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Analysis of Cationic Amino Acid Transport Activity in Canine Lens Epithelial Cells

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Abstract: Cationic amino acid transport activity in a canine lens epithelial cells (LEC) line was investigated. The transporter activity of arginine was 0.424 ± 0.047 nmol/mg protein min, while the presence of N-ethylmaleimide, an inhibitor of the canine cationic amino acid transporter (CAT), reduced transport activity by 30%. A full-length cDNA sequence of canine *CAT1* was 2558 bp long and was predicted to encode the 629 amino acid polypeptides. The deduced amino acid sequence of canine *CAT1* showed similarities of 92.1% and 88.6% to those of the human and mouse, respectively. Western blot analysis detected a band at 70 kDa in a membrane protein sample of LEC. RT-PCR analysis confirmed that *CAT1* was ubiquitously detected in all tissues examined.

Key words: *CAT1*, cDNA sequence, distribution, lens epithelial cells

Introduction

Many amino acid transport systems have been distinguished based on differences in their substrate selectivity, ion-dependence, pH sensitivity, kinetics and regulatory properties, using membrane vesicle preparations or cultured cells [3, 4]. Among them, system y^+ was designated as a transporter of Na^+ -independent cationic amino acids. This designation is now attributed to what are termed cationic amino acid transporters (CAT), which belong to the SLC7 gene family. The family of CAT comprises four members, *CAT1*, *CAT2A*, *CAT2B* and *CAT3*, all of which exhibit a nearly identical substrate pattern for cationic L-amino acids [7, 11]. *CAT2A* and *CAT2B* are splice variants that differ only in a stretch of 42 amino acids [5–8, 17, 19]. *CAT1* is ubiquitously

expressed except in the liver. *CAT2A* is observed in the liver, skeletal muscle and pancreas, while *CAT2B* is an inducible isotype in many cell types. *CAT3* is observed in thymus, ovary, testis, and brain.

The prominent effect of proinflammatory cytokines is to induce cells expressing the inducible isoform of the nitric oxide synthase (NOS) family, the iNOS, which results in nitric oxide (NO) synthesis [15]. High production of NO functions as a local defense against bacteria [21]. This has been demonstrated in resistance to *Pseudomonas aeruginosa* ocular infection at the ocular surface [14]. A precursor for the synthesis of NO is the semi-essential amino acid L-arginine, which serves also as a component for protein synthesis. L-arginine becomes limited in inflammation because of the substrate competition between high iNOS expression and arginase

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(required for protein synthesis). Transport of L-arginine into the cell is enabled primarily by CAT.

Lens epithelial cells (LECs) are the progenitors of the lens fibers *in vivo* and undergo a developmental transition into fiber cells of the lens cortex, a process characterized by distinct biochemical and morphologic changes such as the synthesis of crystallin proteins, cell elongation, loss of cellular organelles, and disintegration of the nucleus [2]. In spite of the importance of cationic amino acids on the ocular surface, little information is available regarding cationic amino acid transport activity in canine LECs. Previously, we developed a lens epithelial cell line originated from a mature cataract of a dog and reported several characteristics of this cell line [18]. In the present study, we investigated the cationic amino acid transport activity of the lens epithelial cell line and determined the cDNA sequence of canine *CATI* as the first step in clarifying the relationship between *CAT* and the cationic amino acid metabolism on the canine ocular surface.

Materials and Methods

Animal and cell samples

All experiments were performed according to the guidelines of the Laboratory Animal Care Committee of Azabu University, and were in compliance with the Fundamental Guidelines for Proper Conduct of Animal Experiment and Related Activities in Academic Research Institutions. The canine lens epithelial cell line derived from a mature cataract was maintained as described previously [18]. The RNA samples for RT-PCR analysis were obtained from a healthy male Shiba dog (six years old).

Measurement of arginine transport activity

Radioactive (^3H -) arginine was purchased from American Radiolabeled Chemicals (St Louis, MO, USA). Arginine uptake of LEC was measured as described previously [18]. Briefly, the cells were plated in 5×10^5 cells/6-well plate 24 h before the experiment. After washing the cells, a medium containing $100 \mu\text{M}$ arginine with a radioisotope was added and incubated at 37°C for 10 min. To study the effect of N-ethylmaleimide (NEM) on the transport activity, pretreatment with 0.2 mM NEM for 10 min was carried out before incubation with medium containing radiolabeled arginine. Uptake was terminated by washing with ice-cold phosphate-buffered saline. After solubilizing the cells with 1% SDS, the

radioactivity was measured with a liquid scintillation counter, and the protein content was determined by the Micro BCA method. Arginine uptake was expressed as $\text{nmol/mg protein min}$. Arginine uptake of canine red blood cells was measured as described elsewhere [11].

Determination of cDNA sequence of canine CATI

Total RNA was isolated from the lens epithelial cell line established previously [24] using an RNA extraction solution (Isogen, Nippon Gene, Tokyo, Japan). The primers used in this study are shown in Table 1. The primer sets (s1 and a1) for amplification of a partial canine *CATI* cDNA were prepared from the conserved region sequences between humans and mice (DDBJ accession No. BC063303 and BC145779, respectively). RT-PCR amplification was performed employing a SuperScriptIII First-Strand Synthesis System kit (Invitrogen, Carlsbad, CA, USA) with Ex Taq Hot Start Version DNA polymerase (Takara Bio, Kyoto, Japan). The band was excised from the agarose gel and purified using a Wizard SV Gel and PCR Clean-Up System (Promega, Tokyo, Japan). The extracted and purified DNA were cloned into a pCR II-TOPO cloning vector (Invitrogen) and sequenced with a BigDye Terminator kit ver.3.1 Cycle Sequencing Kit (Applied Biosystems, Carlsbad, CA, USA). The nucleotide sequence obtained exhibited high similarities (90%) to human *CATI* cDNA sequences. In order to determine the 3' and 5' regions of cDNA, RACE methods were carried out using a SMARTer RACE cDNA Amplification kit (Clontech, Mountain View, CA, USA) and a set of canine *CATI* gene-specific primers (GSP1 and GSP2).

Western blot analysis of CATI protein in various canine tissues

The cell membrane of brain tissue for Western blot analysis was prepared as reported by Denker *et al.* [9]. In brief, LECs or cerebellums were homogenized at 4°C in buffer containing 0.1 M KCl , $5 \text{ mM Na}_2\text{HPO}_4$ pH 7.5, 0.75 mM Na-EGTA (pH 7.5), 1 mM DDT , 5 mM MgCl_2 , $200 \mu\text{g/ml}$ phenylmethylsulfonyl fluoride, and $4 \mu\text{g/ml}$ leupeptin. Homogenates were centrifuged for 10 min to remove debris. The 1-vol. supernatant was laid over a 5-vol. sucrose solution containing 0.8 mM sucrose and 2 mM Na-EGTA and was centrifuged at $32,000 \times g$ for 40 min. Protein concentration of the pellet was determined by the BCA method, and was used for Western blot analysis as previously described [24]. Briefly, the

Table 1. Sequences of oligonucleotides used in this study

Primer		Sequence (5'-3')	Expected product (bp)
Oligonucleotide for cloning of canine <i>CAT1</i>			
s1	Sense	CGGGCTCAGCITACCTCTACAGCT	
a1	Antisense	CAAAGAGGAAGGCCATCACAGCAGC	
(Human <i>CAT1</i> : BC063303)			
GSP1 (for 5' RACE)	Antisense	GTCCGCGAGAACTCCGCAATGGGTTTGC	
GSP2 (for 3' RACE)	Sense	AAGTATGCAGTGGCCGTCGGCTCCCTCT	
Oligonucleotide for RT-PCR			
<u>Transcript</u>			
<i>CAT1</i> (AB762780)	Sense	CGGGCTCAGCITACCTCTACAGCT	392
	Antisense	AGTGCCAATGGACATGAGGTCCACCA	
<i>GAPDH</i> (AB038240)	Sense	ATC ACC ATC TTC CAG GAG CGA GA	192
	Antisense	GTC TTC TGG GTG GCA GTG ATG G	

The accession number is indicated in parentheses.

membranes were solubilized, electrophoresed into 12% polyacrylamide gels, and immunoblotted with a chemiluminescence autoradiograph. They were then treated with the primary antibody (rabbit anti-human *CAT1*, $\times 1,000$, Proteintech, Chicago, IL, USA), followed by the secondary antibody (anti-rabbit IgG (H+L) goat IgG Fab' HRP, $\times 20,000$, Seikagaku Corp., Tokyo, Japan). The *CAT1* protein was detected with an ECL Plus a chemiluminescence detection system (GE Healthcare Bioscience, Chalfont, UK) and exposed to x-ray film.

RT-PCR analysis of *CAT1* mRNA in canine tissues

In order to examine the expression of *CAT1* mRNA in various organs of a dog, we performed RT-PCR using newly designed primers specific to canine *CAT1* (GSP1 and GSP2: Table 1). RT-PCR conditions were as follows: 94°C for 2 min and 30 cycles of three steps: 94°C for 10 s, 60°C for 10 s and 72°C 30 s.

Results

Arginine transport activity of the canine lens epithelial cell line is shown in Fig. 1 (A). The transport activity was 0.424 ± 0.047 nmol/mg protein min, while the presence of NEM, the inhibitor of *CAT*, significantly reduced arginine transport activity by 30%. Red blood cells of the canine showed 17.33 ± 0.46 μ mol/l cells h arginine transport activity. Likewise, NEM reduced cationic amino acid transport activity by about 38% (B). Fig. 2A (left) shows the electrophoresis of RT-PCR products of canine *CAT1* using primers (s-1 and a-1) that were well conserved between the human and rodent. The nucleotide sequence comprising 1070 bp showed high

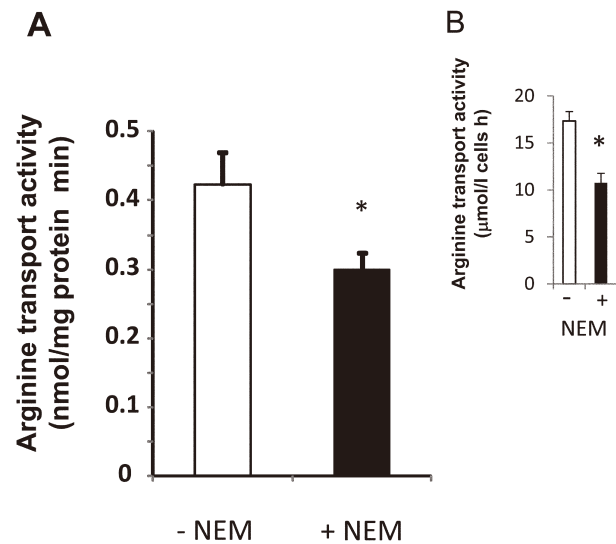


Fig. 1. Arginine transport activity of LECs (A) and red blood cells (B) in the presence (closed column) or absence (open column) of 0.1 mM NEM. Values are means and SD of 4 individual experiments. Statistical differences between the treatments were determined by the Student's *t*-test (* $P < 0.05$).

similarities (90%) to mouse *CAT1* cDNA sequences. The primers used for RACE were prepared from the sequence details listed in Table 1. Fig. 2A (right) also shows 3' and 5'RACE products. An obtained nucleotide sequence (DDBJ accession number AB762780) corresponding to a full-length canine *CAT1* cDNA was 2558 bp in length and contained an entire open reading frame of 1887 bp, encoding canine *CAT1* having 629 amino acids and a theoretical mass of 68 kDa (Fig. 2B). Figure 3 compares canine *CAT1* with those of reported in humans and rodents. The deduced amino acid sequence of *CAT1*

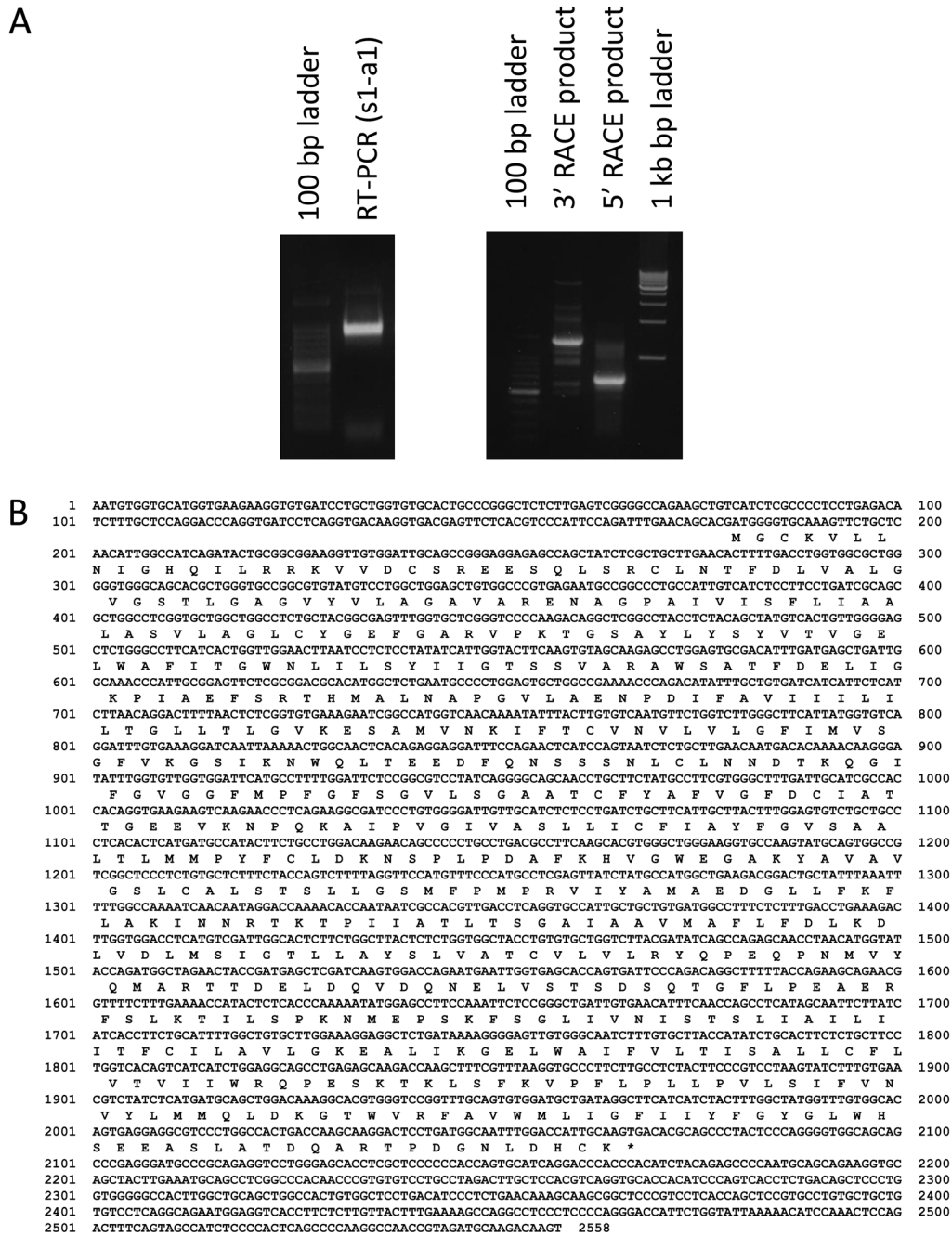


Fig. 2. PCR-based cloning of 5'- and 3'-stretched cDNA clones for canine *CAT1* (A). Electrophoresis of RT-PCR products of canine *CAT1* using primers (s-1 and a-1) that are well conserved between humans and rodents (A) (left). 5' and 3'RACE products with the primers shown in Table 1 (right). Nucleotide and deduced amino acid sequences of the canine are shown (B). Full-length canine *CAT1* cDNA was 2,558 bp in length and contained an entire open reading frame of 1,887 bp, encoding canine *CAT1*, which had 629 amino acids. The DDBJ accession number is AB762780. The termination codon is asterisked.

showed high similarities (92.1 and 88.6%) to those of the human and mouse, respectively. Canine *CAT1*, as found in humans, possesses a seven-amino acid insertion between amino acid 224 and 225, and a one-amino acid

insertion was found in between amino acid 231 and 232 of mouse *CAT1*. Canine *CAT1* possessed 14 membrane-spanning domains, conserved consensus sequences for N-glycosylation sites, and phosphorylation by protein



Fig. 3. Amino acid sequences of canine *CAT1* were compared with those of the human and mouse. Multiple sequence alignments were performed using the GENETYX software (ver. 10). Asterisks and dots indicate identical residues and conservative substitutions, respectively. Transmembrane domains are overlined.

kinase C (PKC) in a putative model according to Albritton *et al.* [1] (data not shown). Figure 4A shows RT-PCR analysis of *CAT1* expression in canine various tissues. A single distinct band was observed in all the tissues examined including the liver. Western blot analysis using anti-human *CAT1* detected a band at 70 kDa in the membrane of LECs (Fig. 4B).

Discussion

In this study, we investigated the cationic amino acid transport activity in canine LEC, found the NEM-sensitive Arg transport component, and determined a full-length cDNA sequence of canine *CAT1*. The deduced amino acid sequence of canine *CAT1* showed high similarities to those of the human and mouse. Glu¹⁰⁷ was reported to be essential for the transport activity of m*CAT1* [7] and it was also conserved in canine. RT-PCR analysis confirmed that *CAT1* was detected in all tissues examined including the liver. Western blot analysis using anti-human *CAT1* detected the band in 70 kDa in the membrane protein of LECs. It was reported that *CAT1* is expressed almost ubiquitously except in the adult liver, but its expression level varies considerably in dif-

ferent tissues and cell types [20]. RT-PCR analysis showed that *CAT1* expression was observed in all tissues examined including the liver in the canine (Fig. 4A).

Cationic amino acids supplied through the *CAT* proteins feed into protein synthesis and other enzymatic reactions dependent on them, including synthesis of nitric oxide (NO), urea, creatine and agmatine from arginine or synthesis of polyamines, proline and glutamine from ornithine. *CAT1* is the major cationic amino acid transporter in most cells. Notably, homozygous *CAT1* knockout mice die on day 1 after birth, are 25% smaller than their wild-type littermates, and suffer from severe anemia, while the heterozygous mice exhibit no phenotype abnormality [25]. *CAT1* expression can be modulated by a variety of stimuli including cell proliferation, growth factors, cytokines, and hormones. The transport activity of human *CAT1* is decreased after activation of protein kinase C (PKC) in human endothelial cells, indicating posttranslational regulation [13]. *CAT1* activity can also be modulated by interaction with cytoskeletal proteins [27]. Although there are some cationic amino acid transport systems, *CAT* is the only NEM-sensitive transport system [10]. So far it has not been determined whether or not NEM inhibits all *CAT* isoforms, and the

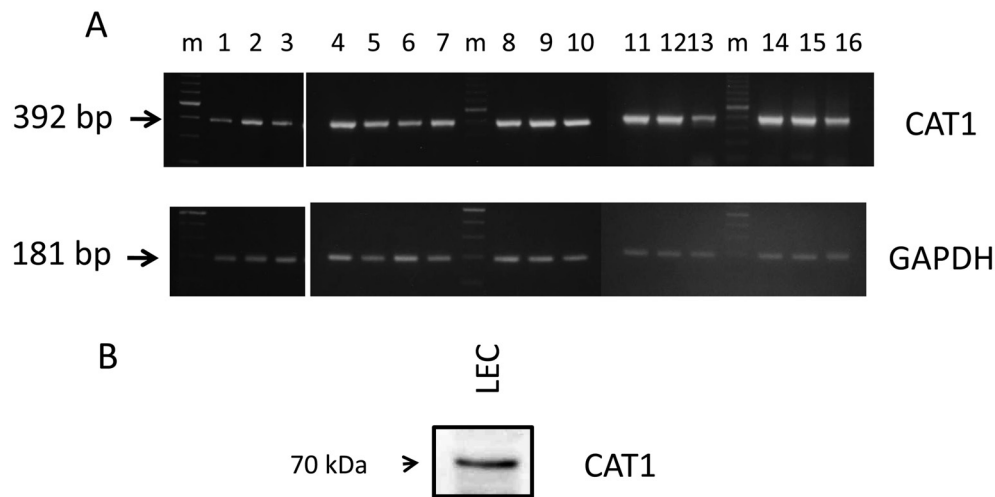


Fig. 4. RT-PCR analysis of canine *CAT1* mRNA in various dog tissues (A). Integrity of RNA was examined using glyceraldehyde-3-phosphate dehydrogenase (*GAPDH*). Lane 1, nictitating membrane gland; lane 2, lacrimal gland; lane 3, LECs; lane 4, cerebellum; lane 5, trachea; lane 6, kidney; lane 7, liver; lane 8, salivary gland; lane 9, lung; lane 10, testis; lane 11, heart; lane 12, ileum; lane 13, colon; lane 14, bladder; lane 15, skeletal muscle; lane 16, placenta. Western blot analysis of canine *CAT1* expression in the LEC membrane (20 μg) using anti-human *CAT1* antiserum (B).

cysteine residues in the *CAT* proteins sensitive to NEM have not yet been identified.

The ocular surface is constantly exposed to environmental pathogens, particularly those vulnerable to infection. An advanced immune defense system is therefore essential to protect the eyes from microbial attack. Defensins are a family of highly conserved arginine- and lysine-rich cationic proteins, which have an important role in combating microbial infection. They are essential components of the innate immune system and are the first line of defense against microbials on the ocular surface [12]. Defensins are attracted by the microbial membrane's negative charge and cause disruption by first binding and then intercalating, to form pores that destroy the integrity of the lipid layer. This dissipates the membrane potential and kills the cells [28]. Two groups of defensins are recognized in mammals: α -defensins, produced by neutrophils and the Paneth cell of the small intestine, and β -defensins secreted by epithelial-derived tissues. β -defensin production at mucosal surfaces is an important part of the innate immune system. In order to produce the defensins, the cells forming them require large amounts of L-arginine and lysine.

In this report, we investigated the cationic amino acid transport activity in canine LECs, found the NEM-sensitive Arg transport component, and determined a full-length cDNA sequence of canine *CAT1*. The deduced

amino acid sequence of canine *CAT1* showed high similarities to those of the human and mouse. RT-PCR analysis confirmed that *CAT1* was ubiquitously detected in all tissues examined including the liver. Interestingly, in diseases accompanied by L-arginine deficiency [16, 22], e.g., psoriasis, dry skin, and diabetes of rheumatoid arthritis, there is a significant association with increased β -defensin production as well as dry eye in humans [23, 26]. The data clarified in this paper may facilitate study of the cationic amino acid metabolism and disease on the canine ocular surface. We will next investigate the relationship between β -defensin expression and *CAT1* activity on microbial infectious conditions in LECs.

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References

1. Albritton, L.M., Tseng, L., Scadden, D., and Cunningham, J.M. 1989. A putative murine ecotropic retrovirus receptor gene encodes a multiple membrane-spanning protein and

- confers susceptibility to virus infection. *Cell* 57: 659–666. [CrossRef] [Medline]
2. Babizhayev, M.A. and Costa, E.B. 1994. Lipid peroxide and reactive oxygen species generating systems of the crystalline lens. *Biochim. Biophys. Acta* 1225: 326–337. [CrossRef] [Medline]
 3. Christensen, H.N., Handlogten, M.E., Lam, I., Tager, H.S., and Zand, R. 1969. A bicyclic amino acid to improve discriminations among transport systems. *J. Biol. Chem.* 244: 1510–1520. [Medline]
 4. Christensen, H.N. 1990. Role of amino acid transport and countertransport in nutrition and metabolism. *Physiol. Rev.* 70: 43–77. [Medline]
 5. Closs, E.I., Albritton, L.M., Kim, J.W., and Cunningham, J.M. 1993. Identification of a low affinity, high capacity transporter of cationic amino acids in mouse liver. *J. Biol. Chem.* 268: 7538–7544. [Medline]
 6. Closs, E.I., Gräf, P., Habermeier, A., Cunningham, J.M., and Förstermann, U. 1997. Human cationic amino acid transporters hCAT-1, hCAT-2A, and hCAT-2B: three related carriers with distinct transport properties. *Biochemistry* 36: 6462–6468. [CrossRef] [Medline]
 7. Closs, E.I. 2002. Expression, regulation and function of carrier proteins for cationic amino acids. *Curr. Opin. Nephrol. Hypertens.* 11: 99–107. [CrossRef] [Medline]
 8. Closs, E.I., Lyons, C.R., and Kelly, C. 1993. Cunningham JM. Characterization of the third member of the MCAT family of cationic amino acid transporters. Identification of a domain that determines the transport properties of the MCAT proteins. *J. Biol. Chem.* 268: 20796–20800. [Medline]
 9. Denker, B.M., Kwon, E.D., Kuhajda, F.P., and Agre, P. 1988. Identification, purification, and partial characterization of a novel Mr 28,000 integral membrane protein from erythrocytes and renal tubules. *J. Biol. Chem.* 263: 15634–15642. [Medline]
 10. Devés, R. and Boyd, C.A. 1998. Transporters for cationic amino acids in animal cells: discovery, structure, and function. *Physiol. Rev.* 78: 487–545. [Medline]
 11. Devés, R., Angelo, S., and Chávez, P. 1993. N-ethylmaleimide discriminates between two lysine transport systems in human erythrocytes. *J. Physiol.* 468: 753–766. [Medline]
 12. Garreis, F., Schlorf, T., Worlitzsch, D., Steven, P., Bräuer, L., Jäger, K., and Paulsen, F.P. 2010. Roles of human beta-defensins in innate immune defense at the ocular surface: arming and alarming corneal and conjunctival epithelial cells. *Histochem. Cell Biol.* 134: 59–73. [CrossRef] [Medline]
 13. Graf, P., Förstermann, U., and Closs, E.I. 2001. The transport activity of the human cationic amino acid transporter hCAT1-1 is down-regulated by the activation of protein kinase C. *Br. J. Pharmacol.* 132: 1193–1200. [CrossRef] [Medline]
 14. Hazlett, L.D., Mc, D., Clellan, S., Goshgarian, C., Huang, X., Thakur, A., and Barrett, R. 2005. The role of nitric oxide in resistance to *P. aeruginosa* ocular infection. *Ocul. Immunol. Inflamm.* 13: 279–288. [CrossRef] [Medline]
 15. Hoffmann, G., Schobersberger, W., Rieder, J., Smolny, M., Seibel, M., Fürhapter, C., and Fritsch, P. 1999. Human dermal microvascular endothelial cells express inducible nitric oxide synthase in vitro. *J. Invest. Dermatol.* 112: 387–390. [CrossRef] [Medline]
 16. Jaeger, K., Paulsen, F., and Wohlrab, J. 2008. Characterization of cationic amino acid transporters (hCATs) 1 and 2 in human skin. *Histochem. Cell Biol.* 129: 321–329. [CrossRef] [Medline]
 17. Kakuda, D.K., Finley, K.D., Dionne, V.E., and MacLeod, C.L. 1993. Two distinct gene products mediate γ^+ type cationic amino acid transport in *Xenopus* oocytes and show different tissue expression patterns. *Transgene* 1: 91–101.
 18. Kanemaki, N., Saito, M., Onda, K., Maruo, T., Ogiwara, K., Naya, Y., Morishita, T., and Ochiai, H. 2012. Establishment of a lens epithelial cell line from a canine mature cataract. *Exp. Anim.* 61: 41–47. [CrossRef] [Medline]
 19. Kavanaugh, M.P., Wang, H., Zhang, Z., Zhang, W., Wu, Y.N., Dechant, E., North, R.A., and Kabat, D. 1994. Control of cationic amino acid transport and retroviral receptor functions in a membrane protein family. *J. Biol. Chem.* 269: 15445–15450. [Medline]
 20. Kim, J.W., Closs, E.I., Albritton, L.M., and Cunningham, J.M. 1991. Transport of cationic amino acids by the mouse ecotropic retrovirus receptor. *Nature* 352: 725–728. [CrossRef] [Medline]
 21. Liew, F.Y. and Cox, F.E.G. 1991. Nonspecific defence mechanism: the role of nitric oxide. *Immunol. Today* 12: A17–A21. [CrossRef] [Medline]
 22. Lucotti, P., Setola, E., Monti, L.D., Galluccio, E., Costa, S., Sandoli, E.P., Fermo, I., Rabaiotti, G., Gatti, R., and Piatti, P. 2006. Beneficial effects of a long-term oral L-arginine treatment added to a hypocaloric diet and exercise training program in obese, insulin-resistant type 2 diabetic patients. *Am. J. Physiol. Endocrinol. Metab.* 291: E906–E912. [CrossRef] [Medline]
 23. McDermott, A.M. 2004. Defensins and other antimicrobial peptides at the ocular surface. *Ocul. Surf.* 2: 229–247. [CrossRef] [Medline]
 24. Ochiai, H., Saito, M., Maruo, T., and Kanemaki, N. 2010. Molecular cloning of canine excitatory amino acid transporter 5 and its detection in primary lens epithelial cells. *Exp. Anim.* 59: 449–457. [CrossRef] [Medline]
 25. Perkins, C.P., Mar, V., Shutter, J.R., del Castillo, J., Danilenko, D.M., Medlock, E.S., Ponting, I.L., Graham, M., Stark, K.L., Zuo, Y., Cunningham, J.M., and Bosselman, R.A. 1997. Anemia and perinatal death result from loss of the murine ecotropic retrovirus receptor mCAT-1. *Genes. Dev.* 11: 914–925. [CrossRef] [Medline]
 26. Rahman, A., Yahya, K., Ahmed, T., and Sharif-Ul-Hasan, K. 2007. Diagnostic value of tear films tests in type 2 diabetes. *J. Pak. Med. Assoc.* 57: 577–581. [Medline]
 27. Zharikov, S.I., Sigova, A.A., Chen, S., Bubb, M.R., and Block, E.R. 2001. Cytoskeletal regulation of the L-arginine/NO pathway in pulmonary artery endothelial cells. *Am. J. Physiol. Lung Cell Mol. Physiol.* 280: L465–L473. [Medline]
 28. Zou, G., de Leeuw, E., Li, C., Pazgier, M., Li, C., Zeng, P., Lu, W.Y., Lubkowski, J., and Lu, W. 2007. Toward understanding the cationicity of defensins. Arg and Lys versus their noncoded analogs. *J. Biol. Chem.* 282: 19653–19665. [CrossRef] [Medline]