A Novel Polybrene/Chondroitin Sulfate C Double Coated Capillary and Its Application in Capillary Electrophoresis

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A new capillary coated by double polymer, polybrene/chondroitin sulfate C (P/CC), was developed using a simple procedure. The P/CC double coated capillary showed long lifetime, strong chemical stability and good reproducibility. It endured during more than 100 replicated analyses and was also tolerant to HCl (1 mol/L), NaOH (0.01 mol/L), CH_3OH and CH_3CN. The P/CC double coated capillary can be applied to basic drug analyses. The adsorption of basic drugs to the capillary wall was suppressed and the peak tailing greatly decreased. The use of the P/CC double coated capillary allowed excellent separation of the enantiomers of some basic drugs by using chondroitin sulfate C as the chiral selector, and the peak symmetry of basic drugs was further improved under these conditions.

Keywords capillary electrophoresis, anionic capillary coating, basic drug, chiral separation, chondroitin sulfate C

Introduction

Capillary electrophoresis (CE) has become an important separation tool because it can take advantages of high resolution, relatively fast separation, convenient selection of separation condition, and extremely small volume of sample and separation media.[1-3] Various separation modes have been developed based on the conventional electrophoretic technique or a combination of electrophoresis and chromatography. A wide variety of substances, from ions to biopolymers, now can be analyzed by choosing the suitable separation mode according to the physicochemical properties of the analytes. Recently the separation of enantiomers by CE has also received considerable attention especially in the field of pharmaceutical science.[4-9] CE techniques have been demonstrated to be as effective as high performance liquid chromatography (HPLC) for the separation of enantiomers.[10,11] Especially chiral separation of basic drugs by CE using polysaccharides as chiral selectors were very remarkable.[12-15] However, when those basic solutes were analyzed by using uncoated fused silica capillaries, adsorption of the samples to the capillary wall occurred leading to heavy peak tailing of analytes.[16,17] It was found that such adsorption of basic drugs to the capillary wall was only observed under acidic conditions and no significant tailing was experienced at neutral pH.[18] The severe peak tailing of basic drugs at low pH is obviously related to the protonation of the amino/imino groups in the drugs and the association of the silanol group on the capillary wall, although further studies will be necessary for complete understanding of this tailing phenomenon. Therefore, minimization of the adsorption of basic drugs to the capillary wall is required.

In CE, the adsorption of solutes to the capillary inner wall is often experienced. The common strategies to avoid the adsorption are to modify the capillary inner wall. The modification of the capillary wall can generally be classified into the following categories: to adsorb the cationic modifier to the capillary wall permanently by physical adsorption,[19,20] and to fix the hydrophilic layer permanently by covalent bonding or cross-linking.[21,22] The conventional physical adsorption modification of

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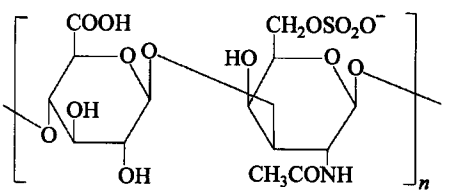
capillary wall has disadvantages of limited pH range and short lifetime although it offers advantages of simple coating procedure and good reproducibility.[23] On the other hand, the covalent bonding or cross-linking has a long lifetime while it requires a relatively complicated coating procedure. It would be an ideal capillary modification if the stable coating could be achieved in a simple procedure.

In this research, a novel anionic capillary coating with successive multiple ionic polymer layers, polybrene/chondroitin sulfate C (P/CC) double coated capillary was developed. It was formed by attaching a cationic polymer, polybrene, to the inner surface of the capillary and then immobilizing the negatively charged polymer chondroitin sulfate C tightly to the polybrene layer. Its simplicity was almost similar to that of the conventional physical adsorption modification, while the stable coating was obtained due to the double layer of the ionic polymer. The P/CC double coated capillary was applied to the basic drug analyses and their chiral separation using polysaccharides as chiral selectors with satisfaction.

Experimental

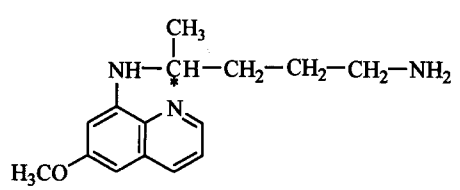
Materials

Polybrene (hexadimethrine bromide) from Aldrich Chemical Company (Milwaukee, WI, USA) and chondroitin sulfate C (sodium salt) from Wako Pure Chemicals (Chuo-ku, Osaka, Japan) were used as coating reagents. Cinamyl alcohol, used as a tracer of the electroosmotic flow (EOF) was obtained from Nacalai Tesque (Nakakyo-ku, Kyoto, Japan). Primaquine diphosphate (antimalarial drug) and laudanosine (tetanic poison) were obtained from Aldrich. Chloroquine diphosphate (antimalarial drug) and propranolol hydrochloride (β-blocker) were obtained from Sigma Chemical Company (St. Louis, MO, USA). Diltiazem hydrochloride (calcium channel blocker) was purchased from Wako and Sigma. All these basic drugs were racemic compounds except diltiazem, and used as tested solutes. Although the diltiazem preparation employed in this work was considered to be a racemic mixture from the data in the catalog, the communication with the reagent seller revealed that this preparation was an almost pure sample of the *cis*-(+)-enantiomer, because it had a high optical rotation of +113° and gave a single peak in HPLC. Fig. 1 gives the structure of chondroitin sulfate C which is the most potent chiral selector among polysaccharides. Fig. 2 shows all basic drugs employed in this study.

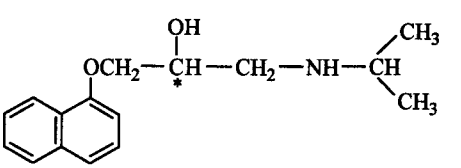


Chondroitin sulfate C

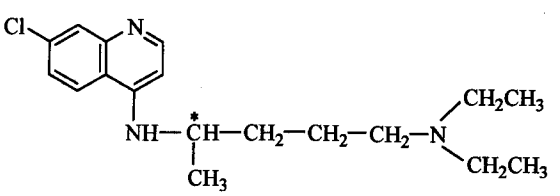
Fig. 1 Structure of chondroitin sulfate C.



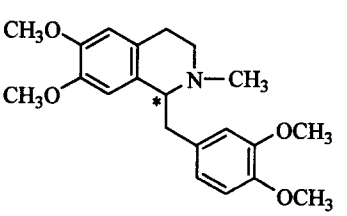
Primaquine
(PRI)



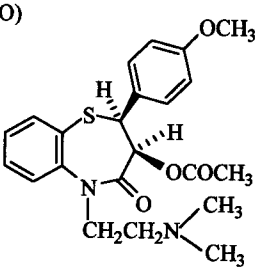
Propranolol
(PRO)



Chloroquine
(CHL)



Laudanosine
(LAU)



Diltiazem (2*S*,3*S*)
(DIL)

Fig. 2 Structures of basic drugs used.

All other reagents were of the highest grade commercially available. Glass ware-distilled deionized water was used for preparation of running buffers and reagent solutions.

Apparatus and methods

The instrument used was a CAPI-3100 capillary electrophoresis system of Otsuka Electronics (Hirakata-shi, Osaka, Japan) otherwise stated, which consisted of a sampling device, a power supply, a photodiode array UV detector and a data processor. The capillary of 50, 70 or 80 cm total length × 50 μm I.D. was used for the separation. The capillary was thermostated at 20 ℃. Samples were introduced by vacuum injection (0.5 kg/cm^2) for 0.5—4.0 s. Separations were performed in the constant voltage mode with an applied voltage of 20 kV. The analytes were detected by measurement of UV absorbance at the wavelength of 259 nm (primaquine), 256 nm (chloroquine), 220 nm (propranolol), 230 nm (laudanosine) or 236 nm (diltiazem). Uncoated fused silica capillaries (375 μm O.D. × 50 μm I.D.) were obtained from Polymicro Technologies (Phoenix, AZ, USA).

Phosphate buffers at pH 2.05, 3.00, 6.00, 7.00 and 8.00 (I = 0.05), acetate buffers at pH 4.00 and 5.00 (I = 0.05), borate buffers at pH 9.17 and 11.00 (I = 0.05) and a phosphate buffer at pH 2.90 (20 mmol/L), as running buffers, were used for evaluation of the performance of a P/CC double coated capillary and an uncoated capillary. Running buffer solutions containing a chiral selector were freshly prepared by dissolving additives in a phosphate buffer (20 mmol/L) having a specified pH, and then the pH was exactly adjusted to the desired value by adding 10 *W/V*% phosphoric acid or sodium hydroxide (1 mol/L). The pH values of these running buffers were always checked before and after each experiment. All above buffer solutions were filtered through a 0.45 μm-pore size filter and degassed by sonication prior to use.

Stock solutions of each racemic sample were prepared at a concentration of about 1 mg/mL. The solvent for sample stock solutions was methanol (laudanosine) or water (others). Sample solutions for separation were prepared by diluting one of the stock solutions with water to a concentration of about 200 μg/mL.

The capillaries were preconditioned using water followed by running buffer for a short time before each run for all analyses. At the end of all daily experiments the capillaries were washed with sodium hydroxide (1 mol/L) (for analyses using an uncoated capillary) or a 3 *W/V*% aqueous solution of chondroitin sulfate C (for analyses using a P/CC double coated capillary) followed by water.

The degree of peak tailing was expressed as symmetry factor S ($W_{0.05}/2f$), where $W_{0.05}$ and f are the whole width and the front half width, respectively, of the peak at the 5% position of peak height. Resolution was calculated from $R_s = 2(t_2 - t_1)/(w_2 + w_1)$, where t_1 and t_2 are the migration time of the first and second eluted enantiomers, respectively, and w_1 and w_2 are the peak widths of the first and second eluted enantiomers, respectively. The $W_{0.05}$, f, w_1 and w_2 values were measured on printed electropherograms in which the abscissa scale was 50 cm/min.

Preparation of polybrene/chondroitin sulfate C (P/CC) double coated capillary

The scheme of preparation of a P/CC double coated capillary is illustrated in Fig. 3.

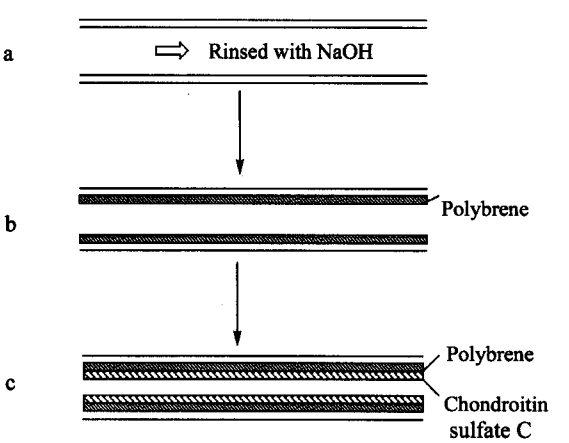


Fig. 3 Diagrammatic expression of the procedure of double coating.

Step (a) shows the activation of silanol groups. A capillary was rinsed with sodium hydroxide (1 mol/L) for 15 min and then water for 15 min. Step (b) shows the first layer coating. After preconditioning, a solution of 5 *W/V*% polybrene in water was passed through the capillary for 15 min at a constant flow rate and the capillary was allowed to stand for another 15 min for completion of the first cationic layer. The capillary was then rinsed with water for 15 min to remove the excess polybrene solution. Step (c) shows the second layer coating. The capillary

was washed with a 3 *W/V%* aquoues chondroitin sulfate C solution for 15 min, and allowed to stand for another 15 min for completing coupling of the anionic polymer to the polybrene layer. Finally, the capillary was rinsed with water for 15 min to remove the excess anionic polymer. All these procedures were performed at room temperature.

Results and discussion

Evaluation of a P/CC *double coated capillary*

In order to evaluate the performance of a P/CC double coated capillary, EOF, the chemical stability, reproducibility and endurance of this double coating were first investigated.

Measurement of EOF

The electrophoretic mobility of EOF was expressed by the following equation:

$$Ll/Vt$$

where L, l, V and t are total capillary length, effective capillary length (the length between inlet and detection window), applied voltage and migration time of cinamyl alcohol (a tracer of EOF), respectively. EOF will be reversibly changed during coating because a cationic polymer polybrene was attached as a first layer and an anionic polymer condroitin sulfate C was attached as a second layer. The EOF of an uncoated capillary was from anode to cathode. After the cationic polymer polybrene was attached as the first layer, the EOF was reversed from cathode to anode. After the anionic polymer condroitin sulfate C was attached as the second layer, the EOF was reversed again from anode to cathode. Fig. 4 shows the EOF of an uncoated capillary and a P/CC double coated capillary over the range of pH 2.05—11.00.

Below pH 7.0 the EOF of the P/CC double coated capillary was faster than that of the uncoated capillary. But this was reversed above pH 7.0. It was remarkable that the change of EOF with pH in the P/CC double coated capillary was milder than that in the uncoated capillary. This is because chondroitin sulfate C as the second layer on the double coated capillary inner wall has two anionic groups, *i.e.*, the sulfate and carboxyl groups. The dissociation of the sulfate group is considered to be almost complete over the whole pH range examined because it is a strong acid, resulting in smaller change of negativity of the second layer with pH. In the meantime, the dissociation of the carboxyl group will be dependent on pH. It is evident that the extent of dissociation increases with the increase of pH. The almost changeless EOF of the P/CC double coated capillary below pH 3.0 means that the carboxyl group is completely associated, whereas this group is completely dissociated above pH 6.0 because of steady EOF over the range of pH 6.0—11.0. Such mild EOF change of the P/CC double coated capillary with pH is favorable for obtaining high reproducibility in migration time.

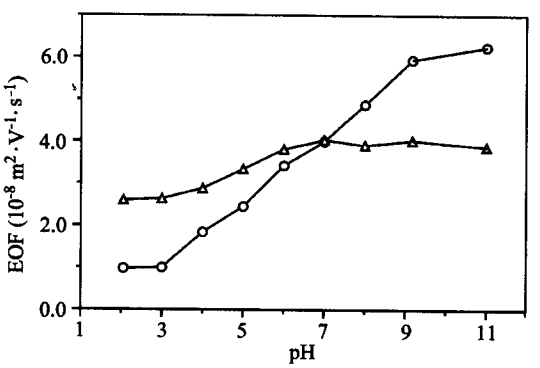


Fig. 4 EOF of the uncoated and P/CC double coated capillaries ($n = 5$). Capillary: uncoated (○) or P/CC double coated (△) (50.0 cm × 50 μm I. D., effective length 37.5 cm); running buffer: phosphate buffer at pH 2.05, 3.00, 6.00, 7.00, 8.00 ($I = 0.05$), acetate buffer at pH 4.00, 5.00 ($I = 0.05$), or borate buffer at pH 9.17, 11.00 ($I = 0.05$); temperature: 20 ℃; applied voltage: 20 kV; detection wavelength: 259 nm.

Chemical stability

To evaluate the stability of the P/CC double coated capillary under applied conditions, chemical stability should be examined. The results are shown in Table 1. EOF was first measured at pH 3.0 after P/CC double coated capillaries had been prepared. The capillaries were then washed with a solvent for 15 min, and the EOF was measured again under the same condition. Each EOF was obtained from five replicated analyses. The coating stability was evaluated on the basis of the change of EOF, which was expressed as the degradation ratio defined in Table 1.

Table 1 Chemical stability of the P/CC double coated capillary ($n = 5$)[a]

Solvent	EOF_1[b] ($\times 10^{-8}$ $m^2 \cdot V^{-1} \cdot s^{-1}$)	EOF_2[c] ($\times 10^{-8}$ $m^2 \cdot V^{-1} \cdot s^{-1}$)	Degradation ratio[d] (%)
NaOH (0.01 mol/L)	2.638	2.627	0.42
NaOH (0.1 mol/L)	2.621	2.091	20.2
HCl (1 mol/L)	2.643	2.626	0.64
CH_3OH	2.630	2.603	1.0
CH_3CN	2.626	2.648	0.84

[a] Capillary: P/CC double coated (50.0 cm × 50 μm I.D., effective length 37.5 cm); running buffer: phosphate buffer at pH 3.00 (I = 0.05); other conditions as in Fig. 4. [b] EOF_1 was measured before rinse with the solvents. [c] EOF_2 was measured after rinse for 15 min with the solvents. [d] Degradation ratio: $|EOF_1 - EOF_2|/EOF_1 \times 100\%$.

The P/CC double coated capillary was unstable after NaOH (0.1 mol/L) rinse, but it was stable to such solvents as HCl (1 mol/L), NaOH (0.01 mol/L), CH_3OH and CH_3CN because all the degradation ratios were less than 1.0%. The stability of this capillary under extremely acidic and weak alkaline conditions is a remarkable property because other modified capillaries, whether the coating procedure is based on physical adsorption or covalent bonding and cross-linking, are mostly unstable under above conditions. This strong stability of the P/CC double coated capillary is due to the attachment of the double ionic polymer layers, and the tolerance to both NaOH and HCl assures the wide pH range analysis.

Endurance

One of the most important problems that the physical adsorption coating must overcome is its short-term endurance. One-layer adsorption of a cationic polymer such as polybrene or polyethylenimine endures only 25 runs.[23] An endurance test of the P/CC double coated capillary against continuous analysis was performed, where the condition was the same as in Section "*Reproducibility*" except at pH 3.0. Each run was performed for 10 min. The endurance was evaluated by measuring EOF, migration time of primaquine at pH 3.0 where both EOF and the migration time of primaquine would decease greatly if the coating were detached. The results showed that EOF and the migration time of primaquine almost did not change after 100 runs. The P/CC double coated capillary was intended to achieve strong endurance rather than the one layer adsorption. This strong endurance is also due to the double attachment of ionic polymers. It is suggested that the interaction between polybrene and the anionic polymer chondroitin sulfate C is stronger than that between the capillary wall and polybrene.

Reproducibility

It is not easy to get the high reproducibility of EOF in an uncoated capillary. The comparison of run-to-run reproducibility between a P/CC double coated capillary and an uncoated capillary was investigated. The run-to-run reproducibility was evaluated on the basis of the relative standard deviation (RSD) of EOF and migration time of primaquine obtained from five replicated analyses in one capillary at pH 3.00, 6.00, 9.17, respectively. Table 2 gives the results.

Table 2 Comparison of run-to-run reproducibility between an uncoated capillary and a P/CC double coated capillary ($n = 5$)[a]

pH	Uncoated capillary				P/CC double coated capillary			
	EOF		Primaquine		EOF		Primaquine	
	t (min)	RSD (%)	t (min)	RSD (%)	t (min)	RSD (%)	t (min)	RSD (%)
3.00	15.638	8.0	3.681	7.5	5.933	1.5	2.631	1.2
6.00	4.574	4.1	2.863	4.3	4.099	1.3	2.686	1.2
9.17	2.630	3.2	2.001	3.1	3.887	1.4	2.683	1.3

[a] Running buffer: phosphate buffer at pH 3.00 or 6.00 (I = 0.05), or borate buffer at pH 9.17 (I = 0.05); other conditions as in Fig. 4.

Both EOF and the migration time of primaquine in the uncoated capillary varied. Especially the RSD was as high as 7.5%—8.0% at pH 3.0. On the other hand, the variance decreased greatly with the attachment of double ionic layers and the RSD became less than 1.5%. This is because the differences of silanol groups affect the reproducibility of EOF in the uncoated capillary. But once the double coating was formed, the variance of silanol groups could be negligible because the double ionic layers perfectly covered the bare capillary wall and silanol groups. The capillary-to-capillary reproducibility of the P/CC double coated capillary was also evaluated based on RSD of EOF and migration time of primaquine obtained from five replicated analyses in five capillaries at pH 3.00, 6.00, 9.17, respectively. The analytical conditions were the same as in the run-to-run reproducibility test except that analyses were performed in five P/CC double coated capillaries. Execllent capillary-to-capillary reproducibility was obtained and RSD was less than 1.7%. The good reproducibility is one of the great advantages of the P/CC double coated capillary.

Thus it can be seen that the P/CC double coated capillary not only offers merits in its simple procedure but also has an advantage over any other kinds of capillaries in long lifetime, wide pH range used and good reproducibility. Additionally chondroitin sulfate C in a running buffer can repair the second anionic polymer layer in a P/CC double coated capillary in every run when chondroitin sulfate C is used as a chiral selector. This is also beneficial for obtaining longer lifetime and better reproducibility.

Application

Analysis of basic drugs

The ability for the P/CC double coated capillary to perform the basic drug analysis was evaluated by comparing the *S* values of the peaks of test samples under the acidic condition between an uncoated capillary and a P/CC double coated capillary. Three basic drugs, primaquine, propranolol and diltiazem, used as the test samples, were analyzed in an uncoated capillary or a P/CC double coated capillary using a 20 mmol/L phosphate buffer at pH 2.9. The results are shown in Table 3.

In the uncoated capillary three basic drugs gave very severe tailing peaks and their *S* values were as high as 16.9—18.2. It was remarkable that the use of the P/CC double coated capillary overcame these problems of peak tailing. The *S* values of three basic drugs deceased greatly to 2.2—3.7. Fig. 5 shows a typical example of the comparison of electropherograms (for primaquine) between an uncoated capillary and a P/CC double coated capillary.

Table 3 Comparison of *S* values of three basic compounds between two kinds of capillaries[a]

Solute	*S* value			
	Uncoated capillary	P/CC double coated capillary		
		1	2	3
Primaquine	17.1	2.6	2.4	2.5
Propranolol	18.2	3.7	3.5	3.7
Diltiazem	16.9	2.3	2.2	2.2

[a] Capillary: uncoated (50.0 cm × 50 μm I.D., effective length 37.5 cm) or P/CC double coated (80.0 cm × 50 μm I.D., effective length 67.5 cm); running buffer: 20 mmol/L phosphate buffer (pH 2.90); temperature: 20 ℃; applied voltage: 20 kV; detection wavelength: 259 nm (primaquine), 220 nm (propranolol) or 236 nm (diltiazem). Each *S* value was the average of 5 repeated estimations.

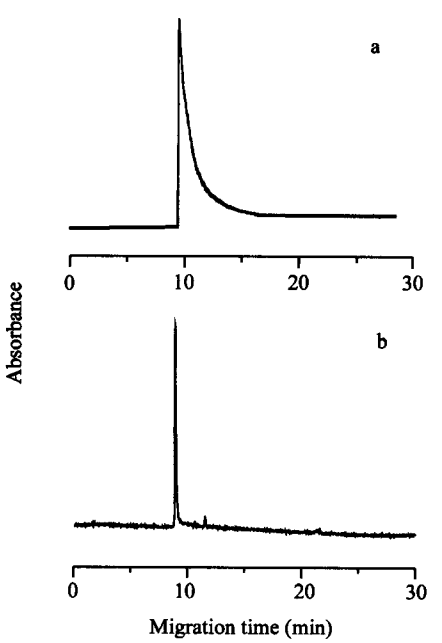


Fig. 5 Comparison of primaquine peaks between an uncoated capillary (a) and a P/CC double coated capillary (b). Capillary: uncoated (70.0 cm × 50 μm I.D., effective length 50.0 cm) (a), P/CC double coated (80.0 cm × 50 μm I.D., effective length 67.5 cm) (b); running buffer: 20 mmol/L phosphate buffer (pH 2.90); other conditions as in Fig. 4.

In order to examine the ability of the P/CC double coated capillary to avoid the peak tailing of basic drugs more deeply, a correlation between S values of primaquine and buffer pH was investigated over the pH range of 2.05—11.00. The results are given in Fig. 6.

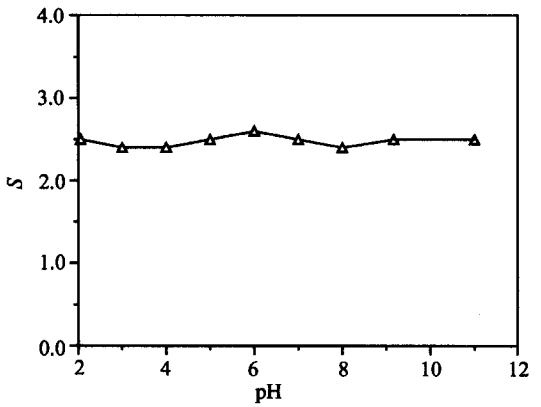


Fig. 6 pH dependence of the S value of primaquine in the P/CC double coated capillary. Capillary: P/CC double coated (80.0 cm × 50 μm I.D., effective length 67.5 cm); other conditions as in Fig. 4.

Obviously primaquine gave relatively small S values over a wide pH range tested. Furthermore, all the S values did not change greatly. These results demonstrate that the P/CC double coated capillary is effective for decreasing peaking tailing of basic drugs. This is because the double ionic polymer layers in the P/CC double coated capillary perfectly cover the bare capillary wall and silanol groups and the adsorption of basic drugs to the capillary wall is suppressed. It is recommended that a P/CC double coated capillary be used for the analysis of basic compounds in capillary electrophoresis.

Chiral separation of basic drugs using chondroitin sulfate C as a chiral selector

Recently polysaccharides, which contain sugar units as chiral moieties, have been used as chiral selectors in enantioseparation by CE.[12,13] They showed wide enantioselectivity for racemic compounds, especially for basic drugs. These substances are very advantageous because they have good ultraviolet (UV) transparency and charged polysaccharides have good solubility in aqueous solutions. Furthermore, there is a wide range of polysaccharide species to choose from, each providing unique characteristics for enantioseparation. We performed chiral separation of four basic drugs, primaquine, chloroquine, propranolol and laudanosine, as test samples in the P/CC double coated capillary at pH 2.9 using chondroitin sulfate C which is the most potent chiral selector among polysaccharides. Fig. 7 shows the electropherograms of enantioseparation of these basic drugs.

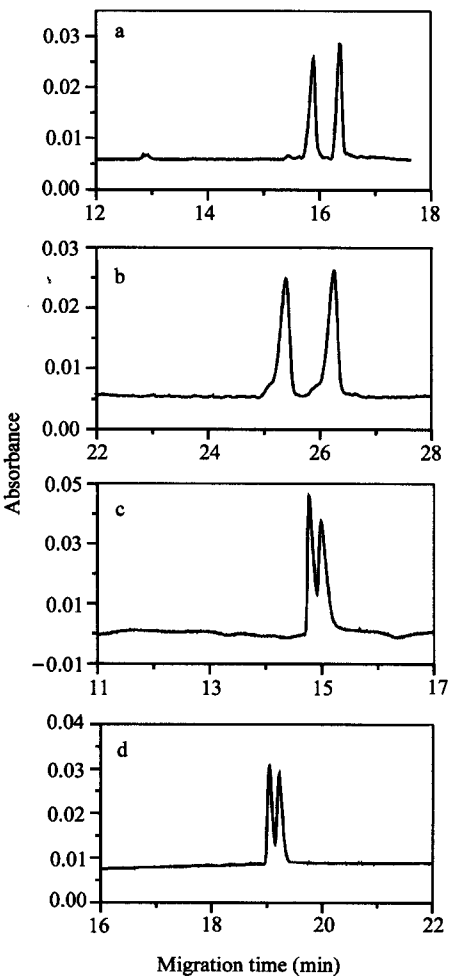


Fig. 7 Chiral separation of basic drugs with chondroitin sulfate C in the P/CC double coated capillary. (a) primaquine, (b) chloroquine, (c) propranolol and (d) laudanosine. Capillary: P/CC double coated (80.0 cm × 50 μm I.D., effective length 67.5 cm); running buffer: 20 mmol/L phosphate buffer (pH 2.90) containing 3 *W/V%* chondroitin sulfate C; temperature: 20 ℃; applied voltage: 20 kV; detection wavelength: 259 nm (primaquine), 256 nm (chloroquine), 220 nm (propranolol), or 230 nm (laudanosine).

Compared with in the system of single phosphate

buffer, the peak tailing of all basic drugs decreased further under these conditions, giving S values of about 0.9 (primaquine), 0.9 (chloroquine), 2.0 (propranolol), and 1.2 (laudanosine). This probably resulted from the interaction between basic drugs and additives flowing counter wise. Primaquine and chloroquine were completely separated, giving R_s values of 2.58 and 2.69 respectively. Propranolol and laudanosine were partially separated and their R_s values were 0.90 and 1.04. Thus chiral separation of basic drugs with chondroitin sulfate C was successfully performed in the P/CC double coated capillary. The use of this double coating minimizes the adsorption of basic drugs to the capillary inner wall.

It should be mentioned that separations were performed in a chondroitin sulfate *C*-containing buffer filled in a polybrene/chondroitin sulfate C double coated capillary in this enantioseparation system. It will be significant to find out which of both two states of chiral selectors contributes to enantioseparation. Therefore, the following experiment was performed. The migration time of primaquine served as a representative basic drug and cinnamyl alcohol served as a tracer of EOF was determined in both a P/CC double coated capillary and an uncoated capillary filled with phosphate buffers not containing chondroitin sulfate C at pHs 3.00, 6.00 and 9.17. The electrophoretic mobility of primaquine was calculated by $L \cdot l \cdot V^{-1}(t^{-1} - t_0^{-1})$. The symbols, t_0 and t, are the migration time of cinnamyl alcohol and primaquine, respectively. Table 4 compares the electrophoretic mobility of primaquine between a P/CC double coated capillary and an uncoated capillary.

Obviously no significant change in the electrophoretic mobility of primaquine was observed at all pH values between these two capillaries. This indicates that there is almost no reaction between primaquine and chondroitin sulfate C on the inner wall of the P/CC double coated capillary. In addition, any separation tendency was not observed between primaquine enantiomers under above conditions in the P/CC double coated capillary, too. It is evident that chondroitin sulfate C in the running buffer plays a major part in chiral recognition rather than that on the inner wall of the P/CC double coated capillary in present enantioseparation system.

The high velocity of EOF in the P/CC double coated capillary at low pH will allow other applications. It is also possible that protein analyses are performed in this double coating in order to avoid the protein adsorptions to the capillary wall. More applications of the P/CC double coated capillary are still being investigated.

Table 4 Comparison of the eletrophoretic mobility of primaquine between an uncoated capillary and a P/CC double coated capillary ($n = 5$)[a]

pH	Uncoated capillary			P/CC double coated capillary		
	Migration time (min)		Mobility of PRI ($\times 10^{-8}$ m$^2 \cdot$V$^{-1} \cdot$s^{-1})	Migration time (min)		Mobility of PRI ($\times 10^{-8}$ m$^2 \cdot$V$^{-1} \cdot$s^{-1})
	PRI	EOF		PRI	EOF	
3.00	3.681	15.638	3.246	2.631	5.933	3.305
6.00	2.863	4.574	2.042	2.686	4.099	2.005
9.17	2.001	2.630	1.868	2.683	3.887	1.804

[a] Running buffer: phosphate buffer at pH 3.00 or 6.00 ($I = 0.05$), or borate buffer at pH 9.17 ($I = 0.05$); other conditions as in Fig. 4.

Conclusion

A novel stable capillary coating was achieved in a simple procedure. The P/CC double coated capillary not only offered merits in its simple procedure but also showed long lifetime, strong chemical stability and good reproducibility. Heavy peak tailing or adsorption of basic drugs on the inner wall of a fused silica capillary in CE can be overcome by using a P/CC double coated capillary. It is recommended that chiral separation of basic drugs with chondroitin sulfate C by CE be performed in the P/CC double coated capillary, and the peak symmetry of basic drugs was further improved under these conditions.

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