Synthesis and Characterization of a Trifunctional Aminoamide Cellulose Derivative

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As part of an effort to synthesize a dendronized cellulose, we have synthesized a trifunctional aminoamide derivative, which is the first generation of a dendron substituent. We anticipate that a dendronized cellulose would have applications in complexing metals and could be employed as an adjuvant for drugs. The trifunctional aminoamide substituent was introduced by coupling di-*tert*-butyl 4-[2-(*tert*-butoxycarbonyl)ethyl]-4-aminoheptanedicarboxylate, BA, directly to a (carboxymethyl)cellulose (CMC) backbone and converting the *tert*-butyl ester peripheral groups to aminoamide substituents by use of *N*,*N*-dimethyl-1,3-propanediamine. Confirmation of the proposed chemical structure of the intermediates as well as the water-soluble aminoamide derivative (CMCBADMPDA) was obtained by Fourier transform infrared (FT-IR) and NMR spectroscopy. The degree of substitution (DS) was determined to be 0.40 ± 0.01 by thermogravimetric analysis. Typical weight average molecular weight (M_w), molecular weight distribution (MWD), and molecular size of the dendronized polymers were found to be 97,000, 1.7, and 17.4 nm for derivatives of a CMC with corresponding M_w, MWD, and root-mean-square radius (RMS) of 230 000, 3.2, and 24 nm. A differential refractive index (d*n*/d*c*) for the aminoamide derivative measured in aqueous 0.40 N ammonium acetate−0.01 N NaOH was found to be 0.1473. The intrinsic viscosity of the dendronized cellulose decreased significantly when compared with that of CMC, that is, 0.40 dL/g relative to 5.60 dL/g. The hydrophobicity of the CMCBADMPDA microenvironment in aqueous solution was probed by evaluating the relative fluorescence intensities of the I_{373}/I_{384} pyrene bands; a slightly more hydrophobic environment was observed.

Introduction

In the early 1950s, Flory[1] predicted the dendritic growth of molecules and several structural variations. The pioneer work of Vögtle in the late 1970s opened a new area, synthesis of polymers with dendritic structure.[2,3] The works of Tomalia et al.,[4,5] Newkome et al.,[6] Grayson and Fréchet,[7] and Percec and co-workers[8] have greatly enriched the diversities of dendrimer structures. Although it was almost immediately recognized as an important alternative structure,[9,10] dendronized polymer or side-chain dendritic polymer has not received much attention.[4,11,12] Recently, a fourth-generation dendronized polystyrene with unique properties attributed to the high concentration of dentritic substituents was reported,[13] and interest in the potential applications of these new materials is increasing. Polystyrene dendrigrafts with poly(methyl vinyl ether) external branches are effective encapsulants for pyrenes and tetraphenylporphyrin complexes.[14] Quenching of a fluorescent poly-2,7-fluorene backbone could be achieved by self-encapsulation in a dendritic matrix.[15] The utility of dendritic polymers in biomedical applications including diagnostics has been demonstrated.[16]

Incorporation of dentritic structures onto cellulose is an effective means for amplifying the number of functional groups along the cellulose backbone as the polyfunctionality of dendrimers increases geometrically with each generation. Dendrimers can be synthesized with both hydrophilic and hydrophobic structures, which allow diversity in potential applications in pharmaceutical science.[17] It is reasonable to imagine that dendrimers of cellulose would be biocompatible and they may have important applications in human health.

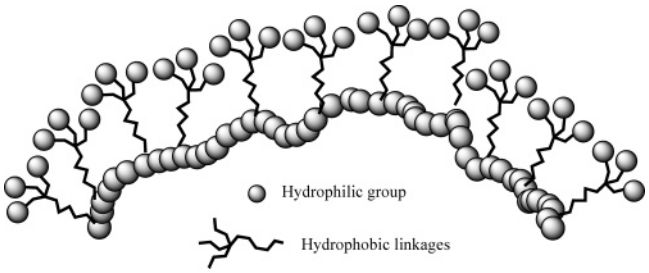

Figure 1. Illustration of a comb copolymer with radiant hydrophilic brushes and amphiphilic teeth.

In addition to our earlier report,[18] recently a report on a dendronized cellulose has appeared.[19] In this report the incorporation of dendritic substituents onto the cellulose backbone by utilizing an isocyanate derivative of a second-generation dendrimer is described, but only spectral data are cited to characterize the products. To date, no evaluation of the solution properties of a cellulose with polyfunctional substituents has been reported. In our group, we envisioned and initiated the synthesis of a dendronized cellulose derivative with an interesting architecture, that is, a cellulose comb copolymer with radial hydrophilic brushes where anhydroglucose units compose the backbone and amphiphilic teeth cap the side chains (Figure 1). Hydrophobic groups are attached directly to the cellulose backbone as the stem of amphiphilic teeth. The multiplicity of hydrophilic groups forms a radiant hydrophilic brush structure.

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Suitably activated carboxymethyl derivatives can be elaborated with Behara's amine, di-*tert*-butyl 4-[2-(*tert*-butoxycarbonyl)-ethyl]-4-aminoheptanedicarboxylate, BA, which was synthesized and used as a building block for polyamide dendrimers by Newkome and Weis.[20] In this paper, BA was used in the dendrimer construction to form a hydrophobic polyester derivative that is insoluble in common organic solvents. Conversion of the ester functionalities to aminoamide moieties with *N*,*N*-dimethyl-1,3-propanediamine (DMPDA) afforded a water-soluble hydrophilic brush. Potential applications as a polymeric drug, drug carrier, and polymeric catalyst are being investigated.

Experimental Section

Materials. Sodium (carboxymethyl)cellulose (CMC) (DS = 0.7, MW = 250K), hydrochloric acid, methanol, tetrabutylammonium hydroxide (TBAH, 40% in water), *N*,*N*-dimethylformamide (DMF), 2-chloro-*N*-methylpyridinium iodide (CMPI), triethylamine, formic acid, nitromethane, *tert*-butyl acrylate, sodium bicarbonate, magnesium sulfate, Celite, ethyl alcohol, ether, Raney nickel, pyrene, and *N*,*N*-dimethyl-1,3-propanediammine (DMPDA) were purchased from the Aldrich Chemical Co. Dialysis membranes [molecular weight cutoff (MWCO) 6000−8000] were purchased from Spectrum Laboratories, Inc.

Instrumentation. Fourier transform infrared (FT-IR) spectra were obtained on a Perkin-Elmer 1760X FT-IR spectrometer by use of KBr/sample disks. ^{1}H NMR spectrum of the polymer was obtained on a Bruker DPX250 MHz spectrometer. Deuterium oxide (D_2O) was used as the solvent. Weight loss and derivative weight loss curves were obtained on a high-resolution modulated TGA 2950 thermogravimetric analyzer from TA Instruments. All runs were performed under nitrogen atmosphere and through a ramp starting from room temperature and going up to 500 °C at 5 °C/min. Intrinsic viscosity measurements were performed with aqueous solutions of CMC and its derivatives with concentrations ranging from 0.03 to 0.40 g/dL at 25 °C. A Z107 Ubbelohde viscometer from Cannon Instrument Co. with a solvent flow time of 77.26 s was used to measure the intrinsic viscosities. All measurements were made in 0.1 N NaCl to minimize any Donnan effects.

A gel-permeation chromatography (GPC) system equipped with a differential refractometer combined with a DAWN DSP laser photometer from Wyatt Technology Corporation (GPC-LS) was used to determine molecular sizes, molecular weights, and molecular weight distributions (MWD), M_w/M_n, of polymers. ASTRA software was employed for data collection and analysis. The samples were eluted with aqueous 0.4 N ammonium acetate−0.01 N NaOH through two PL Aquagel-OH 8 μm columns at a flow rate of 1.0 mL/min. The differential refractive indexes (d*n*/d*c*) of the polymers in the same solution were measured on a Brice-Phoenix differential refractometer, model BP-2000-V, from Phoenix Precision Instrument Co. The fluorescence spectra of pyrene (2 μM) in aqueous solution were recorded on a Perkin-Elmer luminescence spectrometer, model LS50B, while the sample was excited at 335 nm. Both the excitation bandwidth and emission bandwidth were 2.5 nm.

Di-*tert*-butyl 4-[2-(*tert*-Butoxycarbonyl)ethyl]-4-aminoheptanedicarboxylate, BA. Behara's amine was synthesized according to the procedure described by Newkome and Weis.[20] Michael condensation of *tert*-butyl acrylate with nitromethane afforded di-*tert*-butyl 4-[2-(*tert*-butoxycarbonyl)ethyl]-4-nitroheptanedicarboxylate. The subsequent hydrogenation was conducted at 60 psi and 45 °C to provide BA in 80% yield.

Synthesis of CMC-DMPDA. NaCMC (1.00 g, 4.59 mmol) was activated with 2-chloro-*N*-methylpyridinium iodide as described by Barbucci et al.[21] The resultant active ester, 2-oxy-*N*-methylpyridinium iodide cellulose methylcarboxylate (MPICMC), was not isolated. To the solution of MPICMC were added DMPDA (20 mL) and three drops of triethylamine, and the mixture was allowed to stir for 1 day. The solution was diluted with 50 mL of water and the low molecular weight byproducts were removed by dialysis. After 1 week, when no further salts were detected in the dialysate, the solution in the dialysis tube was concentrated by use of a rotovaporator. The concentrated solution of the product was dried under a vacuum and afforded CMC-DMPDA (0.91 g, 3.43 mmol, 75% yield). ^{1}H NMR (D_2O), δ (ppm): 1.61 ($CH_2CH_2CH_2$), 2.07 ([$CH_2N(CH_3)_2$], 2.24 [$CH_2N(CH_3)_2$], 2.45 ($CONHCH_2$-CH_2), 3.25−4.5 (broad peaks of anhydroglucose ring). FT-IR (cm^{-1}), KBr pellets: 3423 (s, O−H stretch), 2964 and 2934 (w, C−H stretch), 1649 (s, amide I shoulder), 1595 (amide II band), 1109 and 1059 (s, C−O−C stretch).

Synthesis of CMCBA. Sodium CMC (2.00 g, 9.17 mmol) was dissolved in water (100 mL). The pH of the above solution was adjusted to 4 with acetic acid and 5 mL of 10% HCl to produce protonated CMC, which was then precipitated in methanol (200 mL). After the resultant precipitate was dried by freeze-drying, it was dissolved with aqueous 40% TBAH solution (4.32 mL, 6.59 mmol) and 20 mL of water. The corresponding tetrabutylammonium (carboxymethyl)cellulose (TBACMC) was recovered by lyophilization. The dry TBACMC was dissolved in DMF (200 mL). The solution of CMPI (2.55 g, 10.00 mmol) in DMF (25 mL) was added, and the mixture was stirred for 12 h.[21,22] Up to 600 mL of DMF was added to maintain the system in a homogeneous state. BA (4.19 g, 10.1 mmol) solution in 20 mL of DMF was then added, and the reaction was stirred for 24 h. To isolate the CMCBA, the mixture was dialyzed in deionized water for 1 week. The contents of the dialysis tube were reduced to about 25 mL using a Büchi rotavapor R-200, and then solvent evaporation was continued to dryness in a vacuum oven at room temperature. The insoluble residue, CMCBA (3.02 g, 8.43 mmol, 92% yield calculated on the basis of 0.4 DS) was characterized by FT-IR and TGA.

Synthesis of CMCBADMPDA. CMCBA (1.24 g, 3.46 mmol) was stirred with formic acid (20 mL) and water (4 mL) for 24 h. After the mixture was evaporated to dryness, the solid was washed with water (3 × 10 mL). The resultant "polyacid" was dissolved in aqueous TBAH (5.15 mL, 7.86 mmoL) and water (10 mL). After the mixture was stirred for 24 h, the TBA salt was again dried under vacuum. The TBA salt was dissolved in 100 mL of DMF, and a solution of CMPI (2.5 g, 9.78 mmol) in 25 mL of DMF was added. After the mixture was stirred for 24 h, an excess of DMPDA (25 mL, 198.5 mmol) was added and the mixture was stirred for another 24 h. The product was isolated by dialysis/evaporation as described above. The residue of CMCBADMPDA (0.46 g, 1.18 mmol, 34% yield) was characterized by FT-IR, TGA, and GPC-LS. ^{1}H NMR (250 MHz, D_2O): δ (ppm) 2.07 [a, $N(CH_3)_3$], 2.22 (b, CH_2N), 1.48 (c, $CH_2CH_2CH_2$), 2.45 (d, $CONHCH_2$), 2.22 (f, $NHCH_2$), 1.62 (g, $NC-CH_2$).[23] ^{13}C NMR (62.9 MHz, D_2O): 44.16 [a, $N(CH_3)_3$], 56.22 [b, $CH_2N(CH_3)_2$], 29.80 (c, $CH_2CH_2CH_2$), 44.16 (d, $NHCH_2$), 179.10 (e, CH_2CH_2CONH), 29.80 (f, CH_2CONH), 39.21 (g, CCH_2CH_2), 102.70 (C1), 77.60, 75.36, 71.55, and 70.64 (C2∼C5), 60.63 (C6), 83.40 (C7), 44.16 (C9).

Results and Discussion

(Carboxymethyl)cellulose (CMC) is activated for nucleophilic modification by forming an active ester with 2-chloro-*N*-methylpyridinium chloride (CMPI) as described by Barbucci et al.[21] After conversion of the sodium salt of CMC (CMCNa) to the tetrabutylammonium salt (TBACMC), the salt become soluble in DMF and all of the subsequent transformations can be conducted in homogeneous solutions. The ratio of TBACMC to CMPI can be adjusted to selectively activate a given percentage of carboxyl groups. We have used an excess of CMPI in all conversions to maximize the degree of substitution achieved. All carboxylic acid functionalities were activated by use of the reaction sequence.

Once activated, the MPICMC undergoes nucleophilic attack by an amine, which eliminates *N*-methyl-2-pyridone. A small

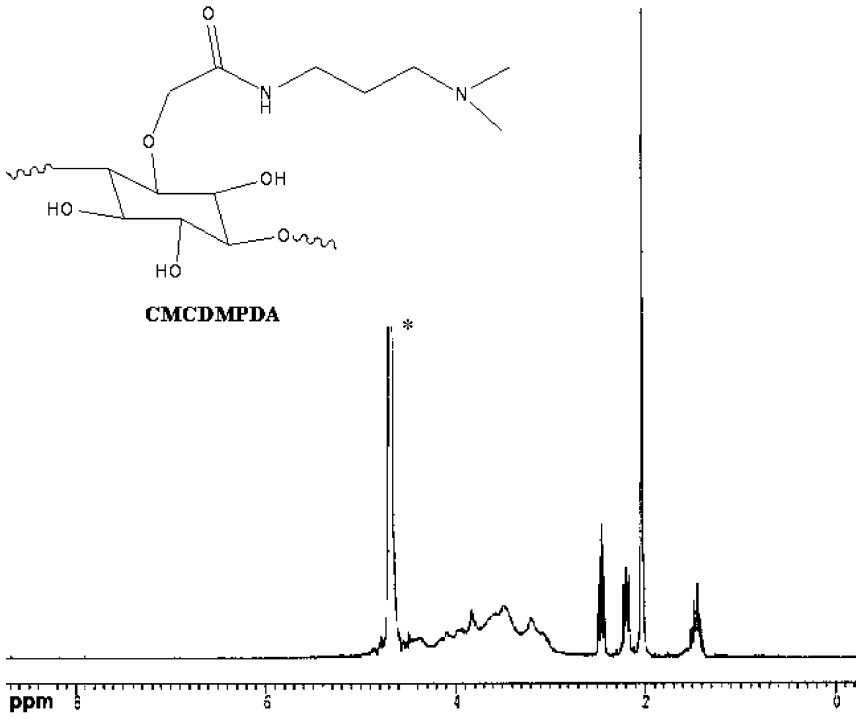
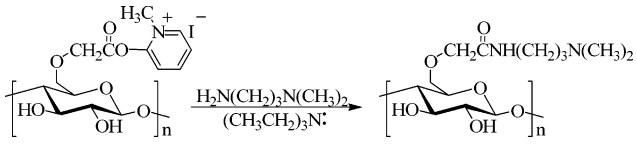


Figure 2. ^{1}H NMR spectrum of CMCDMPDA.

amount of triethylamine was added to the reaction mixture to act as a hydrogen iodide scavenger. The reaction is effectively irreversible and the *N*-methyl-2-pyridone is a cosolvent for the reagents and products. The impact of the CMC-Na activation steps was evaluated by converting it to the corresponding 3-(*N*,*N*-dimethylamino)propanecarboxamide derivative (CMC-DMPDA).



MPICMC CMC-DMPDA

The ^{1}H NMR spectra of this model compound were consistent with the proposed structure as shown in Figure 2. The *N*,*N*-dimethyl resonance at 2.07 ppm is an identifying feature for multifunctional aminoamide derivatives described in this paper. The triplets at 2.24 and 2.45 ppm are assigned to the methylene groups adjacent to the amino and amide functions, respectively. The multiplet at 1.60 is assigned to the central methylene group of the propyl substituent. The anhydroglucose protons appear as broad resonances between 3.25 and 4.5 ppm. The solvent peak is designated with an asterisk. The intrinsic viscosity of this derivative was 3.5 dL/g, suggesting that backbone degradation accompanying NaCMC activation is minimal. The reduction in viscosity could be attributed to the replacement of ionic substituents with neutral aminoamide substituents.

To produce a series of tris-substituted derivatives, the DMPDA was replaced by the macromonomer di-*tert*-butyl 4-[(2-*tert*-butoxycarbonyl)ethyl]-4-aminoheptanedicarboxylate, or Behera's amine (BA).[20] Behera's amine is an AB_3 macromonomer with one reactive amine functionality and three *tert*-butyl ester functionalities. Behera's amine features a chemically stable sp^3 carbon branching center, three preformed branches, an amino moiety with high nucleophilicity, and the eventual quantitative hydrolysis of the *tert*-butyl esters to unveil the carboxylic acid

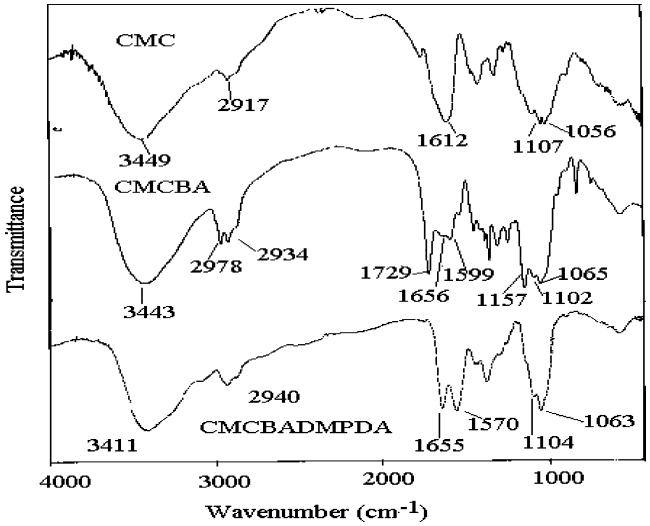


Figure 3. FTIR spectra of CMC, CMCBA, and CMCBADMPDA.

groups. Behera's amine facilitates the synthesis of a multigeneration side-chain dendritic polymer with a minimum of coupling and deprotection steps. The formation and elaboration of the first-generation dendronized cellulose is illustrated in Scheme 1.

FT-IR and NMR Characterization of CMCBA and CMCBADMPDA. The IR spectra of CMC, CMCBA, and CMCBADMPDA (Figure 3) shows that each of the spectra exhibited O−H stretching absorption around 3449 cm^{-1}, C−H stretching absorption around 2900∼3000 cm^{-1}, and C−O−C stretching absorption around 1061 and 1104 cm^{-1}.[24] These absorptions are consistent with a typical cellulose backbone. The 1612 cm^{-1} absorption of C═O of COONa in CMC shifts to the absorption of amide I of 1659 cm^{-1} and amide II of 1580 cm^{-1} in CMCBA. The intensity of these two peaks increases in CMCBADMPDA. The disappearance of the ester carbonyl peak at 1729 cm^{-1} in CMCBA along with an increase in the intensity of the amide peaks at 1655 and 1570 cm^{-1} confirms the formation of

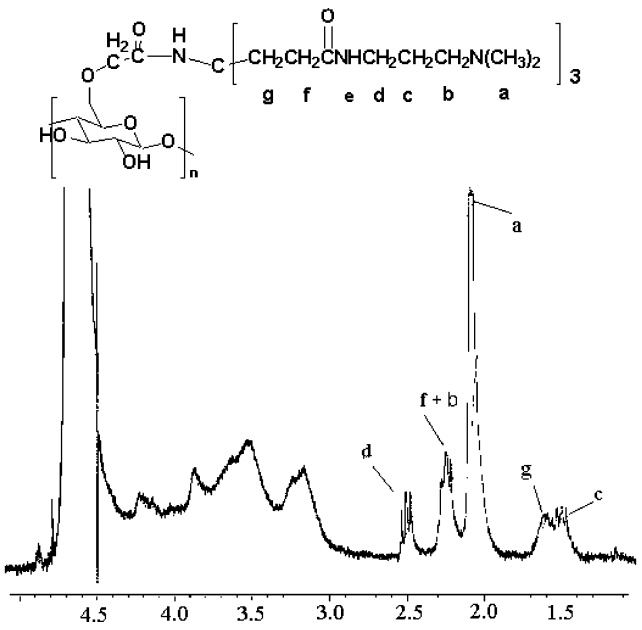


Figure 4. ^{1}H NMR spectrum of CMCBADMPDA.

CMCBADMPDA. Figure 3 clearly shows that BA was attached to CMC in CMCBA and DMPDA was attached on CMCBA in CMCBADMPDA.

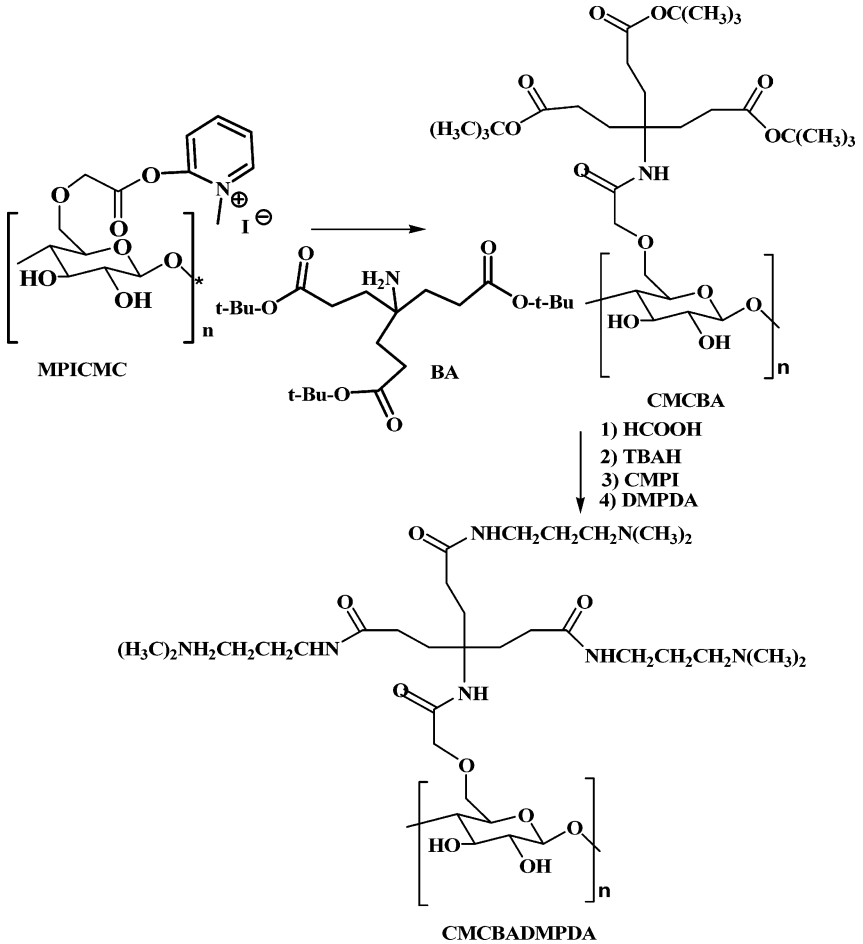
Although the elaboration of cellulose is conducted in solution, once the derivative is isolated it cannot be redissolved. Conversion of the *tert*-butyl ester functions to the more hydrophilic aminoamide groups with *N*,*N*-dimethyl-1,3-propanediamine yielded a water-soluble derivative suitable for solution NMR characterization. ^{1}H NMR (Figure 4) and ^{13}C NMR spectra (Figure 5) were consistent with the proposed structure. The chemical shifts of amide carbon (179.1 and 178.2 ppm) in CMCBADMPDA are close to those corresponding chemical shifts of amide carbon (177.4 ppm) in 1-[[*N*-[3-(*tert*-butoxycarbonyl)-1,1-bis[2-(*tert*-butoxycarbonyl)ethyl]propyl]amino]-carbonyl]adamantane made by Newkome et al.[25] The extremely strong 44.16 [N(CH_3)$_2$] and 2.07 [N(CH_3)$_2$] ppm shifts associated with the strong 29.8 ($CH_2CH_2CH_2N$) and 1.48 (CH_2CH_2-CH_2N) ppm shifts are assigned to the (*N*,*N*-dimethylamino)-propyl subtituent of CMCBADMPDA. The chemical shifts of protons on anhydroglucose rings (3.25−4.5) are broad and overlapping, but the strong resonances confirm the presence of the cellulose backbone. It was impossible to calculate the degree of substitution based on such extensive overlapped proton NMR peaks of CMCBADMPDA.

Characterization of Degree of Substitution of CMCBA and CMCBADMPDA. The poor solubility of CMCBA limited the options for estimating the degree of substitution (DS) achieved. One unique property of *tert*-butyl esters, that is, their thermal decomposition to isobutylene,[26] could be exploited to estimate the number of BA residues introduced.[22,27] We observed that the weight loss of CMCBA of the first peak from 196 °C could be related to the degradation of *tert*-butyl moieties of CMCBA to isobutylene. On the basis of the TGA data (Figure 6), the DS of this CMCBA was calculated to be 0.40 ± 0.01.

$$\text{R-COOC(CH}_3)_3 \xrightarrow{\text{heat}} \text{R-COOH} + \text{H}_2\text{C=C(CH}_3)_2$$

CMCBA decomposed by two major decomposition mechanisms,

Scheme 1. Synthesis of Tris(ester) and Tris(aminoamide) Cellulose Derivatives CMCBA and CMCBADMPDA



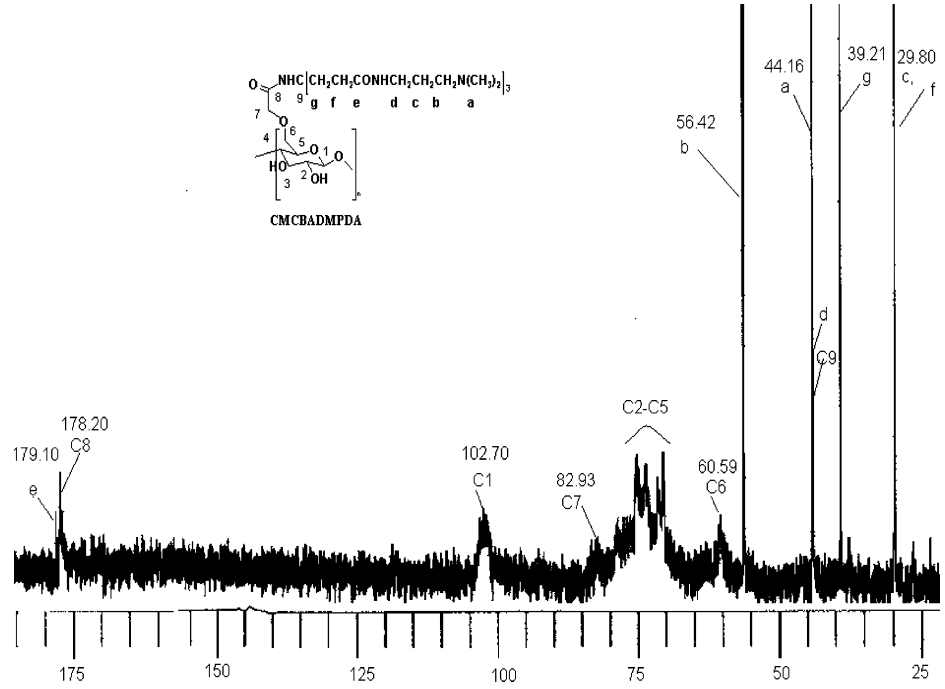


Figure 5. ^{13}C NMR spectrum of CMCBADMPDA.

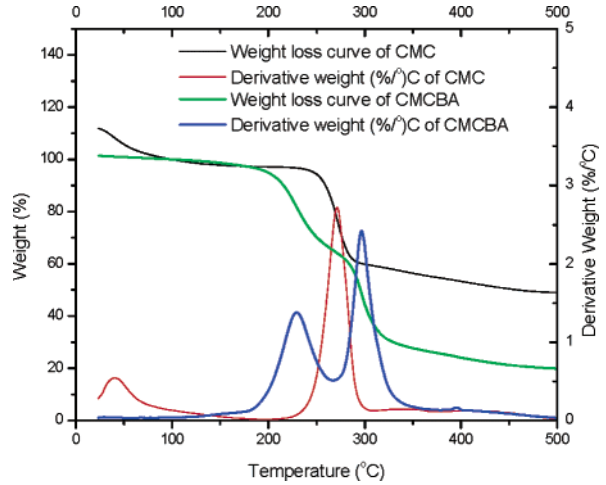


Figure 6. TGA curves of CMC and CMCBA.

degradation of *tert*-butyl moieties followed by degradation of cellulose backbone. The residual dendron substituents remaining after the degradation of *tert*-butyl moieties raised the decomposition temperature of the cellulose backbone relative to that of CMC.

Intrinsic Viscosity of CMCBADMPDA. The impact of the substituents on the hydrodynamic volume of the cellulose derivatives can be estimated by determining the relative intrinsic viscosities of a series of derivatives under the same conditions. Converting the ionic CMC derivative to a nonionic aminoamide derivative was expected to reduce the hydrodynamic volume of the derivative by removing any contributions from ionic repulsion. Indeed, the viscosity observed with CMC, 5.62 dL/g, drops to 3.57 dL/g for the CMCDMPDA derivative. Introduction of a single-generation dendrimer led to a significant reduction in the solution viscosity of the derivatives relative to that of CMC. The intrinsic viscosity of CMCBADMPDA, 0.39 dL/g, is an order of magnitude less than that of CMC and that of CMCDMPDA. Either the chemistry associated with the derivatization with BA lead to extensive chain cleavage or introduction of the tris(aminoamide) substituents lead to a collapse of the extended coil conformation normally exhibited by CMC. This low intrinsic viscosity will be useful for drug delivery applications. The synthesis of the model derivative was not accompanied by a viscosity reduction of this magnitude, so the amination step with BA was not expected to lead to chain cleavage. In addition to the change in polarity and charge density, the dendritic structure increases the density of hydrophobic groups by introducing multiple branching sites along the chain. Aggregation of these groups may lead to collapse of the random chain coil with a significantly lower hydrodynamic volume. However, the possibility that the cellulose backbone has degraded upon being subjected to exposure to the diverse collection of reagents required to remove the *tert*-butyl esters and introduction of the *N*,*N*-dimethylaminoamide groups must be considered. To resolve this question, the new derivative was characterized by various light scattering techniques.

GPC-LS Characterization of CMCBADMPDA. The large reduction in the intrinsic viscosity of CMCBADMPDA could have resulted from the degradation of cellulose backbone during the deblocking of the *tert*-butyl esters in formic acid. The actual molecular weight of the derivative was determined by use of a GPC-LS system based on Zimm approach: $Kc/R_\theta = 1/M_w(1 + q^2R_g^2/3) + 2A_2c$, where $K = [4\pi^2n^2(dn/dc)^2]/\lambda_0^4N_A$ is the optical constant, q is the scattering vector, R_θ is the Rayleigh ratio, R_g is the radius of gyration of polymer molecules, A_2 is the second virial coefficient, c is the concentration of polymer, n is the solution refractive index, λ_0 is the wavenumber of laser light, and N_A is Avogadro's number. The dn/dc of CMCBADMPDA was measured to be 0.1473 for red light at 632 nm based on $\Delta n = c(dn/dc)$, where Δn is the refractive index of polymer solution, in dilute 0.4 N ammonium acetate−0.01 N NaOH solution. Figure 7 shows the laser scattering peaks as well as their corresponding DRI peaks. Table 1 confirms that both the M_n and M_w molecular weights of CMCBADMPDA decreased significantly compared to those of CMC. Further, the M_w/M_n or molecular weight distribution (MWD) of CMCBADMPDA decreased to 1.656 from 3.17. The narrowing of the MWD after our acid treatment suggests either selective hydrolysis of the longer chains or fractionation of the sample during the multiple

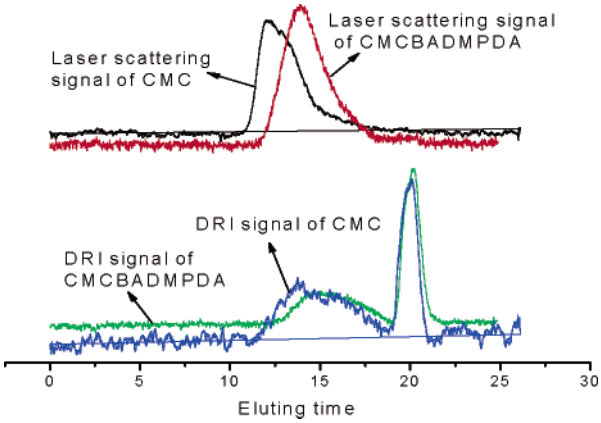


Figure 7. GPC-LS traces of CMC and CMCBADMPDA.

Table 1. Molecular Size, Molecular Weight, and Distribution of CMC and CMCBADMPDA from GPC-LS

polymer	M_n	M_w	M_z	MWD	DP	RMS R_n (nm)
CMC	72 400	229 500	542 900	3.17	332.11	24.0
CMCBADMPDA	59 130	97 940	177 400	1.656	109.64	17.4

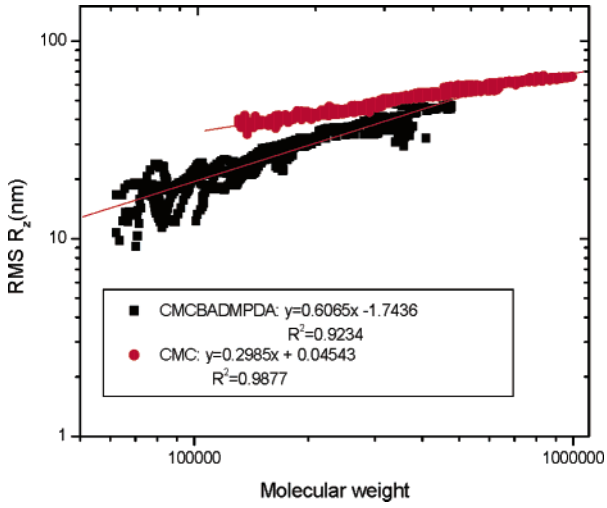


Figure 8. Relationship between RMS R_z values and molecular weights of CMCBADMPDA and CMC.

dissolution and precipitation steps required to complete the modification.

Figure 8 shows the relationship between *z*-average RMS radius R_z and molecular weights in logarithmic scale measured by GPC-LS. The slope for CMCBADMPDA was 0.6065, which is larger than 0.2985 for CMC. For polymers in solutions of good solvents, their radius of gyration (R_g) is proportional to $M^{0.6}$. These data suggests that CMC was not well dissolved in the aqueous solution and CMCBADMPDA was more coillike than CMC. Another factor, the compact conformation of the tris(aminoamide) molecular structure, may also contribute. Based on the linear fit curves in Figure 7, the RMS R_z of CMC molecules with M_w of 97 000 should be around 33.09 nm, while that of CMCBADMPDA with the same M_w was around 19.8 nm. The CMCBADMPDA molecules show more compact conformation compared with CMC molecules in aqueous solution.

Fluorescence Study of Pyrene in Aqueous CMCBADMPDA Solution. Pyrene is used as a molecular probe to characterize the hydrophobicity/hydrophilicity of the microenvironment formed by polyelectrolyte molecules and surfactant

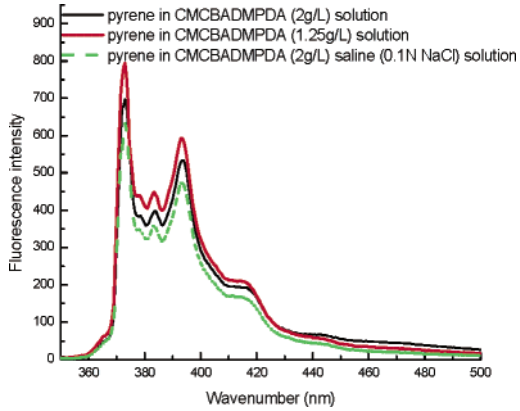


Figure 9. Fluorescence spectra of pyrene (2 μM) in solutions with different concentrations of CMCBADMPDA.

Table 2. I_{373}/I_{384} Ratio of Pyrene (2 μM) in Aqueous Solutions

medium	dendrimer concn (g/L)	NaCl (N)	I_{373}/I_{384}
H_2O			1.85
CMCBADMPDA	1.25		1.77
CMCBADMPDA	1.25	0.1	1.77
CMCBADMPDA	2.0		1.75
CMCBADMPDA	2.0	0.1	1.77

molecules in their aqueous solutions.[28] The ratio of the intensity of the first peak (I_1) at 373 nm to that of the third peak (I_3) at 384 nm in pyrene fluorescence spectra is very sensitive to the polarity of the microenvironment in the solutions. The interaction of pyrene with two different concentrations of CMCBADMPDA in both water and 0.1 N NaCl solutions was evaluated (Figure 9 and Table 2). An average I_{373}/I_{384} ratio of 1.77 was observed. This ratio is slightly lower than that of pyrene in water, but pyrene in the dendronized cellulose solution remains in a hydrophilic environment. The first-generation dendrimer does not introduce a hydrophobic microenvironment large enough to solvate pyrene.

Conclusions

A side chain composed of both a hydrophobic BA and a hydrophilic DMPDA was attached to a CMC backbone, leading to a tris(aminoamide) cellulose derivative with a hydrophilic backbone and amphiphilic side chains. The chemical structure of the derivatives was characterized by FT-IR and NMR. The DS of the derivatives was measured by TGA to be 0.40. The d*n*/d*c* of CMCBADMPDA was measured to be 0.1473 at 632.8 nm. The molecular weight and molecular weight distribution characterized by GPC-LS were substantially less than that of the starting NaCMC, indicating that the substitution reactions were accompanied by backbone cleavage. The RMS radius of CMCBADMPDA at comparable molecular weights was only 60% of the RMS (R_n) for NaCMC, which suggests a more compact molecular conformation than CMC in aqueous media. There is a corresponding decrease in the intrinsic viscosity of the derivatives. A pyrene solvation study of CMCBABADMPDA showed that the first-generation dendrimer failed to form a more hydrophobic environment than water.

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