

REVIEW ARTICLE

Dendrimers Chemistry and Applications: A Short Review

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ARTICLE HISTORY

Received: Dec 23 2019

Accepted: Jan 23, 2020

Abstract: Dendrimers, also known as cascade molecules, arborols, cauliflower or starburst polymers. They are monodisperse, symmetrical, macromolecules with tree like 3D-architecture consists of end-groups, central core and branching units associated to periphery and possess extremely constraint size, topography and surface characteristics like density, backfolding, intrinsic viscosity, light harvesting property, photophysical properties that are fairly distinct from linear polymers. Different types of dendrimers, on the basis of their different properties and associated functional groups, has been studied yet in which one of the unique group of dendrimers is dendritic co-polymer possess two types, first are layer block dendrimers and second are segment block dendrimers. Some new types of dendrimers like IrC₃, IrCl and IrF₂ have been also synthesized by divergent or convergent methods of synthesis. Dendrimers have a lot of applications in different fields like nanotechnology, medical chemistry, light harvesting materials, as sensors, antibacterial and anti-microbial activity.

Keywords: Dendron, Divergent synthesis, Cascade molecules, PPI Dendrimer

Introduction

The word dendrimer, arise from two Greek words dendron (means tree) and meros (means part). Basically symmetric small sized particles containing homogeneous, particular uniform architecture expressed by tree like branches are called as dendrimer. Vogtle discover these molecules in 1978 at the very first time, after that in 1980 Donald Tomailia and his colleagues presented them, still coinciding George R. Newkom discovered them individually. Dendrimers may also known as cascade molecules but this term is not as traditional as dendrimers. Dendrimer is not considered as a compound but only an architectural design. They consist of symmetric branches which are produced over a straight polymer centre or a small molecule. Poly ionic dendrimers could not have persistence

architecture, however there shape, size and flexibility changes with increasing generation. The dendrimers are extremely indistinct or possess narrow morphological range as correlate with other nano-scale synthetic structures like nano-tubes or stag-balls of carbon, traditional polymers. On dendrimer surface, molecular identification incident have being differentiated by wide number of frequently alike peripheral functional groups which are given as dendritic hosts. There are three specific parts of dendrimer structure i.e. end groups, central core and branching units associated to periphery [1]. Commonly, accepted definition of dendrimer is: A dendrimer is a monodisperse macro-molecule having fully branched traditional structure and possess inadequately one branched junction in all repeat unit. Sometimes they are illustrated in terms of polymer or

supramolecular chemistry, whereas in some case, they are not either polymer or supramolecule actually [2]. There are different names for dendrimers like cascade or arborols, cauliflower or star-burst polymer. Dendrimers draw higher diligence for their particular framework and features. These artistically engaging synthetic macromolecules are differentiated from standard polymers by two diagnostic styles. One, these are manufactured by AB_n monomers (where n is usually 2 or 3) instead of classical AB monomers that yield straight (non-branched) polymers. Hence consist of hyper-branched structures. Secondly, they are manufactured in constant manner. These two features are combined to form a non-linear step-wise synthetically growing polymer [3]. One of the important properties related to dendrimers is the addition of one or more layer of branches, known as generations, to the dendrimer framework in every repetition period. Thus one can easily determine the generation number in dendrimer through calculating the sum of branch points, when moving from midst towards edge. Figure 1 represents the typical anatomy of dendrimer. Whereas linear polymer frequently acquire random coil architecture. A three dimensional architecture is preferably explained through presence of a central body in addition to peripheral branches. Dendrimer possess low generation number be inclined to occur comparatively in exposed framework, but at the same time consecutive layers have been added, frequently up to fifth generation, dendrimer acquire a rounded three dimensional architecture that indefinitely related to cylindrical protein. These great structural similarities proposed such dendrimer efficiency in large number of ways as their natural equivalents [4]. In fact, host-guest chemistry can occur either in interior or on periphery of the dendrimer, just as the molecular identification exhibited by proteins may arise within the biopolymer or at its surface. Binding groups on the inner of the dendrimer have been called endo-receptors, however peripheral or end groups participating in complexation chemistry are called as exo-receptors. In addition, dendrimers have been working as building blocks for the self-assembly of some larger meso and nanoscopic structures, which

includes mono and multilayer's, micellar aggregates and distinct hydrogen-bonded superstructures. The field of dendrimer chemistry is presently in a critical growth phase. Dendrons associated to polymers were called dendronized polymers [5]. Because of unique synthetic way, many dendrimers have specific chemical and physical properties.

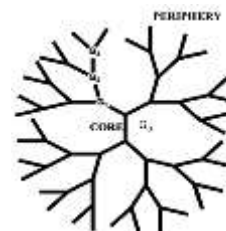


Fig. 1. Typical Anatomy of a dendrimer

The production, literatures about dendrimers and their characterization have increased theoretically. At present time more than 5 literature citations associated to this sort of molecules become visible. As dendrimers have different structures from conventional polymers so have more advantages contrast to conventional polymers in different roles [6]. Commercially available dendrimers are of two types, polyamidoamine (PAMAM) and diaminobutane (DAB). They have distinctive surface comprises of primary amino groups and are highly soluble in aqueous solution. About all amino groups are practically and theoretically uncharged at pH over 9.0 [7]. Dendrimers possess extremely constraint size, topography and surface characteristics and are fairly distinctive from straight(non-branched) polymers. Dendrimers are possible unimolecular drug carrier together with possible framework of peptides forming synthetic proteins [8]. Dendrimers possess distinct shape, size and molecular weight but their reactivity is subjected to generation and also to the chemical combination of innermost branching, core and exterior components. Dendrimer properties are increased because of their unique structures, hence are good choice for increasing solubility and drug transport application [9]. Some hollow internal pits are also present in dendrimers by which they encapsulate hydrophobic drug molecules. They also

have much more density of surface functional groups as compared to other common macromolecules [10].

Dendrimers are different from classical irregular coil molecules on the basis of their special properties as these are extremely branched, three dimensional macromolecules having a branch point at each monomer molecule [11].

Many fundamental properties of dendrimers, like nanoscale shape and size, bring about its economical use for immune-diagnostics, gene therapy and large diversity of other organic purposes i.e. drug transfer, analysis and cure etc.

Another vital property of dendrimers is immunogenicity. As research shows that unmodified amino terminated PAMAM dendrimers have no or weak immunogenicity upto G3-G7. If polyethylene glycol chains are present they decrease the immunogenicity of PAMAM dendrimers and attempt longer life time in blood stream in contrast to unmodified dendrimers [12].

Many researchers observe that as dendrimer molecular weight and generation increases, the latter units of dendrimer become closely wrapped. This feature helps the dendrimer functionality in disease diagnostic and imaging purposes [13]. The presence of different end groups in dendrimer structure can highly regulate its solubility. A dendrimer will be water soluble if it has hydrophilic end groups along with hydrophobic centre. While if a dendrimer have hydrophobic end groups and hydrophilic centre, it will be water insoluble and can easily soluble in oil [14]. The shape of lower generation dendrimer (G 2) is extremely irregular with higher open architecture. While the shape of higher generation dendrimers is not as much irregular. The viscosity of dendrimer solution is also very low, as compared to other linear polymers but the intimate viscosity of dendrimer increase up to 4th generation and then start to decrease [15]. The important properties of dendrimers render them as successful candidate in various applications. Here, we focus on the different types and applications of the dendrimers.

Types of Dendrimers

PAMAM

The shape of polyamidoamine dendrimers (pamam) are the globular. These dendrimers are synthesized usually by ammonia and ethylenediamine which are starting material via divergent method. The presence of various functionality at the end inside the hollow chamber making these dendrimers highly reactive and soluble. The trademark name of sub-class of PAMAM dendrimer is starburst which having triaminoethylene-imine center (Fig. 2) [16].

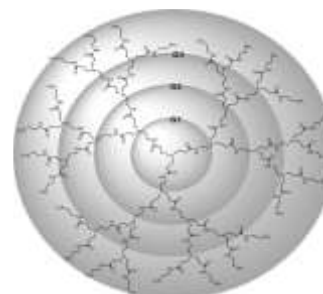


Fig. 2. PAMAM Dendrimer

These dendrimers obtained as a products upto 10th generations which having a molecular weight of over 930,000 g/mole in comparison to the molecular weight of human hemoglobin i.e. approximate 65,000 g/mole/ [17].

PAMAMOS

Polyamidoamine organosilicone dendrimers (PAMAMOS) are radially layered transpose unimolecular thread like structure that contained a deliquescent, nucleophilic polyamidoamine (PAMAM) inside and water-repellent organo-silicon outside. For the preparation of honeycomb-like networks with a nanoscopic PAMAM and organosilicon speciality these dendrimers are uncommon usable precursors [18]. Polyamidoamin organosilicone (PAMAMOS) are first commercially available dendrimer consist on silicon [10]. Figure 3 represents the structure of 3rd generation PAMAMOS dendrimer.

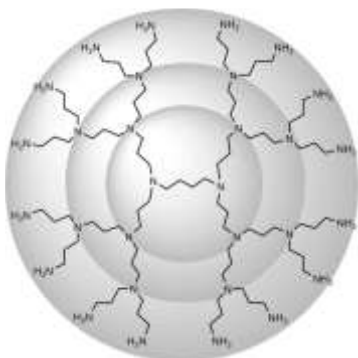


Fig. 3. Third generation of PAMAMOS-dendrimers having tetrafunctional core unit

PPI Dendrimer

The PPI dendrimers also mentioned as poly(propylene imine) explained that propylamine acts as a separator element in an older known dendrimer type which is primarily evolved by a Vogtle. These dendrimers' core is contained by various tertiary tris-propylene amines. The polypropylene imine gives rise to universal application in biology and as well as in material science. Moreover PPI dendrimers are also described as DAB-dendrimers and DAB describes the interior structure which is generally supported on diamino butane [19].

Tecto dendrimer

These are made up of a core dendrimer, which are encircled by different dendrimers, those having a particular function that lead to a smart therapeutic system, which can at the same time recognize the diseased state and deliver API to the identified diseased cell [20].

Multilingual dendrimers

These are the dendrimers that consist of multiple copies of specific functionalities at their surface [11].

Chiral dendrimers

These are commercially available dendrimers. Chiral dendrimers are inverted unimolecular dendrimers which depend upon the formation of natively dissimilar micelles that consist of an exterior hydrophobic organo-silicon but chemically same branches to the chiral center [21].

Chiral dendrimers are possibly used as a host for enantiomeric purposes and act as chiral catalysts for asymmetric formation. The non-racemic, chiral dendrimers are particularly interesting subclasses with a clear stereochemistry. They have possible uses in chiral molecule recognition and asymmetric catalysis [22].

Hybrid dendrimers

These dendrimers are hybrid block or graft copolymer forms which are formed by combination of dendritic and linear polymers. Small segments of dendrimer combine with the reactive chain ends, giving a chance to use it as surface active agents, adhesives (hybrid dendritic linear polymers) or compatibilizers. Hybrid dendrimers have been featured both linear and dendritic polymer [23].

Amphiphilic dendrimers

Amphiphilic dendrimers are formed by combination of two segregate sites, have one half of electron donating and the other half is an electron withdrawing chain end [24].

Micellar dendrimers

Micellar dendrimers are hyperbranched poly-phenylenes water soluble uni-molecular micelles.

Frechet type dendrimers

These dendrimers were invented by Frechet and Hawker which have a skeleton based on hyperbranched poly-benzyl ether. Due to the presence of carboxylic groups as surface groups of these dendrimers which act as attachment points for other functionalities and polar surface groups so that it increases the solubility of these hydrophobic dendrimers [12] in aqueous and polar solvent media.

Liquid crystalline dendrimers

The liquid crystalline dendrimers are oligomers that are extremely branched. These dendrimers consist of a mesogenic group on the dendritic structure which acts as a mesophase. e.g. carbosilane dendrimers which are functionalized mesogens [10].

First photosensitive liquid crystalline dendrimer with terminal cinnamoyl groups was synthesized by Bioko et al. The purity and structure of this liquid crystalline dendrimer was confirmed by ¹H NMR and GPC methods. Under UV irradiation these dendrimers exhibit E-Z isomerization of cinnamoyl groups and three dimension network is formed by a [2+2] photocycloaddition [25].

Peptide dendrimers

Peptide dendrimers are those which hold amino acid as branching or interior unit. The peptide dendrimers extremely branched structure consist peptide bonds and having a non-nature origin. These dendrimers used for the purpose of characterization and delivery of vaccine. Peptide dendrimer are valuable in drug delivery on the basis of its ability takes up by cell. Another application of peptide dendrimer is that it can be used as comparing agents for magnetic resonance imaging (MRI), fluorogenic imaging, magnetic resonance angiography (MRA) and serodiagnosis [26].

Multiple Antigen Peptide Dendrimers

Multiple antigen peptide dendrimers are the dendron like molecular gathering which depend on the frame of lysine. The lysine having a side chain act as outstanding monomer for introduction of the branching end. These dendrimers having a biological application e.g. in a diagnostic research and vaccine [16].

Simple Dendrimers

Simple dendrimers contained simple monomer units e.g. poly(aminoamine) dendrimers which are made with fragments of poly(amidoamine) names as starburst dendrimers [23].

Glycodendrimers

These dendrimers are extensively used for the construction of dendrimers which having a carbohydrates in the structures. These dendrimers are classified in to three types depends upon the position of carbohydrates moiety [21].

Janus Dendrimers

The name of this dendrimers is derived from Roman God, Janus, God of beginnings and transitions that having two faces in opposite sides. These dendrimers having two sides one is polar and another is nonpolar which gives it amphiphilic properties. These dendrimers are formed by coupling two different dendritic building blocks [22].

Synthetic Strategies

Dendrimers are produced by repeating sequence of reaction steps, each repeating step proceeding to one higher generation. The reactions usually used for synthesis of dendrimers are Michael addition, Knoevenagel condensation, N-alkylation, Williamson's ether synthesis, Sonogashira coupling, Mitsunobu esterification, Amidation, Ring opening reactions and Catalytic reduction reactions. The firstly innovated dendrimer, PAMAM was prepared by Michael addition and Amidation reactions. Dendrimers are consists of three major portions i.e. a core, an inner shell and an outer shell. A dendrimer could be produced by changing functionality in each of these contents to classified features as thermal stability, solubility and addition of compounds for accurate application. Synthetic process can also exactly organize the size and number of branches on the dendrimer. There are two main different routes of dendrimer synthesis, divergent approach/route and convergent approach/route. There is one disadvantage of convergent route is that we can't prepare a large molecule for drug loading because of crowding and steric hindrance. Thence, divergent approach for dendrimer synthesis was used [21].

Divergent Approach

The divergent approach is also called as starburst method and includes the synthesis of a dendrimer layer-by-layer from a core to periphery. The dendrimer is arranged to form a multifunctional core which is expanded outward in the order of reactions

usually by Michael addition reaction. Each step of the reaction must be intent to full execution to

avoid mistakes in the dendrimer synthesis which can cause trailing generations i.e. some branches are shorter than that of others [27]. These impurities can collide the functionality and geometry of the dendrimer, but are broadly tough to purify out because the relative size difference between perfect and imperfect dendrimers is very small. The main negative effect of this approach is that the insufficient growth and the side reactions proceed to flawed dendrimers. To reduce these side reaction effects and disfigurement, it is suggested to use a reagent in large excess. During this reaction mechanism, functionality of these branched elements are deactivated or protected. After fulfillment of 1st step these groups are activated or de-protected which goes on further reaction. These reaction steps are repeated in that way until required dendrimer is obtained and a dendrimer develop outwards from core to surface. Furthermore, as the dendrimer grows larger the end groups on the periphery develop into more and more closely packed and due to steric effects, the dendrimer approaches its upper generation limit. This is termed as “de-Gennes dense-packing” designated after Pierre-Gilles De-Gennes or starburst effect after “Tomalia”. Figure 4 represents the schematic diagram of dendrimer synthesis by divergent route [28].

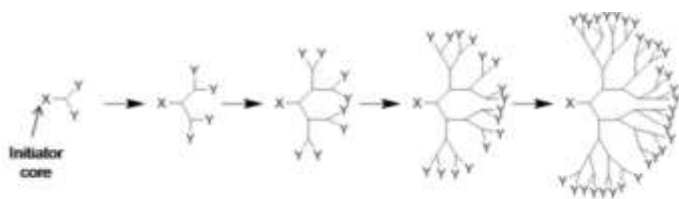


Fig. 4. Schematic Representation of Dendrimer Synthesis Divergent Approach

Convergent Approach

The convergent method of synthesis firstly reported by Frechet and Hawker and it is the reverse of the divergent route, in which the growth of dendrimers starts from periphery to the central core. It includes construction of dendrons with their attachment to a multifunctional core. The number of side reactions is

reduced by limiting the number of reaction sites, that resultantly gives pure dendrimer unlike the divergent synthesis. Convergent synthesis involves the assembly of macromolecules from outside and ends at the core. Convergent synthesis usually initiates from outside surface unit which couples to a monomer unit to give a “Dendron” whose focal point is deactivated/protected. In the 2nd part of the reaction the focal point is going activated for more reaction and the growth of dendron is towards in. At the termination of the reaction these highly branched dendrons proceed to a multi-functional core to synthesize a dendrimer. The growing dendrimer dimensions are applied to limitations that is maintained by steric-effect during reaction of the dendrons at the periphery. Therefore, steric-hindrance at the reactive point inhibits the synthesis of high generations of dendrimers because the terminal macromolecule is prepared by coupling two or more than two wedges which themselves are highly sterical (Fig. 5) [11]

Convergent route of synthesis dominates the purity and structural deformities of divergent synthesis. By this route more sustained and symmetric dendrimers are prepared but with overall yield is low. In other sense, yield is abandoned for purity and this method is commonly used for dendrimer synthesis used in laboratory. For commercial level synthesis, divergent synthesis is still preferred. More often used commercially available dendrimers are PAMAM and PPI which are structure wise different in every batch because of structural deformities. In this route, dendrons are prepared first and in terminal step these are connected together to a core molecule to attain a complete dendrimer. Dendrimers prepared by this way have impurities ratio less, more mono-dispersity and symmetry because desired purification is possible for dendrons before final attachment to core. The size of dendrimer prepared by convergent route has limitations because of steric-effect between dendrons which are going to assemble with core [29].

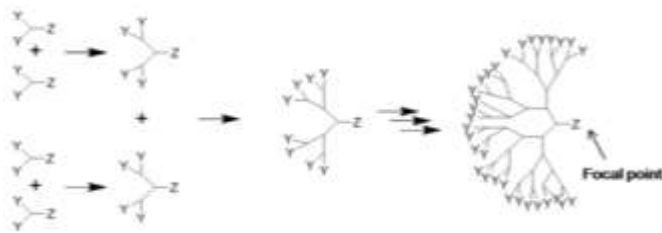


Fig. 5. Convergent route for dendrimer synthesis

Applications of Dendrimers

Dendrimers have a large number of applications. Dendrimers also used in nanotechnology and in medicinal chemistry. Dendrimers have large number of branches. So, due to these branches they have essential applications. It is also observed that they have a large influence for inhibiting the multivalent adhesion activities between bacteria, cells, viruses, proteins. Dendrimers may also act as drug themselves. Dendrimers can be improved with multiple groups in the sequence to allow diverse labels, targeting ligands and other molecular entities with the addition of especial delivery and single entity. The dendrimer drug interaction can be attained in many ways:

(1) Covalent conjugation; (2) Encapsulation in the interior of the dendrimer; (3) Electrostatic encapsulation [30]. Other applications of dendrimers also described below:

Dendrimers Used for Drug Delivery

Dendrimers used for drug delivery of Enoxaprin. Biological availability of Enoxaprin also increase 40% by G2 and G3 generation of positively charged PAMAM dendrimers. These dendrimers also converted into complex form with enoxaprin which after pulmonary administration also efficacious in deep vein thrombosis [16].

Dendrimers also originate to enhance the plasma circulation time via transdermal formulations and solubility. The drug permeation by skin as penetration enhancers also enhance by forming the complex of PAMAM dendrimers with NSAIDS (e.g ketoprofen). Ketoprofen and diflunisal also displayed 3.2 and 3.4

times progressive permeation by associated with PAMAM dendrimers [2].

The human colon adenocarcinoma cell line, Caco2 also used to study the oral drug delivery which also showed that low- generation PAMAM dendrimers also cross cell membranes, by amalgamation of two process, i.e. paracellular transport and adsorptive endocytosis [21].

The applications of hydrogels also increased by the addition of polyethylene glycol or PEG groups in dendrimers which increases the cartilage tissue production and for sealing ophthalmic injuries. For the delivering of the drugs to the eye, hydrogels consist of PEGylated dendrimers were manufactured [26] PEG monomethyl ether chains (i.e. 550 and 2000 Da) also used to modified the anticancer drugs adriamycin and methotrexate which also encapsulated into PAMAM dendrimers, these PEG monoethyl ether chains connected to their surfaces. The anticancer drug 5 fluorouracil also supplied by using PAMAM dendrimers and PEG chains. Cytotoxicity and permeation of dendrimers also increased by encapsulation of 5-fluorouracil into G4. To control the drug delivery, the dendrimers drug interaction techniques also used [16]. Dendrimers have great and perfect properties which also used in applications in targeted drug delivery system. Folic acid PAMAM dendrimers reorganized with carboxymethyl PEG5000 surface chaions contain feasible drug loading, decrease release rate and less haemolytic toxicity in comparison with the non-PEGylated dendrimer, these folic acid PAMAM dendrimers is the effective cell-specific targeting agent distributed by dendrimers [28].

Dendrimers as Magnetic Resonance Imaging contrast Agents

Metal chelates which also dendrimer based are behave as magnetic resonance imaging contrast agents. Dendrimers are highly suitable and used as image contrast media because of their properties [1].

Dendritic Sensors

Dendrimers consist of high number of functional groups but although it is a single molecule. Balzani and coworkers interrogated the fluorescence of fourth generation polymer (propylene amine) dendrimer designed with 32 dansyl units at periphery of it. The high fluorescence of all the dansyl units is quenched when Co^{3+} ion is integrated into dendrimers [19].

Dendrimers Used for Nano-Drugs

Poly(lysine) dendrimers reformed with sulfonated naphthyl groups (anti viral drug) can decrease the spread of herpes simplex virus, transmission of HIV and other sexually transmitted diseases. The dendrimer based nano-drug act by interrupting the reverse transcriptase and integrase enzyme activities that stopped early stage virus /cell adsorption and later stage viral replication [16].

As Bioactive Molecules

Evidences also provide that various classes of dendrimers are energetic against different viruses, bacteria and fungi targeting virulence factors that participating in microbial pathogenesis. By using different mechanisms of actions, dendrimers also employ their effect, which also resembled to the multivalency of the nanomolecules and highly affected by nature and number of their functional surface groups. The feasibility to synthesize and design specific dendrimers is high, which expert to block receptors which used by pathogens for dissemination, adhesion and cell entry [30].

Dendrimers Used as Lighting Harvesting Material

Due to the multiple functionality and structural features dendrimers also used as lighting harvesting material. The functional group decreases by moving from periphery to the core, which render dendrimers in light harvesting. The truxene and thienylethynylene were synthesized by studying on π -conjugated dendrimers family. From periphery to the

core the dendrimers synthesized possessing intrinsic energy gradient, with broad absorption in the UV-Vis range and proficient energy [2].

Dendrimers As Catalysts

Dendritic polymers also utilized as a catalyst in large amount due to two reasons, one is chances of producing a large dendrimer with large number of active sites. These catalyst also act as intermediate between homogenous and heterogenous catalyst which also isolated by filtration. The 2nd reason is that, there is a chance of encapsulating a single catalytic site whose activities also can be increased by dendritic superstructure. Dendrimers have active catalytic site with multifunctional surface. Insoluble material e.g. metal also encapsulated and transfer into the solvent in interior of dendrimer [22].

Dendrimers As Separating Agents

The Dendrimers which are capable to form micelle structure that can be isolated and recovered by ultra filtration membrane have high density of functional moiety. These micelle also provide high surface area and easy method of separation for isolation, high functional density at the surface of the particle and regeneration of the compound. For boron absorption unchanged dendrimic compounds are more effective which also consist of amine and hydroxyl group [25].

Self-Assembly of ssDNAs With Dendrimers

At the various dendrimers/ssDNA charge ratio, self-assembly of ssDNA with dendrimers was observed. The ratio between the number of negative charge on ssDNA molecule and the number of positive charge on dendrimers are the definition of dendrimers/ssDNA charge ratio and they are also represented by P/N. G4 PAMAM dendrimers consist of 64 positive charges and ssDNA chain utilized in stimulation consist of 64 negative charges in case of neutral pH. The ssDNA/dendrimer self-assembled aggregates are very small and not equal in size below the conditions of low charge ratio ($N/P < 1$). In dilute

solution of low dendrimer/ssDNA charge ratios, the rod like DNA/dendrimer aggregates also discovered. Broad but uneven shaped aggregates also found, when the charge ratio extend to N/P= 1.5. To get compact and stable ssDNA dendrimer aggregates, charge ratio also rising to N/P= 3. So, we can regulate the size and morphology of ssDNA dendrimer aggregates, by modifying the charge ratio, which may have some influence on the ssDNA molecule transfection efficiency [31].

Biological Applications of Dendrimers

Dendrimers have large scale uses as an antimalarial, neuro protector agents, anti-arthritis medicine. Dendrimers and their monomers, consist of N-(di(pyridin-2-yl)methylene)ethanamine, N-(pyridine-2-ylmethylene)ethanamine, or 2-(2-methylenehydrazinyl) pyridine terminal groups prepared. These compounds represent strong resistance to the tumor cells & strong proliferative activities. In gene therapy dendrimers also applied. There are also present some other applications of dendrimers i.e. to encapsulate the drug molecules, different branches of dendrimers also used. This method increases the chances of dendrimers to combine with the badly soluble drugs and it enhances the drug solidity, bioavailability and control of drug release. The use of Poly(Amidoamine) dendrimer with hydroxyl and carboxylic surface increase the residence time of pilocarpin in eyes [5].

In Environmental Studies

In environmental studies dendrimers may also act as useful adsorbents for electro-analytical and analytical processes because dendrimers also have numerous numbers of surface functional groups, these groups also connect to different substances' surface. From the aqueous solution one can remove the Cu(II),

Pb(II), Cd(II) ions by the using of Poly(Amidoamine) dendrimer (PAMAM-SBA-15) with the functionalized SBA-15 mesoporous silica gel [31].

Dendrimers As Sensors

Dendrimers have distinctive structure and properties. In sensing of biological and chemical properties the structure and properties of the dendrimers develop interest in interfacing nanoscale dendrimers. For the progress of miniaturized, quick, ultrasensitive and inexpensive environmental monitoring devices different types of nanoparticles also used [15].

Dendrimers act as Possible Globular Protein Mimics

To control the presentation of functional groups at their surfaces proteins utilized macromolecular scaffolds and proteins are amphiphilic molecules. By giving the functionality of proteins as functional materials in biological system, it is advantageous to accept and produce different ways to control presentation of functional groups in synthetic amphiphilic macromolecules. Some proteins also similar in size and shape with PAMAM dendrimers. For example; insulin (3 nm), cytochrome C (4 nm), haemoglobin (5.5 nm) are proteins have same shape and size as ammoniacore PAMAM dendrimers of generation 3, 4 & 5 as shown in Fig. 6. Globular proteins and dendrimers have a large number of similarities. Now, it is essential to note the important differences. Due to the intricate folding of sequenced linear structures of proteins, these globular proteins have tertiary structure. So, they are highly fragile and susceptible to modifying conditions, such as pH, light and temperature. These globular proteins also developed densely packed interiors & surface possessing highly heterogenous domains of functionality, hydrophilicity and hydrophobicity. While dendrimers are robust, covalently fixed in nature, three dimensional structure and also have both homogenous and a solvent filled interior core [32].

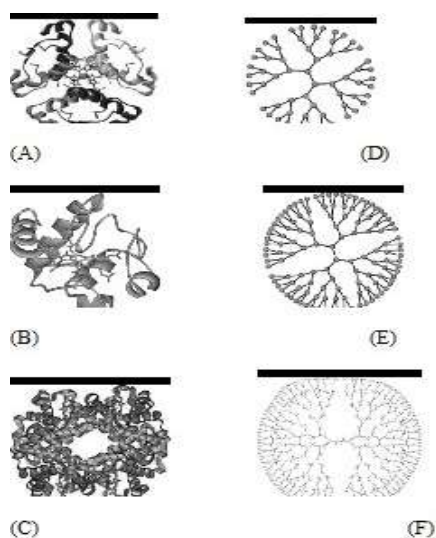


Figure 6. Proteins and PAMAM dendrimers in comparison of Size and Shape: (A) Insulin (B) Cytochrome (C) Haemoglobin and PAMAM dendrimers generation (D) 3, (E) 4, (F) 5.

5. Conclusion

A rapid increase of interest in the chemistry of dendrimers has been observed since the first dendrimer was synthesized. This review summarizes the different types, properties and most common synthetic routes as applied to the preparation of dendrimers. The multi-step synthesis of dendrimers still requires great effort. Dendrimers are characterized by individual features that make them hopeful candidates for a lot of applications. The dendrimers found their way in many applications especially in the field of materials and medicines. The review will help the scientific community to encounter various ideas and develop new dendritic structure with improved properties.

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