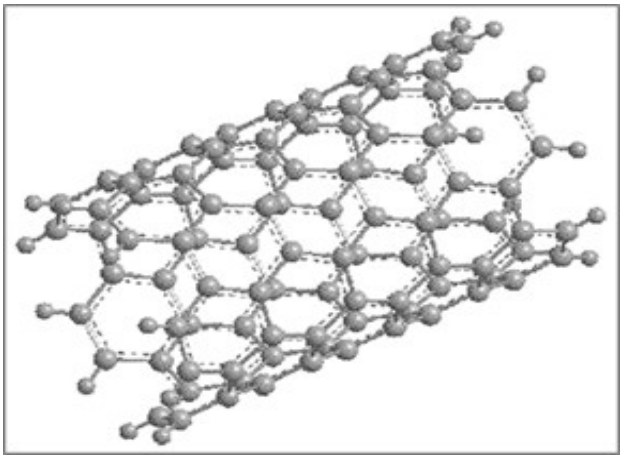

Fig 1. The structure of Carbon nanotube.

Types of Carbon Nanotubes [14]:

There are two types of carbon nanotubes namely Single Walled Carbon Nanotubes (SWNTs) and Multiple Walled Carbon Nanotubes (MWNTs).

Advantages of Carbon nanotubes [15,16]:

- They are biocompatible
- They are non-biodegradable and non-immunogenic.
- They have high elasticity and can be used for intracellular drug delivery.
- They are anticipated to have minimum cytotoxicity.
- They have good tensile strength.
- They have distinct inner and outer structures, which makes them easy to modify according to need.

METHOD OF SYNTHESIS OF CARBON NANOTUBES:

Laser ablation method [17,18]:

Smalley's group at Rice University first reported this method of synthesis in 1995. This method utilizes a pulsed or continuous laser to vaporize a graphite target at 1200°C in an oven. The oven is filled with an inert gas like Helium or argon to maintain the pressure at 500 torr. Rapid expansion and cooling of hot vapor plumes are observed during the process. As the cooling of vaporized species occurs larger clusters of carbon molecules start forming due to the condensation process. The single-walled carbon nanotubes so formed are bundled together by Van Der Wall's forces. The schematic diagram of the laser ablation method is given in Fig 2.

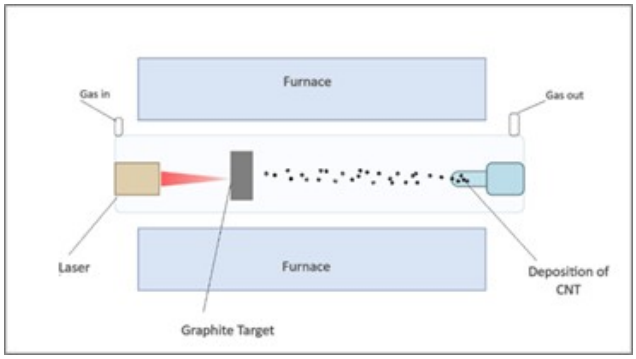

Fig 2. Laser Ablation method.

Arc Discharge method [19-23]:

This method is employed while preparing carbon nanotubes on a large scale. It is the easiest way to prepare carbon nanotubes. In this method, the carbon nanotubes are prepared by using two carbon rods, which are placed, at a distance of 1 mm in an enclosure filled with an inert gas like helium or argon at a pressure between 50 to 700 mbar. Evaporation of carbon rods is carried out at a direct current of 50-100 amps driven by approximately 20 V to generate high-temperature discharge between the electrodes. The discharge vaporizes one of the carbon rods (anode) and small rod-shaped tubes will be deposited on the cathode. The

following Fig 3 shows a schematic diagram of the arc discharge method.

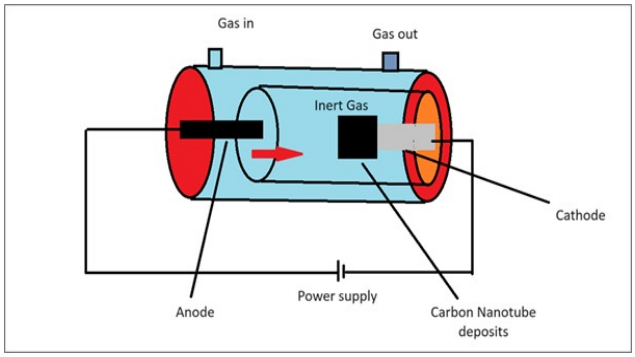

Fig 3. Arc Discharge method.

Chemical Vapor Deposition method [24-26]:

The chemical vapor deposition method is carried out in two steps:

***Step 1: Preparation of Catalyst*:**

The catalyst is usually prepared by sputtering a transition metal like nickel, iron, or cobalt onto a substrate, and then the nucleation process is carried out. Chemical etching or thermal annealing carries out the nucleation of the catalyst deposited on the substrate. The etchant used for the process is usually ammonia.

Step 2:

Synthesis of actual nanotubes: the carbon source is then placed in a gas phase in the reaction chamber where the carbon molecules are converted to atomic level by using energy sources like a heated coil. As a result, the carbon molecules will get diffused towards the substrate and get deposited resulting in the formation of carbon nanotubes.

APPLICATIONS OF CARBON NANOTUBES:

Surface-functionalized carbon nanotubes have widespread application in the human body. The unique structure of carbon nanotubes allows surface functionalization on both surfaces and can be utilized for various disease conditions, more prominent being cancer therapy. The various other applications of carbon nanotubes have been studied concerning drug delivery, biomedical imaging, biosensors, and scaffolds in tissue engineering [27]

Carbon nanotubes and cancer:

Table 1 highlights the contributions of researchers in the field of cancer therapy using carbon nanotubes.

Nanotubes in biomedical imaging [32]:

The optical properties of nanotubes have been of value in biomedical imaging. Single-walled nanotubes have demonstrated strong optical absorption from the ultraviolet (UV) range to near-infrared regions, which are beneficial in various imaging techniques including Raman imaging, photoacoustic imaging, fluorescence imaging, etc. Surface functionalization of the carbon nanotubes can also help in positron emission tomography and magnetic resonance.

Nanotubes as biosensors:

Electrochemical biosensors are normally based on enzymatic catalysis of a reaction that either produces or consumes electrons and is popular for detecting biomolecules in solutions. CNT-based biosensors incorporating enzymes have been produced for the detection of glucose and other biomolecules [33,34].

Tissue engineering:

Carbon nanotubes have also been used in enhancing tissue matrices. Scaffolds prepared from Carbon nanotubes have shown superior results in comparison to other materials that are used for tissue engineering. Recent studies have highlighted that scaffolds made from carbon nanotubes are biocompatible and are more beneficial when combined with biocompatible polymers like chitosan [35,36].

Drug delivery:

Carbon nanotubes have been used to deliver drugs to the target site of action. The large surface area and inner volume of nanotubes make it possible to encapsulate both hydrophilic and lipophilic drugs. It also gives the liberty of loading more than one drug in cases where multi-drug therapy is recommended. Diagnostic materials and targeting ligands can also be surface functionalized on the surface of carbon nanotubes to target drugs to specific sites of action. They can also act as a controlled release drug delivery system by releasing the drug in a controlled manner [37].

Other applications:

Apart from medical applications, Carbon nanotubes have been used in various industries examples of a few are given below:

- Textile industry: to prepare waterproof and tear-resistant fabrics [38].
- Concrete: utilization of carbon nanotubes in concrete increases its tensile strength and prevents cracks from forming [39].
- Fire protection: Thin layers of bucky paper can drastically improve fire resistance owing to the

Table 1. Carbon nanotubes in cancer therapy.

Type of cancer	Description	Outcome
Liver cancer [28]	Pan, *et al*. in their formulated Polyamidoamine dendrimer modified CNTs (dMWCNTs) for delivery of antisense c-myc oligonucleotide (asODN) into liver cancer cell line HepG2 cells.	Cell growth was inhibited by these nanocomposites in a time and dose-dependent manner.
Brain cancer [29]	Xing, *et al*. formulated phospholipid-bearing polyethylene glycol (PL-PEG) functionalized SWCNTs which were conjugated with protein A, which was further coupled with the fluorescein-labeled integrin monoclonal antibody to form SWCNT-integrin monoclonal antibody (SWCNT-PEGmAb).	The formulation presented a high targeting efficiency with low cellular toxicity.
Blood cancer [30]	Taghdisi, *et al*. in their research tertiary complex of Sgc8c aptamer and daunorubicin	Aptamer being responsible for targeting Leukaemia biomarker protein Tyrosine Kinase-7 efficiently targeted the leukaemia cells (MOLT-4 cells) and the release of daunorubicin was pH-dependent after internalization of the nanotubes.
Breast cancer [31]	Liu, *et al*. studied SWNT delivery of paclitaxel (PTX) into xenograft tumors in mice with higher tumor suppression efficacy than the clinical drug formulation Taxol.	The PTX conjugated to PEGylated SWNTs showed high water solubility and maintained alike toxicity to cancer cells as Taxol in vitro. It also caused a significant increase in blood circulation time and improved tumor cell uptake.
Cervical cancer [32]	Wu, *et al*. used chitosan for imaging the tumor cells. In this research, the SWCNTs were modified by chitosan (CHIT) fluorescein isothiocyanate (FITC). Further conjugation was done using folic acid (FA), as the majority of cancer cells overexpress folic acid receptors, to construct the functional FITC-CHIT-SWCNT-FA conjugate.	These novel functionalized SWCNTs were found to have improved solubility and stability in phosphate buffer saline and could be readily transported inside the human cervical carcinoma HeLa cells.

efficient reflection of heat by the dense, compact layer of carbon nanotubes [40].

- Superconductor: Nanotubes have been shown the ability to work as superconductors at low temperatures [41].

CHALLENGES AND FUTURE PERSPECTIVE:

Challenges:

Although Carbon nanotubes have promising applications in drug delivery systems, there are areas of concern that need to be addressed. One of the prime disquietudes is the toxicity within the biological system [42]. Carbon nanotubes have been shown to cause inflammation, *in-vitro* and *in-vivo* cellular damage, and oxidative stress, thus causing concerns regarding their long-term use. Also, their structure and surface chemistry can impact their biological interactions and toxicity [43,44]. More research is being focused on reducing the toxicity and improving the biocompatibility of carbon nanotubes [45].

FUTURE PERSPECTIVE:

Despite the challenges associated with carbon nanotubes, they still have the potential to be promising candidates in today's era for improving drug delivery to the targeted site of action. More research must be focused on reducing the toxicity and improving the biocompatibility

of carbon nanotubes [46]. Engineering Carbon nanotubes to improve their physicochemical properties can positively affect drug release and reduce the side effects [47]. Site-specificity and drug-targeting aspects of carbon nanotubes open up a wide area for innovation which will in the future reap the benefits of improved drug targeting with minimum side effects [48].

CONCLUSION:

Carbon nanotubes are versatile drug delivery systems that show promising results concerning drug targeting and have applications in bioimaging, tissue engineering, etc. They offer some distinctive advantages such as higher tensile strength, high drug loading capacity, better surface modification, and the ability to penetrate the biological systems. Despite various challenges in the formulation and concerns related to toxicity, they are emerging to be one of the most promising drug delivery candidates for the future. Through surface functionalization, targeted delivery strategies, and advancements in nanotechnology, researchers are involved in improving carbon nanotube-based drug delivery systems with enhanced biocompatibility, specificity, and therapeutic efficacy. As the realm of nanoformulations continues to evolve a future with carbon nanotubes playing a pivotal role in drug delivery systems is possible.

ACKNOWLEDGEMENT:

The authors sincerely thank the management of R.C. Patel Institute of Pharmacy and R.C. Patel Institute of Pharmaceutical Education and Research, Shirpur, for providing the library facilities that supported the completion of this review article.

REFERENCES:

1. Hata K, Futaba DN, Mizuno K, Namai T, Yumura M, Iijima S. Water-assisted highly efficient synthesis of impurity-free single-walled carbon nanotubes. Sci, 2004; 306(5700): 1362-1364.
2. Tibbetts GG, Beetz Jr CP. Mechanical properties of vapor-grown carbon fibers. J Phys D: Appl Phys, 1987; 20(3): 292.
3. Xie S, Li W, Pan Z, Chang B, Sun L. Mechanical and physical properties on carbon nanotube. J Phys Chem Solids, 2000; 61(7): 1153-1158.
4. Yu MF, Lourie O, Dyer MJ, Moloni K, Kelly TF, Ruoff RS. Strength and breaking mechanism of multiwalled carbon nanotubes under tensile load. Sci, 2000; 287(5453): 637-640.
5. Paramsothy M. 70th Year Anniversary of Carbon Nanotube Discovery-Focus on Real-World Solutions. Nanomater, 2023; 13(24): 3162.
6. Radushkevich LV, Lukyanovich VM. About the structure of carbon formed by thermal decomposition of carbon monoxide on iron substrate. J. Phys Chem (Moscow), 1952; 26(4438286): 88-95.
7. Oberlin A, Endo M, Koyama T. Filamentous growth of carbon through benzene decomposition. J Cryst Growth, 1976; 32(3): 335-349.
8. Manzano-Ramirez A, Moreno-Barcenas A, Apatiga-Castro M, Mauricio Rivera-Munoz E, Nava-Mendoza R, Velázquez-Castillo R. An overview of carbon nanotubes: synthesis, purification and characterization. Curr Org Chem, 2013; 17(17): 1858-1866.
9. Fischer RH, Molenda VS. The Hyperion Catalysis International, Inc. and Showa Denko KK Agreements: Considerations for Purchasers of Licensed Products. Nanotech L Bus, 2009; 6: 159.
10. Iijima S. Helical microtubules of graphite carbon. Nature, 1999; 56: 354.
11. Monthioux M, Kuznetsov VL. Who should be given the credit for the discovery of carbon nanotubes? Carbon, 2006; 44(9): 1621-1623.
12. Palser AH. Interlayer interactions in graphite and carbon nanotubes. Phys Chem Chem Phys, 1999; 1(18): 4459-4464.
13. Pandey P, Dahiya M. Carbon nanotubes: Types, methods of preparation and applications. Carbon, 2016; 1(4): 15-21.
14. Mehra NK, Jain AK, Lodhi N, Raj R, Dubey V, Mishra D, *et al*. Challenges in the use of carbon nanotubes for biomedical applications. Crit Rev Ther Drug Carrier Syst, 2008; 25(2): 169-206.
15. He H, Pham-Huy LA, Dramou P, Xiao D, Zuo P, Pham-Huy C. Carbon nanotubes: applications in pharmacy and medicine. Bio Med Res Int, 2013; 2013(1): 578290.
16. Sarangdevot K, Sonigara BS. The wondrous world of carbon nanotubes: Structure, synthesis, properties and applications. J Chem Pharm Res, 2015; 7(6): 916-933.
17. Golnabi H. Carbon nanotube research developments in terms of published papers and patents, synthesis, and production. Sci Iran, 2012; 19(6): 2012-2022.
18. Yahya N, Koziol K, Boskovic BO, Yahya N. Synthesis of carbon nanostructures by CVD method.

In: Carbon and Oxide Nanostructures: Synthesis, Characterisation and Applications. USA: Springer; 2011: 23-49.
19. Bethune DS, Kiang CH, De Vries MS, Gorman G, Savoy R, Vazquez J, *et al*. Cobalt-catalysed growth of carbon nanotubes with single-atomic-layer walls. Nature, 1993; 363(6430): 605-607.
20. Yamaguchi T, Bandow S, Iijima S. Synthesis of carbon nanohorn particles by simple pulsed arc discharge ignited between pre-heated carbon rods. Chem Phys Lett, 2004; 389(1-3): 181-185.
21. Wang H, Chhowalla M, Sano N, Jia S, Amaratunga GA. Large-scale synthesis of single-walled carbon nanohorns by submerged arc. Nanotechnol, 2004; 15(5): 546.
22. Anazawa K, Shimotani K, Manabe C, Watanabe H, Shimizu M. High-purity carbon nanotubes synthesis method by an arc discharging in magnetic field. Appl Phys Lett, 2002; 81(4): 739-741.
23. Vander Wal RL, Berger GM, Hall LJ. Single-walled carbon nanotube synthesis via a multi-stage flame configuration. J Phys Chem B, 2002; 106(14): 3564-3567.
24. Kumar M, Ando Y. Chemical vapor deposition of carbon nanotubes: a review on growth mechanism and mass production. J Nanosci Nanotechnol, 2010; 10(6): 3739-3758.
25. Nessim GD. Properties, synthesis, and growth mechanisms of carbon nanotubes with special focus on thermal chemical vapor deposition. Nanoscale, 2010; 2(8): 1306-1323.
26. Beg S, Rizwan M, Sheikh AM, Hasnain MS, Anwer K, Kohli K. Advancement in carbon nanotubes: basics, biomedical applications and toxicity. J Pharmacy Pharmacol, 2011; 63(2): 141-163.
27. Pan B, Cui D, Xu P, Ozkan C, Feng G, Ozkan M, *et al*. Synthesis and characterization of polyamidoamine dendrimer-coated multi-walled carbon nanotubes and their application in gene delivery systems. Nanotechnol, 2009; 20(12): 125101.
28. Ou Z, Wu B, Xing D, Zhou F, Wang H, Tang Y. Functional single-walled carbon nanotubes based on an integrinαvβ3 monoclonal antibody for highly efficient cancer cell targeting. Nanotechnol, 2009; 20(10): 105102.
29. Taghdisi SM, Lavaee P, Ramezani M, Abnous K. Reversible targeting and controlled release delivery of daunorubicin to cancer cells by aptamer-wrapped carbon nanotubes. Eur J Pharm Biopharm, 2011; 77(2): 200-206.
30. Liu Z, Tabakman SM, Chen Z, Dai H. Preparation of carbon nanotube bioconjugates for biomedical applications. Nat Protoc, 2009; 4(9): 1372-1381.
31. Wang X, Liu Z. Carbon nanotubes in biology and medicine: An overview. Chin Sci Bull, 2012 ; 57: 167-180.
32. Gao M, Dai L, Wallace GG. Biosensors based on aligned carbon nanotubes coated with inherently conducting polymers. Electroanalysis, 2003; 15(13): 1089-1094.
33. Ayalasomayajula LU, Ayalasomayajula KU, Pilla SA, Deepika Y, Behera M, Shyamala K, *et al*. A study on biosensors and their Pharmaceutical Applications. J Pharm Adv Res, 2024; 7(11): 2453-2460.
34. Harrison BS, Atala A. Carbon nanotube applications for tissue engineering. Biomater, 2007; 28(2): 344-353.
35. Gholizadeh S, Moztarzadeh F, Haghighipour N, Ghazizadeh L, Baghbani F, Shokrgozar MA, *et al*. Preparation and characterization of novel functionalized multiwalled carbon nanotubes/chitosan/β-Glycerophosphate scaffolds for bone tissue engineering. Int J Biol Macromol, 2017; 97: 365-372.
36. Singh BG, Baburao C, Pispati V, Pathipati H, Muthy N, Prassana SR, *et al*. Carbon nanotubes. A novel drug delivery system. Int J Res Pharmacy Chem, 2012; 2(2): 523-532.
37. Liu Y, Wang X, Qi K, Xin JH. Functionalization of cotton with carbon nanotubes. J Mater Chem, 2008; 18(29): 3454-3460.
38. Nasibulin AG, Shandakov SD, Nasibulina LI, Cwirzen A, Mudimela PR, Habermehl-Cwirzen K, *et al*. A novel cement-based hybrid material. New J Phys, 2009; 11(2): 023013.
39. Zhao Z, Gou J. Improved fire retardancy of thermoset composites modified with carbon nanofibers. Sci Technol Adv Technol Adv Mater, 2009; 10(1): 015005.
40. Tang ZK, Zhang L, Wang N, Zhang XX, Wen GH, Li GD. Superconductivity in 4 angstrom single-walled carbon nanotubes. Sci, 2001; 292(5526): 2462-2465.
41. Lacerda L, Russier J, Pastorin G, Herrero MA, Venturelli E, Dumortier H, *et al*. Translocation mechanisms of chemically functionalized carbon

nanotubes across plasma membranes. Biomater, 2012; 33(11): 3334-3343.
42. Bai W, Wu Z, Mitra S, Brown JM. Effects of multiwalled carbon nanotube surface modification and purification on bovine serum albumin binding and biological responses. J Nanomater, 2016; 2016(1): 2159537.
43. Ursini CL, Maiello R, Ciervo A, Fresegna AM, Buresti G, Superti F, *et al*. Evaluation of uptake, cytotoxicity and inflammatory effects in respiratory cells exposed to pristine and OH and-COOH functionalized multi-wall carbon nanotubes. J Appl Toxicol, 2016; 36(3): 394-403.
44. Chatterjee N, Yang J, Yoon D, Kim S, Joo SW, Choi J. Differential crosstalk between global DNA methylation and metabolomics associated with cell type-specific stress response by pristine and functionalized MWCNT. Biomater, 2017; 115: 167-180.
45. García-Hevia L, Villegas JC, Fernández F, Casafont Í, González J, Valiente R, *et al*. Multiwalled carbon nanotubes inhibit tumor progression in a mouse model. Adv Healthcare Mater, 2016; 5(9): 1080-1087.
46. Holden KB, Hopkins J, Belton A, Butty K, Tabor DC, Satcher D. Leveraging science to advance health equity: a regional health policy research center's approach. Ethn Dis, 2019; 29(Suppl 2): 323.
47. Judge A, McClintock K, Phelps JR, MacLachlan I. Hypersensitivity and loss of disease site targeting caused by antibody responses to PEGylated liposomes. Mol Ther, 2006; 13(2): 328-337.
48. Środa K, Rydlewski J, Langner M, Kozubek A, Grzybek M, Sikorski AF. Repeated injections of PEG-PE liposomes generate anti-PEG antibodies. Cell Mol Biol Lett, 2005; 10(1): 37-47.

Conflict of Interest: None
Source of Funding: Nil
Paper Citation: Patil[1] PS[*], Badgujar SV, Haswani NG, Rathod[1] KP, Shirsath MR. Carbon Nanotubes: A Review**.** J Pharm Adv Res, 2025; 8(2): 2583-2589.