Synthesis of Dendrimer-Type Chiral Stationary Phases Based on the Selector of (1*S*,2*R*)-(+)-2-Amino-1,2-diphenylethanol Derivate and Their Enantioseparation Evaluation by HPLC

BAO-JIANG HE,[1] CHUAN-QI YIN,[1] SHI-RONG LI,[2] AND ZHENG-WU BAI[1,3]*

[1]*School of Chemical Engineering and Pharmacy, Wuhan Institute of Technology, Wuhan, China*
[2]*Hubei Key Laboratory of Biologic Resources Protection and Utilization, Hubei Institute for Nationalities, Enshi, Hubei, China*
[3]*Key Laboratory of Green Chemical Process of Ministry of Education, Wuhan Institute of Technology, Wuhan, China*

ABSTRACT In our recent work, a series of dendritic chiral stationary phases (CSPs) were synthesized, in which the chiral selector was L-2-(*p*-toluenesulfonamido)-3-phenylpropionyl chloride (selector I), and the CSP derived from three-generation dendrimer showed the best separation ability. To further investigate the influence of the structures of dendrimer and chiral selector on enantioseparation ability, in this work, another series CSPs (**CSPs 1-4**) were prepared by immobilizing (1*S*,2*R*)-1,2-diphenyl-2-(3-phenylureido)ethyl 4-isocyanatophenylcarbamate (selector II) on one- to four-generation dendrimers that were prepared in previous work. **CSPs 1** and **4** demonstrated the equivalent enantioseparation ability. **CSPs 2** and **3** showed the best and poorest enantioseparation ability respectively. Basically, these two series of CSPs exhibited the equivalent enantioseparation ability although the chiral selectors were different. Considering the enantioseparation ability of the CSP derived from aminated silica gel and selector II is much better than that of the one derived from aminated silica gel and selector I, it is believed that the dendrimer conformation essentially impacts enantioseparation. *Chirality 22:69–76, 2010.*

KEY WORDS: (1*S*,2*R*)-(+)-2-Amino-1,2-diphenylethanol; dendrimer; chiral stationary phase; enantioseparation; high-performance liquid chromatography

INTRODUCTION

In chiral stationary phase (CSP) pool, there are a few CSPs belong to the category of dendrimer or dendrimer-like type.[1,2] Dendrimers are monodisperse oligomers and polymers usually with special function.[3–5] They are usually related to the fields of catalysis,[6–9] drug delivery,[10–13] liquid crystalline materials[14] and contrast media for clinic diagnosis.[15,16] In a few reported works, dendrimers are used in chromatography.[17–19] In our previous works, we synthesized two kinds of dendrimer-like CSPs. One was prepared directly on silica gel with chiral low-molecular-weight compounds, where the yielded chiral dendrimers was utilized as chiral selectors.[20] Of this type of CSPs, one-generation CSP showed the best enantioseparation ability, while the enantioseparation ability of two- and three-generation CSPs decreased in turn. Regarding the other kind of CSPs, the dendrimers were prepared on silica gel with achiral low-molecular-weight compounds, and then chiral selectors were immobilized on the prepared dendrimers.[21] Three-generation CSP showed the best separation ability. However, the resolutions of the latter series of CSPs, in general, are comparatively low. The reason, discussed in the previous work, is that the amide bonds contained in the dendrimers significantly impairs the resolutions. In enantioseparation, there are achiral elements to affect chiral discrimination, such as the spacers and functional groups to immobilize selectors, etc.[22] To further investigate the influence of the structures of dendrimers and selectors on the enantioseparation ability, in this work, another chiral selector that is derivatized from (1*S*,2*R*)-(+)-2-amino-1,2-diphenylethanol is linked to the dendrimers that are prepared on the silica gel. The comparison of enantioseparation ability of the prepared CSPs is made.

MATERIALS AND METHODS

Materials and Chemicals

3-Aminopropyltriethoxysilane was purchased from Chemical Factory of Wuhan University (China). Phenyl isocyanate was obtained from Wanke Tech. of Hangzhou (China). 1,4-Phenylene diisocyanate was from Xinyi Pesticite Factory of Jiangsu (China). (1*S*,2*R*)-(+)-2-Amino-1,2-diphenylethanol was available from Likai Chiral. of

Contract grant sponsor: National Natural Science Foundation of China (NSFC); Contract grant numbers: 20371037 and 20675061
*Correspondence to: Zheng-Wu Bai, School of Chemical Engineering and Pharmacy, Wuhan Institute of Technology, Wuhan, Hubei Province 430073, China. E-mail: zhengwu_bai@yahoo.com
Received for publication 23 August 2008; Accepted 19 January 2009
DOI: 10.1002/chir.20708
Published online 24 March 2009 in Wiley InterScience (www.interscience.wiley.com).

Chengdu (China). Silica gel (LiChrosorb Si100) was from Merck (Darmstadt, Germany) with a particle size of 5 μm, a pore size of 100 Å and a surface area of 300 m^2 g^{-1}. Pyridine was refluxed with CaH_2 and redistilled. Triethylamine (TEA) was dried with P_2O_5 and redistilled. All other chemicals for synthesis were of analytic grade and used as received. All mobile phases were freshly prepared, filtered and degassed.

Instruments and Measurements

Elemental analysis was performed on an Elemental VarioEL III CHNOS apparatus (Germany). IR spectra were recorded on a Nicolet FTIR instrument with KBr pellets. Solid-state ^{1}H NMR spectra were recorded on a Varian Infinity Plus 300 spectrometer, operating at 300 MHz. The CSPs were packed into stainless steel columns (250 mm × 4.6 mm) with an Alltech slurry packer of model 1666. Enantioseparation was implemented on an Agilent 1100 chromatographic apparatus consisted of an Agilent G1365B DAD, an Agilent G1311A Quat Pump, an Agilent G1379A degasser and an Agilent G1313A ALS autosampler.

Preparation of Chiral Stationary Phases

(1*S*,2*R*)-1,2-Diphenyl-2-(3-phenylureido)ethyl 4-isocyanatophenylcarbamate, L-2-(*p*-toluenesulfonamido)-3-phenylpropionyl chloride, aminated silica gel and one- to four-generation dendrimers **(G1-4)** were, respectively, prepared in the same batch of previous works.[21,22] The dendrimers were prepared using aminated silica gel as the core, and using ethylene diamine and methyl acrylate as the building blocks.

Selector II (4.0 g) and di-n-butyltin dilaurate (2 ml) were added to a suspension of one-generation dendrimer (**G1**, 3.73 g) dispersed in pyridine (16 ml). After stirred at 80°C for 24 h, the resulting mixture was filtered. The collected solid was extracted with DMF and THF, and dried under vacuum to give **CSP 1** as a yellow solid (4.19 g).

CSP 1: FTIR (KBr, cm^{-1}): 3454 (N—H), 1646 (—NH—CO—), 1557 (—NH—CO—), 1103 (Si—O); Solid-state ^{1}H NMR (25°C) δ: 0.9 (s, Si—CH_2), 1.4 (s, Si—CH_2—C*H*$_2$), 2.4-2.7 (m, Si—CH_2—CH_2—C*H*$_2$), 4.3 (m, CON*H*—CH_2), 5.0–5.5 (m, —CH—), 6.5 (m, CH—N*H*), 6.9–7.6 (m, Ar—H), 9.1 (m, Ar—NH—CO).

The above identical procedures were applied for the preparation of **CSP**s **2**, **3** and **4**, with two-, three-, and four-generation dendrimer respectively.

CSP 2: FTIR (KBr, cm^{-1}): 3454 (N—H), 1645 (—NH—CO—), 1544 (—NH—CO—), 1107 (Si—O); Solid-state ^{1}H NMR (25°C) δ: 0.9 (s, Si—CH_2), 1.4 (s, Si—CH_2—C*H*$_2$), 2.4–2.7 (m, Si—CH_2—CH_2—C*H*$_2$), 4.2 (m, CON*H*—CH_2), 5.0–5.4 (m, —CH—), 6.5 (m, CH—N*H*), 6.5–7.6 (m, Ar—H), 9.2 (m, Ar—NH—CO).

CSP 3: FTIR (KBr, cm^{-1}): 3454 (N—H), 1643 (—NH—CO—), 1550 (—NH—CO—), 1102 (Si—O); Solid-state ^{1}H NMR (25°C) δ: 0.9 (s, Si—CH_2), 1.4 (s, Si—CH_2—C*H*$_2$), 2.3-2.7 (m, Si—CH_2—CH_2—C*H*$_2$), 4.5 (m, CON*H*—CH_2), 4.9–5.5 (m, —CH—), 6.6 (m, CH—N*H*), 6.8–7.6 (m, Ar—H), 9.2 (m, Ar—NH—CO).

CSP 4: FTIR (KBr, cm^{-1}): 3448 (N—H), 1647 (—NH—CO—), 1546 (—NH—CO—), 1104 (Si—O); Solid-state ^{1}H NMR (25°C) δ: 0.9 (s, Si—CH_2), 1.4 (s, Si—CH_2—C*H*$_2$), 2.2–2.7 (m, Si—CH_2—CH_2—C*H*$_2$), 4.3 (m, CON*H*—CH_2), 5.0–5.3 (m, —CH—), 6.6 (m, CH—N*H*), 6.8–7.7 (m, Ar—H), 9.0 (m, Ar—NH—CO).

CSP 5 was prepared with 3.58 g aminated silica gel, 3.11 g selector I and 3 ml TEA, according to the procedure described in the previous work that L-2-(*p*-toluenesulfonamido)-3-phenylpropionyl chloride was immobilized on the dendrimers.[21]

FTIR (KBr, cm^{-1}) 3450 (N—H), 1648 (—CONH—), 1399 (—SO_2—NH—), 1104 (Si—O); Solid-state ^{1}H NMR (25°C) δ: 0.9 (s, Si—CH_2), 1.4 (s, Si—CH_2—C*H*$_2$), 2.0 (s, ArSO_2—NH), 2.2 (s, Ar—CH_3), 2.8 (m, N—CH_2), 3.3 (m, Ar—CH_2), 3.8 (m, CONH—C*H*$_2$), 5.0 (m, ArCH_2—C*H*), 6.5 (s, CO—NH), 6.8–7.5 (m, Ar—H).

Column Packing and Enantioseparation Conditions

CSPs 1-5 were, respectively, packed into five columns through a slurry packing method with chloroform to form the slurries and hexane as the packing solvent. The enantioseparation on these five CSPs was conducted in various mobile phase conditions at 25°C with 1 ml/min flow rate except when indicated. The sample solutions (1 mg/ml) were prepared by dissolving the chiral solutes in methanol and were filtered before injection. The injection volume is 15 μl.

RESULTS AND DISCUSSION

Characterization of Dendritic Stationary Phases

As shown in Figure 1, **CSPs 1-4** were prepared by immobilizing selector II onto one- to four-generation dendrimers (see Figure 2), which were synthesized in the previous work.[22] The structure of these dendrimers is not perfect due to the intramolecular amidation and bulkiness of dendritic linker to small molecules, i.e. ethylene diamine and methyl acrylate, during the formation of dendrimers. The elemental analysis of the CSPs, the increment of carbon content of the CSPs and related selector loadings are tabulated in Table 1. The selector loadings are calculated according to the following formula:

Selector loading $= \frac{C_1 - C_0}{M \times n} \times 10^4 \mu mol/g$[$C_0$ and C_1: the carbon content of dendrimers (aminated silica gel for **CSP 5**) and corresponding CSPs; C_1-C_0: the increment of carbon contents of the CSPs. *M*: the relative atom weight of carbon; *n*: the number of carbon atom in each selector].

Comparison Between Selector Loadings of CSPs 1-4 and Enantioseparation Ability

The column efficiency of **CSPs 1-5** was determined as 16,700, 15,400, 17,300, 20,600 and 32,800 plates per meter respectively, with biphenyl as the sample, a mixture of hexane and isopropanol (90/10, v/v) as the mobile phase. The enantioseparation ability was investigated with structurally various chiral analytes (see Figure 3). The chromatographic data are presented in Table 2. **CSPs 1-4** separated 8, 13, 6, and 9 chiral compounds respectively. Comparing the selector loadings and the numbers of separated

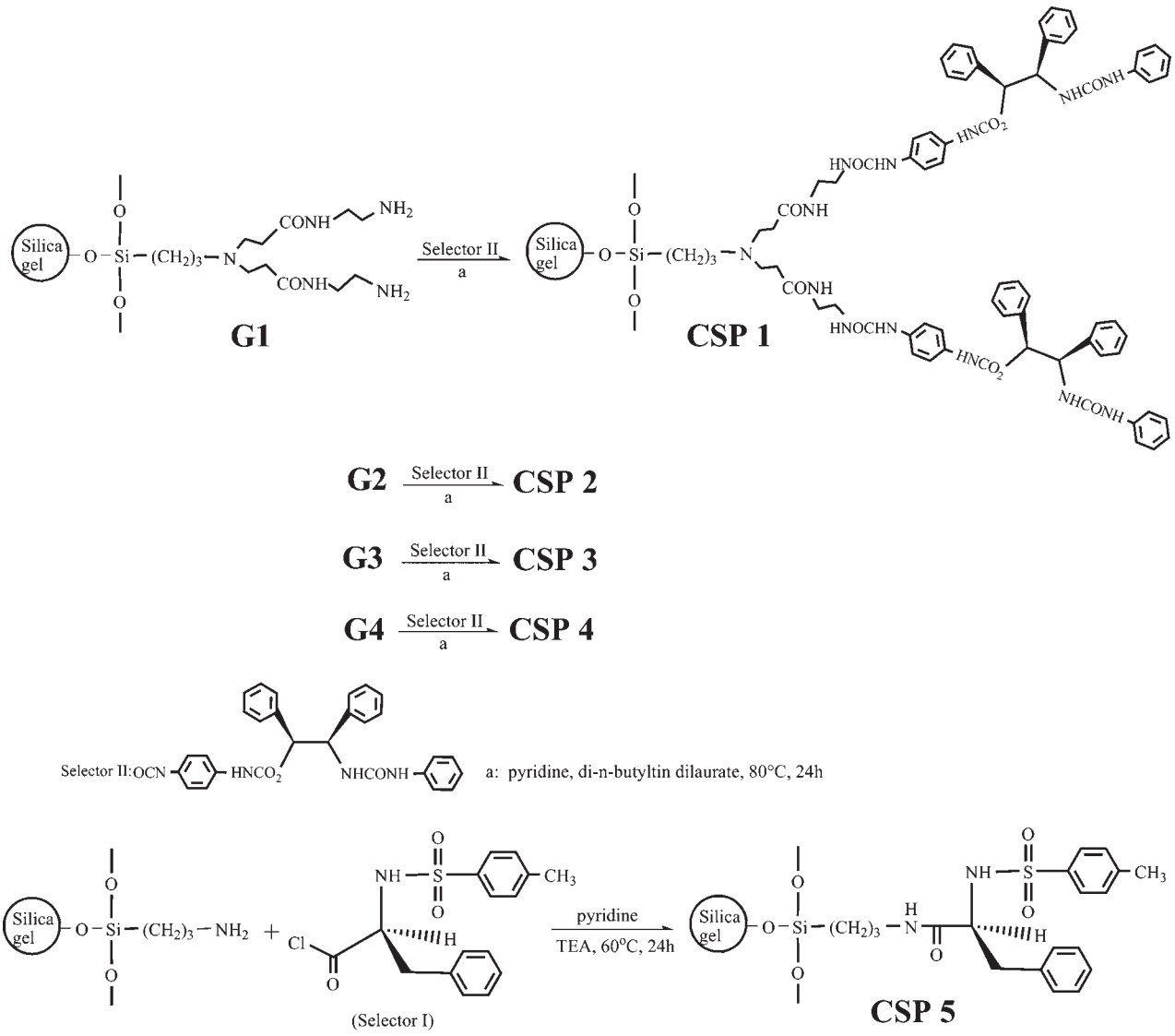

Fig. 1. The synthetic scheme of CSPs **1-5**.

chiral compounds, the CSP of highest selector loading, such as **CSP 1,** does not have most powerful separation ability. In previous work, the CSP, which is prepared by immobilizing selector II on 3-aminopropyl silica gel shows excellent enantioseparation ability.[22] This enantioseparation ability difference corresponds to the different structures of these two CSPs. For **CSP 1** in this work, the chiral selector is anchored to the first-generation dendrimer; and in previous work, it is immobilized on 3-aminopropyl silica gel that is the core of the dendrimer. There are many amide bonds in the dendrimer. Thus, it is suggested that the hydrogen bonding inside the dendrimer and the jam between chiral selector and dendrimer reduce the enantioseparation ability. **CSP 3** has lowest enantioseparation ability due to its too low selector loading. **CSP 4** shows equivalent separation ability comparing to **CSP 1**, although its selector loading is much lower than that of **CSP 1**. It is believed that the selector and the dendrimer in **CSP 4** are not crowded because of its lower selector loading. **CSP 2** has comparatively optimal selector loading in view of this series of CSPs, where selector and dendrimer are not so crowded and the selector loading is sufficient for chiral recognition. Therefore, it shows best separation ability. In our ongoing work, where the chiral selector is a derivative of tartaric acid, it is found that enantioseparation ability is related to selector loading. Furthermore, at the same separation conditions, the CSP of higher selector loading exhibit lower overall enantioseparation ability. Together with the observations in this work, it is concluded that there should be an optimal selector loading for a CSP to demonstrate its enantioseparation ability.

The Relationship Between Enantioseparation and the Structure of CSPs 1-4 and Chiral Analytes

The structures of chiral compounds separated by **CSPs 1-4** can be divided into two classes. One class is featured by the functional groups that can interact with selector

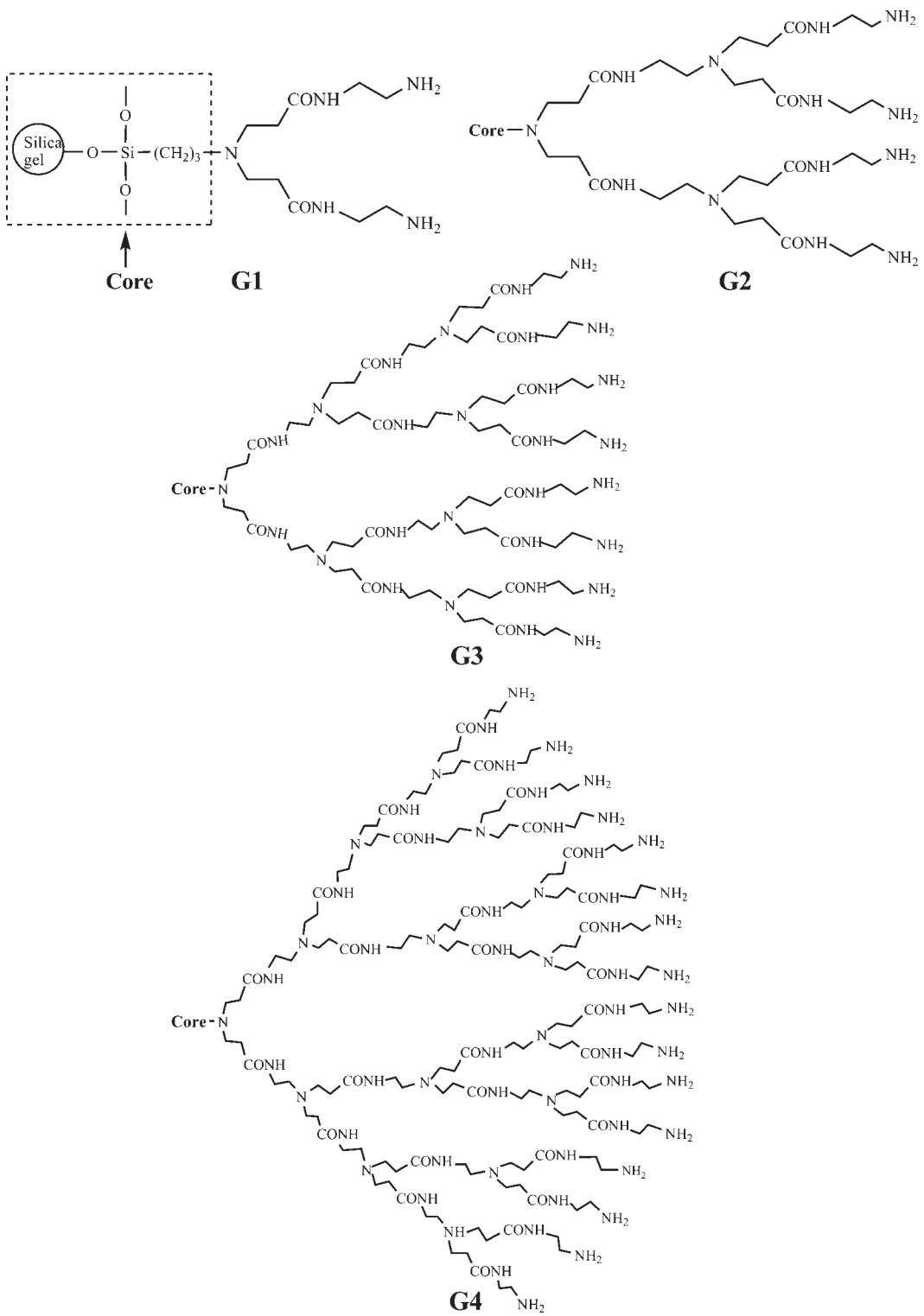

Fig. 2. The structures of generation-various dendrimers. G 1, G 2, G 3, and G 4 represent one to four-generation dendrimer respectively.

through hydrogen bonding, such as compounds 1, 4, 9, 14, 16, 22, and 23, which were all separated by **CSPs 1-4**. As for the enantioseparation of compounds 3 and 4, it is believed that the difference attributes to the slight change in their structures. There is a sulfur atom in the lactone, in which only one oxygen atom contributes hydrogen bonding interaction because of the lower electronegativity of sulfur. In compound 4, two oxygen atoms in the lactone can interact with proton, and as a result compound 4 was separated better by **CSPs 1-4** than compound 3. Another

TABLE 1. Elemental analysis data and chiral selector loadings for CSPs

Elemental analysis	CSP 1	CSP 2	CSP 3	CSP 4	CSP 5
C%	21.41	23.96	25.60	29.49	17.98
H%	3.38	3.97	4.36	5.09	3.42
N%	5.14	6.87	7.92	9.93	4.35
C content Increment (%)[a]	*7.86*	*5.77*	*2.44*	*2.86*	*12.59*
Selector loading, μmol/g	226	166	70	82	656

[a]The difference of carbon contents of **CSPs 1–5** and corresponding supports are given as italic values. The elemental analysis of generation-various dendrimers and aminated silica gel is same as those in previous work.[21]

one class is featured by bearing the structure of π-acidity in chemical property, such as compounds 5, 14, 20, 21, 24, and 25 etc. There are aromatic amide bonds contained in selectors, which are π-basic. π-Acids readily interact with π-bases to form temporary diastereoisomers between chiral analytes and selectors. The enantioseparation is caused due to the stability difference of these diastereoisomers. The similar instance occurs for the enantioseparation resulted from the stability difference of these diastereoisomers formed by hydrogen bonding interaction. For compounds 13 and 14, there is a chlorine atom at *para* position of the phenyl in compound 14, and this phenyl bears strong π-acidity because the chlorine atom withdraws electron. Therefore, compound 14 is chirally recognized by **CSPs 1** and **2**, while compound 13 is only recognized by **CSP 4**. Forasmuch compound 7 shows π-basicity because the amino at *para* position of the phenyl donates electron, and compound 8 shows π-neutrality, they are very similar in enantioseparation. In addition, the size and shape of chiral analytes probably impact the formation of temporary diastereoisomers and subsequent enantioseparation.

The influence of achiral elements on enantioseparation has been reported in a few works.[23–25] **CSPs 1-4** are derived from the same selector; however, the chiral analytes that are separated by **CSPs 1-4** are not completely the same in structures. Therefore, the chiral recognition is also affected by achiral elements for **CSPs 1-4**. There are a lot of amide bonds in the dendrimers that can interact with chiral analytes by hydrogen bonding. Chiral analytes simultaneously interact with the amide bonds and selectors to form temporary diastereoisomers, whose stability difference results in enantioseparation. For example, although the selector loading of **CSP 4** is quite low, its enantioseparation ability is equivalent to that of **CSP 1**, because chiral analytes interact with the amide bonds in the dendrimer in addition to with the selector to form diastereoisomers that probably lead enantioseparation.

The Influence of Mobile Phase Composition on Enantioseparation of CSPs 1-4

Mobile phases complicatedly impact separation not only by eluting chiral nanlytes out, being involved in the formation of temporary diasetereoisomers but also. As a whole, **CSPs 1-4** show their enantioseparation ability in reversed phase mode. Despite of the same selectors on **CSPs 1-4**, the favorable mobile phases are different. **CSP 1** shows its enantioseparation ability preferably in methanol-contained mobile phases; and **CSPs 2-4** preferably in acetonitrile-contained mobile phases. This difference is mainly owing to the generation-different dendrimers and selector loadings. **CSP 1** was prepared from one-generation dendrimer with highest selector loading. In this case, the selector and dendrimer crowd each other, making it inconvenient for chiral analytes to interact with the amide bonds. Thus, methanol participates in the diastereoisomer formation, by bridging chiral analytes and amide bonds through hydrogen bonding. Because **CSPs 2-4** are derived from two-, three-, and four-generation dendrimers respectively, where the selectors are not so congested, the amide bonds in selectors and in dendrimers are exposed to chiral analytes for interaction. Hereby, methanol is not needed to be involved in the diastereoisomer formation.

The Influence of Selector Structure on Enantioseparation

The dendrimers in this work were prepared in the same batch in our previous work,[21] and the difference of these two series of CSPs only lies on their chiral selectors. Generally, the enantioseparation ability of the CSPs in this work is not improved in comparison with the previous work, where the chiral selector is L-2-(*p*-toluenesulfonamido)-3-phenylpropionyl chloride (see Figure 1). There are one chiral center and two phenyls in selector I; while there are two chiral centers and four phenyls in selector II. Relative to selector II, the molecular size of selector I is smaller, and its steric hindrance for the interaction with chiral analytes is less; whereas, appropriate steric hindrance is a necessary element for chiral recognition. To compare the enantioseparation ability of chiral selectors of L-2-(*p*-toluenesulfonamido)-3-phenylpropionyl chloride and (1*S*,2*R*)-1,2-diphenyl-2-(3-phenylureido)ethyl 4-isocyanatophenylcarbamate, the former selector was immobilized on 3-aminopropyl silica gel by the reported method to give **CSP 5**.[21] Its enantioseparation ability has also been evaluated (Table 2), and is lower than that of the CSP of the latter selector.[22] No improvement in enantioseparation ability attributes to the support of the CSPs of this work, which is functionalized with generation-various dendrimers. There are more amide bonds in selector II, and they are desired to interact with chiral analytes. However, these amide bonds also interact with other amide bonds in the dendrimers. Wherefore, the possibility of the interaction between the selector and the chiral analytes does not increase as expected.

CONCLUSIONS

In comparison with the previous work, the prepared CSPs, whose chiral selector bears one more chiral center, more amide bonds and more phenyls, do not demonstrate improved enantioseparation ability. The CSPs prepared from one- and four-generation dendrimers have the equivalent enantioseparation ability due to the huddle of the selector and the dendrimer in **CSP 1** and the comparative sparsity of selector in **CSP 4**. The CSP prepared from

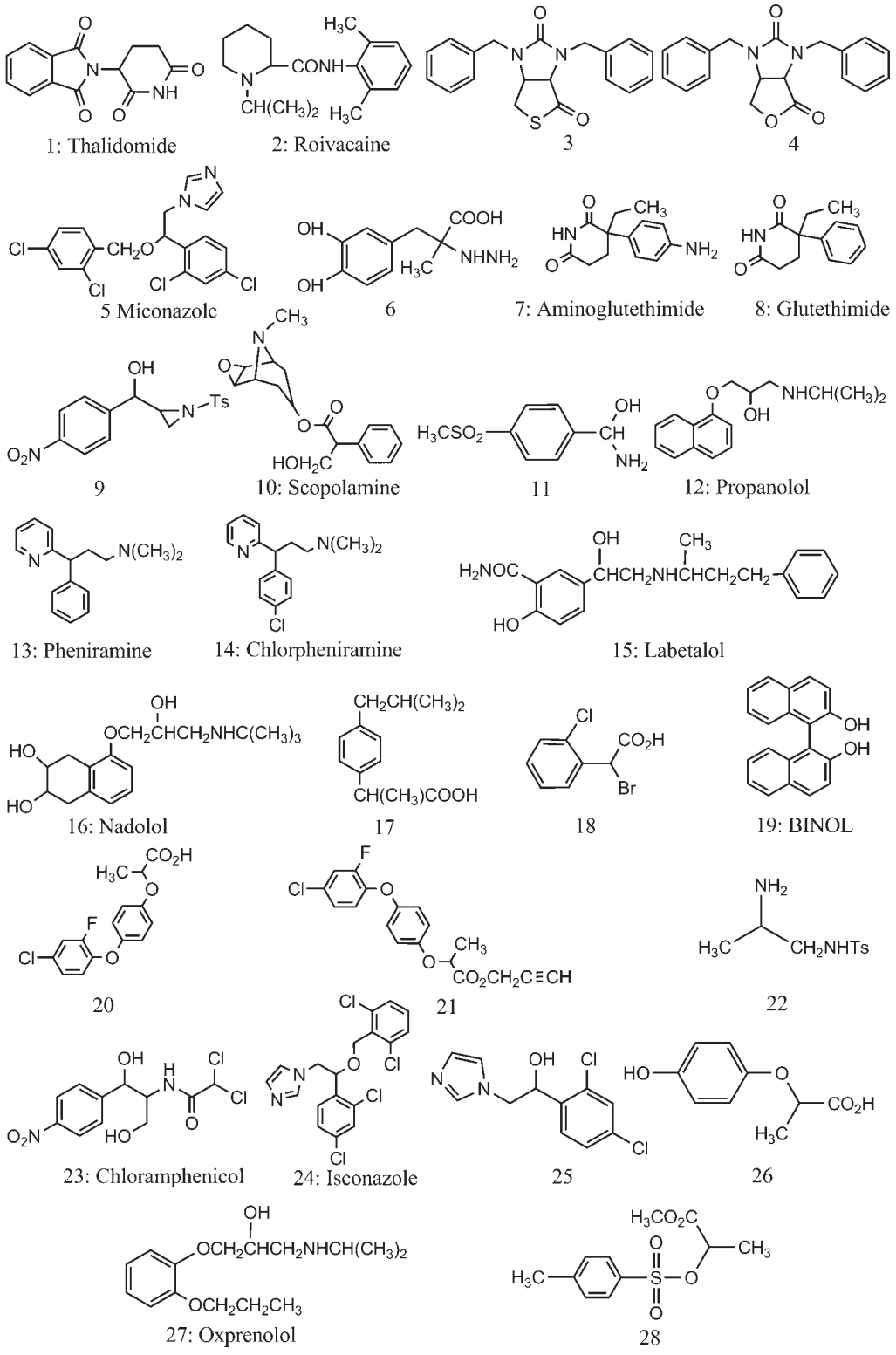

Fig. 3. The chiral analytes separated by **CSPs 1-5**.

three-generation dendrimer has the poorest enantioseparation ability due to its lowest selector loading; while the CSP prepared from two-generation dendrimer exhibits the strongest enantioseparation ability due to its optimal selector loading. **CSP 1** shows enantioseparation ability preferably in methanol-contained mobile phases, because its selector and the dendrimer jam each other; and the amide bonds are shielded to chiral analytes, leading the necessity

TABLE 2. Chromatographic resolution of racemates on CSPs 1–5[a]

	CSP 1				CSP 2				CSP 3				CSP 4				CSP 5			
S/N	k	α	R_s	Separation conditions	k	α	R_s	Separation conditions	k	α	R_s	Separation conditions	k	α	R_s	Separation conditions	k	α	R_s	Separation conditions
1	0.90	1.14	0.46	A (50:50)[j]	0.62	1.64	0.97	C (50:50)[j]					0.19	1.58	0.40	G (70:30)[j]	0.17	4.93	0.43	A (70:30)[j]
2					0.11	1.68	0.51	C (50:50)[k]												
3					1.54	1.71	1.19	C (50:50)[j]									0.14	24.4	9.42	A (60:40)[i]
4	0.65	2.79	4.02	A (70:30)[j]	0.95	1.70	1.38	C (50:50)[j]	0.43	2.20	2.15	C (60:40)[j]	0.16	1.44	0.36	C (60:40)[j]	1.17	1.39	1.08	A (70:30)[m]
5					0.12	1.64	0.53	C (60:40)[j]									0.20	1.73	0.63	D (70:30)[m]
6									0.38	1.08	0.68	E (65:35)[l]								
7									0.20	1.09	0.15	C (60:40)[j]								
8									0.20	1.10	0.18	C (60:40)[j]								
9					1.21	1.34	0.82	C (50:50)[j]					0.65	1.51	0.57	H (60:40)[k,b]	1.55	2.00	5.18	A (70:30)[m]
10					0.21	1.18	0.33	A (60:40)[j]												
11													0.09	1.47	0.18	C (70:30)[k]				
12					0.15	1.62	0.70	C (60:40)[j]									0.12	1.98	0.72	C (65:35)[l]
13													0.19	1.96	0.90	A (70:30)[l,b]				
14	1.68	1.29	1.22	A (50:50)[j]	0.11	2.01	0.67	A (50:50)[j]									0.13	2.95	1.07	C (65:35)[k]
15					0.17	1.64	0.69	A (60:40)[j]												
16	0.65	3.33	9.61	B (50:50)[j]													0.12	1.86	0.61	C (65:35)[l]
17	0.47	1.09	0.59	C (70:30)[j]																
18	0.42	2.07	2.99	A (70:30)[j]																
19									0.37	1.15	0.32	B (60:40)[l]								
20													0.27	2.34	0.95	A (60:40)[k,b]				
21	1.21	1.78	1.85	D (95:5)[j]									0.16	1.46	0.41	C (60:40)[j]				
22													0.17	1.37	0.33	C (60:40)[j]				
23	0.33	1.65	2.21	C (60:40)[m]	0.12	5.80	3.71	C (50:50)[j]	0.06	8.70	3.15	F (60:40)[l]					0.07	12.4	6.57	A (95:5)[l]
24					0.19	1.80	0.78	C (60:40)[j]					0.13	1.50	0.25	C (70:30)[j]				
25					0.13	2.01	0.70	C (50:50)[j]									0.71	1.69	1.43	D (70:30)[k]
26																	0.25	1.45	0.56	D (70:30)[m]
27																	0.50	1.22	0.46	C (50:50)[k]
28																	0.92	1.74	1.06	A (45:55)[k]

Retention factor (k_1): $(t_1 - t_0)/t_0$, where t_1 is the retention time of the first-eluted enantiomer, and t_0 is determined by measuring the retention time of the solvent, which is used to prepare samples. Separation factor (α): k_2/k_1; Resolution (R_s): $2(t_2 - t_1)/(w_1 + w_2)$, where w_1 is the bandwidth of the first-eluted enantiomer, and t_2 and w_2 are the retention time and bandwidth of the second-eluted enantiomer, respectively.

[a]Eluent: A: methanol/water; B: acetonitrile/water/TEA; C: acetonitrile/water; D: n-hexane/isopropanol; E: acetonitrile/water/trichloroacetic acid (TCA); F: methanol/water/TCA; G: *n*-hexane/ethnol; H: methanol/water/TEA. UV detection; [i]205 nm; [j]225 nm; [k]245 nm; [l]265 nm; [m]285 nm. The concentration of additives: TEA/water: 1 ml/100 ml; TCA/water: 1g/100 ml.

[b]Flow rate: 0.60 ml/min.

of the offset of methanol involved in the formation of temporary diastereoisomers for chiral recognition.

LITERATURE CITED

1. Ling FH, Lu V, Svec F, Fréchet JMJ. Effect of multivalency on the performance of enantioselective separation media for chiral HPLC prepared by linking multiple selectors to a porous polymer support via aliphatic dendrons. J Org Chem 2002;67:1993–2002.
2. Mathews BT, Beezer AE, Snowden MJ, Hardy MJ, Mitchell JC. The synthesis of immobilised chiral dendrimers. New J Chem 2001; 25:807–818.
3. Yates CR, Hayes W. Synthesis and applications of hyperbranched polymers. Eur Polym J 2004;40:1257–1281.
4. Javor S, Delort E, Darbre T, Reymond JL. A peptide dendrimer enzyme model with a single catalytic site at the core. J Am Chem Soc 2007;129:13238–13246.
5. Suman B, Kumar S. Adsorption of charged dendrimers: a Brownian dynamics study. J Phys Chem B 2007;111:8728–8739.
6. Reek JNH, Arévalo S, Heerbeek R, Kamer PCJ, Leeuwen PWNM. Dendrimers in catalysis. Adv Catal 2006;49:71–151.
7. Krishna TR, Jayaraman N. Synthesis and catalytic activities of Pd^{II}-phosphine complexes modified poly(ether imine) dendrimers. Tetrahedron 2004;60:10325–10334.
8. Bu J, Judeh ZMA, Ching CB, Kawi S. Epoxidation of olefins catalyzed by Mn(II) salen complex anchored on PAMAM-SiO_2 dendrimer. Catal Lett 2003;85:183–187.
9. El-Shehawy AA. Synthesis of novel well-defined chain-end-functionalized polystyrenes with dendritic chiral ephedrine moieties and their applications as highly enantioselective diethylzinc addition to N-diphenylphosphinoyl arylimines. Tetrahedron 2007;63:11754–11762.
10. Crampton HL, Simanek EE. Dendrimers as drug delivery vehicles: non-covalent interactions of bioactive compounds with dendrimers. Polym Int 2007;56:489–496.
11. Dufès C, Uchegbu IF, Schätzlein AG. Dendrimers in gene delivery. Adv Drug Delivery Rev 2005;57:2177–2202.
12. Svenson S, Tomalia DA. Dendrimers in biomedical applications-reflections on the field. Adv Drug Delivery Rev 2005;57:2106–2129.
13. Koo OM, Rubinstein I, Onyuksel H. Role of nanotechnology in targeted drug delivery and imaging: a concise review. Nanomedicine: nanotechnology, biology, and medicine 2005;1:193–212.
14. Donnio B, Buathong S, Bury I, Guillon D. Liquid crystalline dendrimers. Chem Soc Rev 2007;36:1495–1513.
15. Duanmu C, Saha I, Zheng Y, Goodson BM, Gao Y. Dendron-functionalized superparamagnetic nanoparticles with switchable solubility in organic and aqueous media: matrices for homogeneous catalysis and potential MRI contrast agents. Chem Mater 2006;18:5973–5981.
16. Takahashi M, Hara Y, Aoshima K, Kurihara H, Oshikawa T, Yamashita M. Utilization of dendritic framework as a multivalent ligand: a functionalized gadolinium(III) carrier with glycoside cluster periphery. Tetrahedron Lett 2000;41:8485–8488.
17. Castagnola M, Cassiano L, Lupi A, Messana I, Patamia M, Rabino R, Rossetti DV, Giardina B. Ion-exchange electrokinetic capillary chromatography with Starburst (pamam) dendrimers: a route towards high-performance electrokinetic capillary chromatography. J Chromatogr A 1995;694:463–469.
18. Blokhina SV, Usol'tseva NV, Ol'khovich MV, Sharapova AV. Liquid-crystalline polypropyleneimine dendrimer as a stationary phase for gas chromatography. J Anal Chem 2007;62:559–563.
19. Ogasawara S, Ikeda A, Kikuchi J. Positive dendritic effect in DNA/porphyrin composite photocurrent generators containing dendrimers as the stationary phase. Chem Mater 2006;18:5982–5987.
20. Huang SH, Li SR, Bai ZW, Pan ZQ, Yin CQ. Dendrimer-like chiral stationary phases derived from (1R, 2*R*)-(+)-1,2-diphenylethylenediamine and 1,3,5-benzenetricarbonyl trichloride. Chromatographia 2006;64: 641–646.
21. Yin C-Q, He B-J, Huang S-H, Zhang J-Y, Bai Z-W, Li Z-Y. Synthesis of dendritic stationary phases with surface-bonded L-phenylalanine derivate as chiral selector and their evaluation in HPLC resolution of racemic compounds. Chirality 2008;20:846–855.
22. Yin C-Q, He B-J, Li S-R, Liu Y-Q, Bai Z-W. Immobilization of (1*S*,2*R*)-(+)-2-amino-1, 2-diphenylethanol derivates on aminated silica gel with different linkages as chiral stationary phases and their enantioseparation evaluation by HPLC. Chirality (in press).
23. Bai Z-W, Lai X-H, Chen L, Ching C-B, Ng S-C. Arylcarbamoylated allylcarbamido- β-cyclodextrin: synthesis and immobilization on nonfunctionalized silica gel as a chiral stationary phase. Tetrahedron Lett 2004;45:7323–7326.
24. Bargmann-Leyder N, Truffert J-C, Tambuté A, Caude M. Evaluation of Pirkle-type chiral stationary phases by liquid and supercritical fluid chromatography: influence of the spacer length and the steric hindrance in the vicinity of the stereogenic centre. J Chromatogr A 1994;666:27–40.
25. Berthod A, Chang C-D, Armstrong DW. β-Cyclodextrin chiral stationary phases for liquid chromatography. Effect of the spacer arm on chiral recognition. Talanta 1993;40:1367–1373.