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Characteristics of organic cation transporter in rat renal basolateral membrane

Toshiya Katsura, Mikihisa Takano, Yoshiko Tomita, Masato Yasuhara, Ken-ichi Inui [1] and Ryohei Hori

Department of Pharmacy, Kyoto University Hospital, Faculty of Medicine, Kyoto University, Sakyo-ku, Kyoto (Japan)

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Characteristics of organic cation transport system were studied in rat renal basolateral membrane and compared with those in brush-border membrane. We first examined the effect of various chemical modifiers on tetraethylammonium uptake by the membrane vesicles. Treatment with *N,N'*-dicyclohexylcarbodiimide and phenylglyoxal (carboxyl groups and arginine residues specific reagent, respectively) resulted in inhibition of tetraethylammonium transport in both basolateral and brush-border membranes. Tetraethylammonium uptake by brush-border, but not by basolateral, membrane vesicles was decreased by diethyl pyrocarbonate, histidine residues specific reagent, treatment. Treatment of sulfhydryl groups with $HgCl_2$ decreased tetraethylammonium transport in both membranes. However, in contrast to brush-border membrane, unlabeled tetraethylammonium failed to protect against the inhibition of [^{14}C]tetraethylammonium uptake by *p*-chloromercuribenzene sulfonate in basolateral membrane. We next examined the inhibitory effect of various organic cations on tetraethylammonium uptake. The order of inhibitory potency of organic cations was somewhat different between two membranes. These findings suggest that the characteristics of organic cation transport systems in basolateral and brush-border membranes were different in regard to essential amino acid residues and the affinity of substrates.

Introduction

Organic cations are actively secreted by renal proximal tubules [1]. Many investigations using isolated renal brush-border and basolateral membrane vesicles have provided further information on the transport characteristics of organic cations in renal proximal tubules. Specific transport of organic cations such as N^1-methylnicotinamide and tetraethylammonium was shown in both basolateral and brush-border membranes [2–4]. In basolateral membrane, interior-negative membrane potential [3,4] and/or exchange mechanism [5–7] serve as the driving force. H^+ gradient-dependent uphill transport of organic cations (electroneutral H^+/organic cation antiport system) was demonstrated in brush-border membrane vesicles from rat [3,8–12], rabbit [4,13–15], dog [16,17], snake [18] and human [19]. Since the luminal pH is more acidic than the intracellular pH in proximal tubules [20], it is reasonable to assume that the inward H^+ gradient (from lumen to cell) can serve as a driving force for the secretion of organic cations.

The characteristics of the H^+/organic cation antiport system in brush-border membrane have been relatively well investigated. For example, it was demonstrated that the H^+/organic cation antiport is sensitive to pH [11,21]. Additionally, sulfhydryl groups [10,17], carboxyl groups [22] and histidine residues [12] were reported to be essential for the organic cation transport in renal brush-border membrane using chemical modifiers for amino acid residues. In contrast, there has been little information about the molecular nature of the organic cation transport system in basolateral membrane.

In the present study, we examined the effect of various chemical modifiers on tetraethylammonium transport in rat renal basolateral membrane in comparison with that in brush-border membrane. We also

Correspondence to: R. Hori, Department of Pharmacy, Kyoto University Hospital, Sakyo-ku, Kyoto 606-01, Japan.

[1] Present address: Department of Hospital Pharmacy, School of Medicine, Tokyo Medical and Dental University, Bunkyo-ku, Tokyo 113, Japan.

Abbreviations: Hepes, *N*-2-hydroxyethylpiperazine-*N'*-2-ethanesulfonic acid; Mes, 2-(*N*-morpholino)ethanesulfonic acid; DCCD, *N,N'*-dicyclohexylcarbodiimide; PGO, phenylglyoxal; DEPC, diethyl pyrocarbonate; PCMBS, *p*-chloromercuribenzene sulfonate.

studied the effect of organic cations on tetraethylammonium transport, to compare the affinity of various organic cations for the transport system in these membranes. The results suggest that carboxyl groups, arginine residues and sulfhydryl groups, but not histidine residues, should be involved in organic cation transport in basolateral membrane. In basolateral membrane, *N*-acetylprocainamide was a more potent inhibitor of tetraethylammonium transport than cimetidine. These characteristics of organic cation transport system in basolateral membrane were different from those in brush-border membrane.

Materials and Methods

Preparation of basolateral membrane vesicles

Basolateral membrane vesicles were isolated from the renal cortex of male Wistar albino rats (200–230 g) according to the method of Percoll density gradient centrifugation as previously described [3,23]. Unless otherwise noted, the purified basolateral membrane was suspended in a buffer consisting of 100 mM mannitol, 10 mM *N*-2-hydroxyethylpiperazine-*N'*-2-ethanesulfonic acid (Hepes) (pH 7.5), and 100 mM KCl (Buffer A). The membrane vesicles were used for transport studies on the day they were prepared.

Preparation of brush-border membrane vesicles

Brush-border membrane vesicles were isolated from the renal cortex of male Wistar albino rats (200–230 g) by the Mg/EGTA precipitation method according to Biber et al. [24] and our previous report [25] with several modifications. All steps were performed on ice or at 4°C. The cortex was homogenized with Ace Homogenizer AM-4 (Nihonseiki Co., Ltd., Tokyo, Japan) at 18000 rpm for 2 min in the buffer consisting of 300 mM mannitol, 12 mM Tris-HCl (pH 7.1) and 5 mM EGTA, and then the same buffer was added to make a 10% homogenate. After diluting with distilled water (1:1), $MgCl_2$ was added to a final concentration of 10 mM, and the homogenate was allowed to stand for 15 min. The homogenate was centrifuged at $1900 \times g$ for 15 min in a Hitachi High Speed Refrigerated Centrifuge SCR 20B (rotor: RPR20-2). The supernate was centrifuged at $24000 \times g$ for 30 min. The pellet was resuspended in the buffer consisting of 150 mM mannitol, 6 mM Tris-HCl (pH 7.1) and 2.5 mM EGTA, and homogenized in a glass/Teflon Potter homogenizer with 10 strokes at 1000 rpm. $MgCl_2$ was added to a final concentration of 10 mM, and the suspension was allowed to stand for 15 min. The suspension was centrifuged at $1900 \times g$ for 15 min, and then the supernate was centrifuged at $24000 \times g$ for 30 min. The final pellet (purified brush-border membrane) was resuspended in a buffer consisting of 100 mM mannitol, 100 mM KCl and either 10 mM Hepes (pH 7.0; Buffer B) or 10 mM 2-(*N*-morpholino)ethanesulfonic acid (Mes) (pH 6.0; Buffer C). Aminopeptidase (EC 3.4.11.2) and γ-glutamyltransferase (EC 2.3.2.2), marker enzymes for brush-border membrane, were enriched approximately 14-fold, whereas Na^+/K^+-adenosinetriphosphatase (EC 3.6.1.3), a marker enzyme for basolateral membrane, was not detectable. The membrane vesicles were used for transport studies on the day they were prepared.

Transport studies

The uptake of labeled tetraethylammonium by basolateral and brush-border membrane vesicles was measured by a rapid filtration technique [23]. The reaction was rapidly initiated by the addition of a buffer (20–80 μl) containing [^{14}C]tetraethylammonium to 20 μl of membrane suspension (2–10 mg of protein per ml) at 25°C. At the stated times, the incubation was stopped by diluting the reaction mixture with 1 ml of ice-cold stop solution. The composition of the stop solution was: 150 mM KCl, 20 mM Hepes-Tris (pH 7.5) and 0.1 mM $HgCl_2$. The contents of the tube were poured immediately onto Millipore filters (HAWP, 0.45 μm, 2.5 cm diameter) and washed once with 5 ml of ice-cold stop solution. In separate experiments, nonspecific adsorption was estimated by the addition of labeled substrate mixture to 1 ml of ice-cold stop solution containing 20 μl of membrane vesicles. This value was subtracted from the uptake data for background correction.

Chemical modification

The membrane vesicles were incubated with chemical modifiers for the indicated times and subsequently transport studies were performed. The condition of treatment was: *N,N'*-dicyclohexylcarbodiimide (DCCD), phenylglyoxal (PGO) and diethyl pyrocarbonate (DEPC), at 25°C for 30 min; $HgCl_2$, at 0°C for 5 min. Stock solutions of DCCD and DEPC were prepared fresh daily in ethanol. Control experiments were performed with an equivalent amount of ethanol. In some experiments, basolateral membrane was pretreated with *p*-chloromercuribenzene sulfonate (PCMBS) as previously described [10].

Analytical methods

Protein was determined, after precipitation with ice-cold 10% (w/v) trichloroacetic acid, by the method of Lowry et al. [26] with bovine serum albumin as a standard. The marker enzymes were assayed as previously described [23].

Materials

[1-^{14}C]Tetraethylammonium bromide (3.0–4.0 mCi/mmol) was obtained from Du Pont-New England Nuclear (Boston, MA, USA). Percoll was obtained

from Pharmacia (Uppsala, Sweden). DEPC and PGO were purchased from Sigma (St. Louis, MO, USA). Hepes, Mes, Tris, PCMBS and DCCD were obtained from Nacalai Tesque (Kyoto, Japan). All other chemicals used were of the highest purity available.

Results and Discussion

First, we preliminarily examined the effect of various chemical modifiers on the initial rate of tetraethylammonium uptake by basolateral and brush-border membrane vesicles. The modifiers used were: DCCD (carboxyl groups), PGO (arginine residues), DEPC (histidine residues), $HgCl_2$ (sulfhydryl groups), *N*-acetylimidazole (tyrosine residues) and fluorescamine (amino groups). Among these reagents, *N*-acetylimidazole and fluorescamine had no effect on tetraethylammonium uptake in either membranes (data not shown). Therefore, in the following experiments, effect of the other chemical modifiers on tetraethylammonium uptake by basolateral membrane vesicles was examined in comparison with that by brush-border membrane vesicles.

Effect of DCCD on tetraethylammonium uptake

Fig. 1 shows the effect of DCCD on tetraethylammonium uptake by basolateral (Fig. 1A) and brush-border (Fig. 1B) membrane vesicles. Both the initial rate of uptake (10 or 30 s) and the equilibrium uptake (30 min) were evaluated. Treatment with DCCD resulted in inhibition of the initial rate of tetraethylammonium uptake both in basolateral and brush-border membranes. On the other hand, the equilibrium values of the uptake were not affected in either membranes, indicating that the intravesicular volume was not altered by DCCD treatment. It was reported that DCCD inactivates the H^+/organic cation antiport system in dog renal brush-border membrane [22]. In the present study, the effect of DCCD was also demonstrated in basolateral membrane.

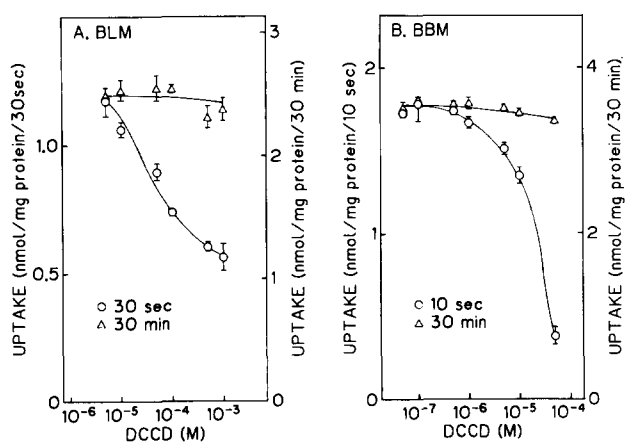

Fig. 1. Effect of DCCD on tetraethylammonium uptake by basolateral and brush-border membrane vesicles. (A) Basolateral membrane (BLM) vesicles suspended in Buffer A were preincubated with various concentrations of DCCD at 25°C for 30 min. The aliquots (20 μl) were incubated for 30 s (○) or 30 min (△) with Buffer A (20 μl) containing 2.5 mM [^{14}C]tetraethylammonium. (B) Brush-border membrane (BBM) vesicles suspended in Buffer B were preincubated with various concentrations of DCCD at 25°C for 30 min. The aliquots (20 μl) were incubated for 10 s (○) or 30 min (△) with Buffer B (20 μl) containing 2 mM [^{14}C]tetraethylammonium. Each point represents the mean ± S.E. of three determinations.

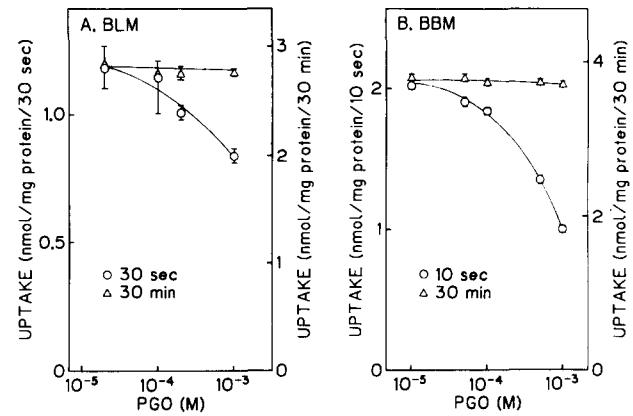

Fig. 2. Effect of PGO on tetraethylammonium uptake by basolateral and brush-border membrane vesicles. Basolateral membrane (BLM, A) and brush-border membrane (BBM, B) were preincubated with various concentrations of PGO at 25°C for 30 min. Then the uptake of [^{14}C]tetraethylammonium was measured as described in Fig. 1. Each point represents the mean ± S.E. of three determinations.

Effect of PGO on tetraethylammonium uptake

Effect of PGO, an arginine residue specific reagent, on tetraethylammonium uptake by basolateral and brush-border membrane vesicles was examined. As shown in Fig. 2, the initial rate of, but not equilibrium, uptake of tetraethylammonium was inhibited by PGO treatment in a concentration-dependent manner in both membranes. Thus, arginine residues should be essential for tetraethylammonium transport in basolateral and brush-border membranes. There are some reports indicating the importance of arginine residues for transport function of anionic substrates [27–29]. The exact role of arginine residues for organic ion transport systems are not clear at this stage.

Effect of DEPC on tetraethylammonium uptake

We previously reported that histidine residues are essential for organic cation transport in renal brush-border membrane using a histidine specific reagent, DEPC [12]. Because tetraethylammonium transport at pH 7.0, but not at pH 7.5, was sensitive to DEPC pretreatment in brush-border membrane [12], the uptake by basolateral membrane vesicles was examined at pH 7.0. As shown in Fig. 3, treatment with DEPC resulted in inhibition of the initial uptake of tetraethylammonium by brush-border membrane vesicles (Fig.

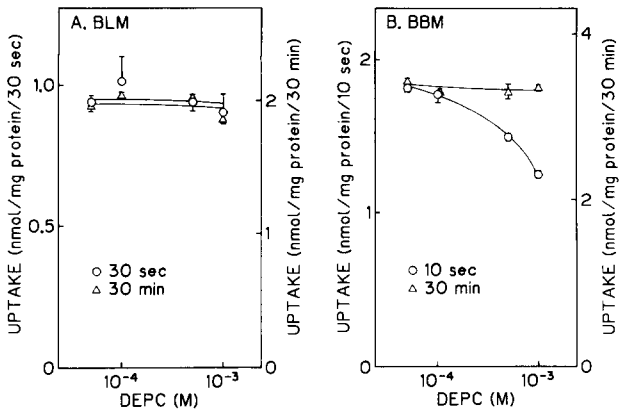

Fig. 3. Effect of DEPC on tetraethylammonium uptake by basolateral and brush-border membrane vesicles. (A) Basolateral membrane (BLM) vesicles suspended in Buffer B were preincubated with various concentrations of DEPC at 25°C for 30 min. The aliquots (20 μl) were incubated for 30 s (○) or 30 min (△) with Buffer B (20 μl) containing 2.5 mM [^{14}C]tetraethylammonium. (B) Brush-border membrane (BBM) vesicles were preincubated with various concentrations of DEPC at 25°C for 30 min. Then the uptake of [^{14}C]tetraethylammonium was measured as described in Fig. 1. Each point represents the mean ± S.E. of three determinations.

3B), but not by basolateral membrane vesicles (Fig. 3A). Tetraethylammonium uptake by basolateral membrane vesicles at pH 7.5 was also insensitive to DEPC treatment (data not shown).

Histidine residues are reported to be involved in many H^+ coupled transport systems such as Na^+/H^+ antiport in bacterial membrane [30] and in renal [31] and placental [32] brush-border membranes and H^+/dipeptide symport in intestinal [33] and renal [34] brush-border membranes. Thus, the lack of inhibitory effect of DEPC treatment on tetraethylammonium transport in renal basolateral membrane may reflect the difference of the driving force for organic cation transport in brush-border and basolateral membranes, that is, the organic cation transport in brush-border, but not in basolateral, membrane is coupled to H^+ gradient.

Effect of $HgCl_2$ on tetraethylammonium uptake

We [10] and others [17] have reported that sulfhydryl groups are essential for organic cation transport in renal brush-border membrane. In the present study, the effect of $HgCl_2$ on tetraethylammonium transport in basolateral membrane was examined. As shown in Fig. 4, the initial rate of tetraethylammonium uptake by basolateral (Fig. 4A), as well as brush-border (Fig. 4B), membrane vesicles was inhibited by $HgCl_2$ treatment in a concentration-dependent manner. In basolateral membrane, however, the equilibrium value of tetraethylammonium uptake was also decreased by $HgCl_2$ treatment. When the membrane vesicles were treated with $HgCl_2$ at concentrations above 0.5 mM, the degree of the inhibition of the initial uptake was much greater than that of the equilibrium uptake. Thus, it is likely that sulfhydryl groups are essential for tetraethylammonium transport in basolateral membrane.

The inhibitory effect of PCMBS, another sulfhydryl reagent, pretreatment on tetraethylammonium uptake was also observed in basolateral membrane and this effect was abolished by subsequent treatment of the vesicles with dithiothreitol (data not shown). However, unlabeled tetraethylammonium (10 mM) did enhance, rather than protect against, the inhibition of tetraethylammonium uptake by PCMBS pretreatment (0.05 mM) (control, 1.05 ± 0.16; PCMBS, 0.78 ± 0.05; PCMBS and tetraethylammonium, 0.47 ± 0.16 nmol/mg of protein per 30 s, mean ± S.E. of three determinations). These results are compatible with those reported by Zimmerman et al. [35]. They used *N*-ethylmaleimide as a sulfhydryl reagent and demonstrated that the substrate tetraethylammonium displayed an enhancement of *N*-ethylmaleimide inactivation, rather than protection, of the organic cation transport system in basolateral membrane. Recently, it was reported that the transcellular transport and accumulation of tetraethylammonium in LLC-PK$_1$, the pig kidney epithelial cell line, is sensitive to PCMBS treatment at the basal side [36]. Thus, it is likely that the sulfhydryl groups play an important role for organic cation transport in renal basolateral membrane. However, the role of sulfhydryl groups in basolateral membrane should be different from that in brush-border membrane, where the substrate protects against the inactivation of the transport system by sulfhydryl reagents [10,17].

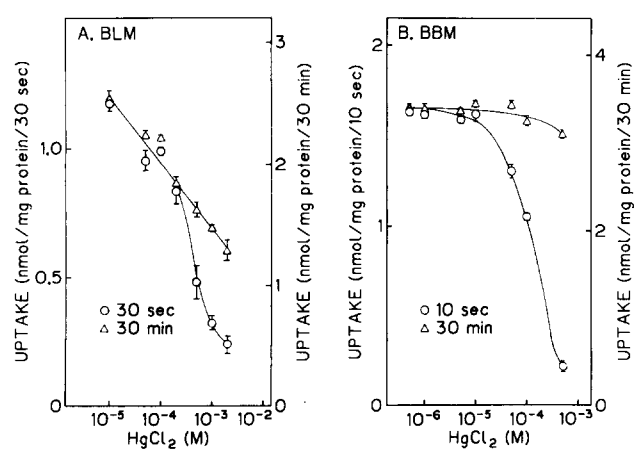

Fig. 4. Effect of $HgCl_2$ on tetraethylammonium uptake by basolateral and brush-border membrane vesicles. Basolateral membrane (BLM, A) and brush-border membrane (BBM, B) were preincubated with various concentrations of $HgCl_2$ at 0°C for 5 min. Then the uptake of [^{14}C]tetraethylammonium was measured as described in Fig. 1. Each point represents the mean ± S.E. of three determinations.

Effect of various organic cations on tetraethylammonium uptake

To evaluate the substrate specificity of organic cation transport system and the affinity of each substrate, effect of various organic cations on [^{14}C]tetraethylammonium uptake by basolateral and brush-border membrane vesicles was examined (Fig. 5). All the organic cations used inhibited the H^+ gradient-dependent tetraethylammonium uptake in brush-border membrane (Fig. 5B). The order of inhibitory potency was: cimetidine > amiloride > *N*-acetylprocainamide > procainamide > unlabeled tetraethylammonium > N^1-methylnicotinamide. This result was similar to the previous reports [4,8]. Tetraethylammonium uptake was also inhibited by these organic cations in basolateral membrane (Fig. 5A). However, the order of inhibitory potency was somewhat different between two membranes (in basolateral membrane; amiloride > *N*-acetylprocainamide > cimetidine > procainamide > unlabeled tetraethylammonium > N^1-methylnicotinamide).

Concentration dependence of the inhibition of [^{14}C]tetraethylammonium uptake by unlabeled tetraethylammonium, cimetidine and *N*-acetylprocainamide was examined (Fig. 6). Among these organic cations, cimetidine was the most potent inhibitor of tetraethylammonium uptake in brush-border membrane. In basolateral membrane, on the other hand, *N*-acetylprocainamide was a more potent inhibitor than cimetidine.

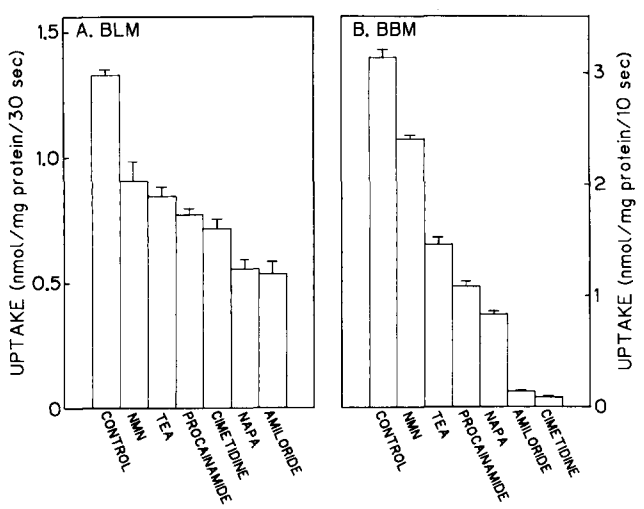

Fig. 5. Effect of various organic cations on tetraethylammonium uptake by basolateral and brush-border membrane vesicles. (A) Basolateral membrane (BLM) vesicles (20 μl) suspended in Buffer A were incubated for 30 s with Buffer A (20 μl) containing 2.5 mM [^{14}C]tetraethylammonium either in the presence or absence of 7.5 mM organic cations. (B) Brush-border membrane (BBM) vesicles (20 μl) suspended in Buffer C were incubated for 10 s with Buffer A (80 μl) containing 0.3125 mM [^{14}C]tetraethylammonium in either the presence or the absence of 0.625 mM organic cations. NMN, N^1-methylnicotinamide; TEA, tetraethylammonium; NAPA, *N*-acetylprocainamide. Each column represents the mean ± S.E. of three determinations.

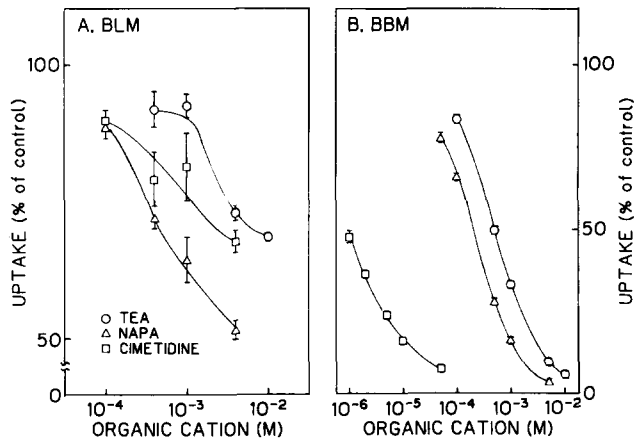

Fig. 6. Concentration dependence of the inhibition of tetraethylammonium uptake by unlabeled tetraethylammonium, *N*-acetylprocainamide and cimetidine. The uptake of [^{14}C]tetraethylammonium by basolateral membrane (BLM, A) or brush-border membrane (BBM, B) vesicles was measured as described in Fig. 5 in the presence of various concentrations of unlabeled tetraethylammonium (TEA; ○), *N*-acetylprocainamide (NAPA; △) and cimetidine (□). Each point represents the mean ± S.E. of three determinations.

Previous studies have shown that the inhibitory potency of organic cations such as cimetidine on tetraethylammonium transport was quite different between brush-border and basolateral membranes [4,8]. Moreover, aminocephalosporin antibiotics such as cephalexin are transported, in part, via the H^+/organic cation antiport system in renal brush-border membrane [9], while cephalexin should not interact with the organic cation transport system in basolateral membrane [37,38]. Taken together, it seems that the substrate recognition of organic cation transport system is qualitatively different between basolateral and brush-border membranes. This may be due to the difference of the molecular nature of the substrate binding site in the carrier protein.

In conclusion, carboxyl groups, arginine residues and sulfhydryl groups, but not histidine residues, should be essential for organic cation transport in renal basolateral membrane. The role of sulfhydryl groups may be different between basolateral and brush-border membranes. Furthermore, the substrate specificity and the affinity of substrates for the organic cation transport systems were different between the two membranes. Further studies are needed to elucidate the exact role of essential amino acid residues for the transport of organic cations in renal basolateral and brush-border membranes.

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References

1 Rennick, B.R. (1981) Am. J. Physiol. 240, F83-F89.
2 Kinsella, J.L., Holohan, P.D., Pessah, N.I. and Ross, C.R. (1979) J. Pharmacol. Exp. Ther. 209. 443–450.
3 Takano, M., Inui, K., Okano, T., Saito, H. and Hori, R. (1984) Biochim. Biophys. Acta 773, 113–124.
4 Wright, S.H. and Wunz, T.M. (1987) Am. J. Physiol. 253, F1040-F1050.
5 Montrose-Rafizadeh, C., Mingard, F., Murer, H. and Roch-Ramel, F. (1989) Am. J. Physiol. 257, F243-F251.
6 Sokol, P.P. and McKinney, T.D. (1990) Am. J. Physiol. 258, F1599-F1607.
7 Dantzler, W.H., Wright, S.H., Chatsudthipong, V. and Brokl, O.H. (1991) Am. J. Physiol. 261, F386-F392.
8 Takano, M., Inui, K., Okano, T. and Hori, R. (1985) Life Sci. 37, 1579–1585.
9 Inui, K., Takano, M., Okano, T. and Hori, R. (1985) J. Pharmacol. Exp. Ther. 233, 181–185.
10 Hori, R., Maegawa, H., Okano, T., Takano, M. and Inui, K. (1987) J. Pharmacol. Exp. Ther. 241, 1010–1016.
11 Maegawa, H., Kato, M., Inui, K. and Hori, R. (1988) J. Biol. Chem. 263, 11150–11154.
12 Hori, R., Maegawa, H., Kato, M., Katsura, T. and Inui, K. (1989) J. Biol. Chem. 264, 12232–12237.
13 McKinney, T.D. and Kunnemann, M.E. (1985) Am. J. Physiol. 249, F532-F541
14 Rafizadeh, C., Manganel, M., Roch-Ramel, F. and Schäli, C. (1986) Pflügers Arch. 407, 404–408.
15 Gisclon, L., Wong, F.M. and Giacomini, K.M. (1987) Am. J. Physiol. 253, F141–F150.
16 Holohan, P.D. and Ross, C.R. (1981) J. Pharmacol. Exp. Ther. 216, 294–298.
17 Sokol, P.P., Holohan, P.D. and Ross, C.R. (1986) J. Biol. Chem. 261, 3282–3287.
18 Dantzler, W.H., Wright, S.H. and Brokl, O.H. (1991) Pflügers Arch. 418, 325–332.
19 Ott, R.J., Hui, A.C., Yuan, G. and Giacomini, K.M. (1991) Am. J. Physiol. 261, F443–F451.
20 Warnock, D.G. and Rector, Jr., F.C. (1981) in The Kidney (Brenner, B.M. and Rector, Jr., F.C., eds.), 2nd Edn., Vol. 1, pp. 440–494, W.B. Saunders Company, Philadelphia.
21 Katsura, T., Maegawa, H., Tomita, Y., Takano, M., Inui, K. and Hori, R. (1991) Am. J. Physiol. 261, F774–F778.
22 Sokol, P.P., Holohan, P.D. and Ross, C.R. (1987) J. Pharmacol. Exp. Ther. 243, 455–459.
23 Inui, K., Okano, T., Takano, M., Kitazawa, S. and Hori, R. (1981) Biochim. Biophys. Acta 647, 150–154.
24 Biber, J., Stieger, B., Haase, W. and Murer, H. (1981) Biochim. Biophys. Acta 647, 169–176.
25 Inui, K., Saito, H. and Hori, R. (1985) Biochem. J. 227, 199–203.
26 Lowry, O.H., Rosebrough, N.J., Farr, A.L. and Randall, R.J. (1951) J. Biol. Chem. 193, 265–275.
27 Sokol, P.P., Holohan, P.D. and Ross, C.R. (1988) J. Biol. Chem. 263, 7118–7123.
28 Passamonti, S., Battiston, L. and Sottocasa, G.L. (1990) Biochim. Biophys. Acta 1025, 122–126.
29 Julien, T., Betakis, E. and Zaki, L. (1990) Biochim. Biophys. Acta 1026, 43–50.
30 Damiano, E., Bassilana, M. and Leblanc, G. (1985) Eur. J. Biochem. 148, 183–188.
31 Grillo, F.G. and Aronson, P.S. (1986) J. Biol. Chem. 261, 1120–1125.
32 Ganapathy, V., Balkovetz, D.F., Ganapathy, M.E., Mahesh, V.B., Devoe, L.D. and Leibach, F.H. (1987) Biochem. J. 245, 473–477.
33 Kato, M., Maegawa, H., Okano, T., Inui, K. and Hori, R. (1989) J. Pharmacol. Exp. Ther. 251, 745–749.
34 Miyamoto, Y., Ganapathy, V. and Leibach, F.H. (1986) J. Biol. Chem. 261, 16133–16140.
35 Zimmerman, W.B., Byun, E., McKinney, T.D. and Sokol, P.P. (1991) J. Biol. Chem. 266, 5459–5463.
36 Saito, H., Yamamoto, M., Inui, K. and Hori, R. (1992) Am. J. Physiol. 262, C59-C66.
37 Takano, M., Okano, T., Inui, K. and Hori, R. (1989) J. Pharm. Pharmacol. 41, 795–796.
38 Takano, M., Kato, M., Takayama, A., Yasuhara, M., Inui, K. and Hori, R. (1992) Biochim. Biophys. Acta 1108, 133–139.