Table 1 Patient background

	TUR-BT	*Radical cystectomy*	P-*value*
No. of cases examined	44	37	
Gender			NS
Male	37 (84.1%)	33 (89.2%)	
Female	7 (15.9%)	4 (10.8%)	
Age (median)	66 (45–79)	66 (39–89)	NS
Pathological stage			$P<0.01$
pTa	14 (31.8%)	0 (0%)	
pT1	25 (56.8%)	11 (29.8%)	
pT2	4 (9.1%)	8 (21.6%)	
pT3	0 (0%)	10 (27.0%)	
pT4	1 (2.3%)	8 (21.6%)	
Hitological grade			$P<0.01$
G1	7 (14.9%)	0 (0%)	
G2	21 (51.1%)	2 (5.4%)	
G3	16 (34.0%)	35 (94.6%)	
Blood group			
A	38	34	
AB	6	3	

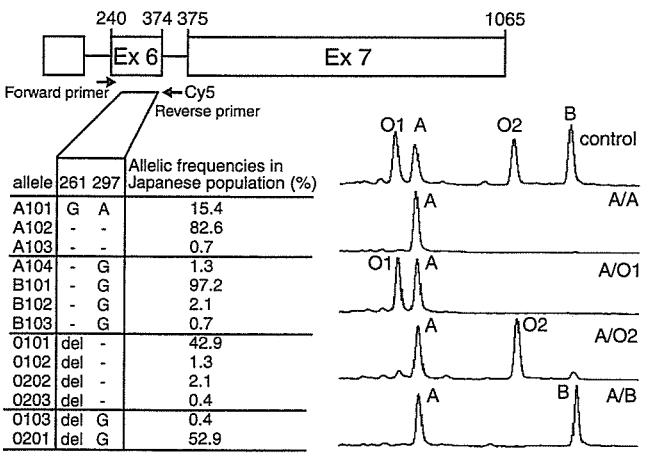
history, the proportion of cases with advanced stage or high-grade tumors was significantly higher in those who underwent radical cystectomy than those who underwent TUR ($P<0.01$). In 44 patients who underwent TUR, DNA was extracted from fresh specimens and normal DNA was extracted from peripheral blood lymphocytes (PBL) by a standard procedure using proteinase K digestion followed by phenol–chloroform extraction. In 37 cases that underwent radical cystectomy, a total of 1130 paraffin-embedded specimens obtained from mapping study of the bladder were histologically confirmed by hematoxylin and eosin staining as being composed of tumor, dysplasia and normal tissues. DNA was extracted from manually dissected tumors and corresponding normal tissues using DEXPAT (TAKARASHUZO Co., Ltd, Shiga, Japan) according to the manufacturer's recommendation.

Expression of Blood-Group A Antigen by Immunohistochemical Staining

In all, 4-μm-thick sections from formalin-fixed, paraffin-embedded specimens of resected tissues that underwent TUR or radical cystectomy were used for immunohistochemical staining (IHC). A mapping study of the bladder specimens revealed concomitant dysplastic lesions in 23 cases that underwent radical cystectomy, and they were then subjected to IHC performed as described previously.[24] Mouse monoclonal antibody (mAb) directed against A antigen (clone 81FR2.2; DAKO, Carpinteria, CA, USA) was used as the primary antibody and the avidin–biotin-conjugated immunoperoxidase technique was performed with a DAKO LSAB2 Kit (DAKO, Carpinteria, CA, USA). Reportedly, the specificity of the mAb 81FR2.2 was characterized by transfection experiment of the A-glycosyl transferase gene to the HeLa cell (genotype OO).[25] Erythrocytes, normal epithelium and vascular endothelium were used as internal positive controls, while muscle and connective tissues served as negative controls. To determine the specificity of A antigen, IHC was performed for normal urothelium of blood group B and O donors. Immunohistochemistry for A antigen was classified as follows: 'negative' if the section had no positively (0%) stained tumor cells, 'positive' if staining was seen across the section (>70% positively stained tumor cells), and 'heterogenous' if <70% of tumor cells stained positively. As to the correlation with A allelic loss or methylation status, cases showing positive or heterogenous expression were compared with those showing negative expression.

Allelic Status on 9q Loci Defined by Blunt-End Single-Strand DNA Conformation Polymorphism Analysis

LOH of the *ABO* gene locus was examined by blunt-end Single-strand DNA conformation polymorphism (SSCP) analysis,[26] using genetic polymorphisms at nucleotide positions 261 and 297 in exon 6 of the *ABO* gene. Genotypes and their allelic frequencies in Japanese population were previously reported[15] and shown in Figure 1. Four groups of alleles, A (A101, A102, A103), B (B101, B102, B103, A104), O1 (O101, O102, O202, O203) and O2 (O103, O201) were identified by the analysis of two genetic polymorphisms (nucleotides 261, 297) in exon 6 of the *ABO* gene. The 5′-terminus of the reverse primer



allele	261	297	Allelic frequencies in Japanese population (%)
A101	G	A	15.4
A102	-	-	82.6
A103	-	-	0.7
A104	-	G	1.3
B101	-	G	97.2
B102	-	G	2.1
B103	-	G	0.7
O101	del	-	42.9
O102	del	-	1.3
O202	del	-	2.1
O203	del	-	0.4
O103	del	G	0.4
O201	del	G	52.9

Figure 1 Schema of single nucleotide polymorphisms (SNPs) in exons 6 of the *ABO* gene and electropherogram of the blunt-end SSCP analysis showing examples of normal DNA from blood group A or A/B donors. SNPs in nucleotide positions 261 and 297 were used for analysis in this study. DNA variants and their allelic frequencies reported in the Japanese are indicated.[15] The blood group *O* gene has a single base deletion at position 261 resulting in a frame-shift mutation and causing protein termination at codon 117.

was labeled with Cy5 flourescent dye. The nucleotide sequences of the forward and reverse primers were 5′-TCTCCATGTGCAGTAGGAAGGATG-3′ and 5′Cy5-ATGGCAAACACAGTTAACCCAATG-3′, respectively. PCR conditions were as follows: 0.5–1.0 μg of genomic DNA as a template, 0.2 μmol/l of each primer, 0.125 mmol/l deoxynucleoside triphosohate (dNTP), 0.25 units of AmpliTaq Gold DNA polymerase (Perkin Elmer-Cetus, Norwalk, CT, USA) in a total reaction volume of 25 μl. After the first denaturation step at 95°C for 12 min, 40 cycles were performed for amplification consisting of 30 s at 95°C, annealing for 30 s at 57°C, and extension for 30 s at 72°C followed by a final extension at 72°C for 7 min. PCR products were then treated with Klenow fragment (TAKARA SHUZO Co., Ltd, Shiga, Japan) to generate DNA fragments with blunt ends. To 1 μl of each PCR product, 0.5 units of Klenow fragment was added, and the mixture was incubated at 37°C for 30 min. One microliter of this reaction mixture was diluted with 10 μl of loading solution (90% deionized formamide, 20 mM EDTA, 0.05% bromophenol blue) and heat denatured at 95°C for 5 min. An ALF red automated DNA sequencer™ (Pharmacia, Tokyo, Japan) was used for blunt-end SSCP analysis. One microliter of the diluted mixture was applied onto a 15% polyacrylamide gel (30:1, acrylamide:bisacrylamide ratio) containing Tris/glycine buffer (25 mM Tris, 192 mM glycine). Electrophoresis was performed at 30 W for 16 h using a continuous buffer system consisting of 25 mM Tris and 192 mM glycine. During electrophoresis, the gel was maintained at a constant temperature of 18°C by a circulating water bath. The data were analyzed using the ALF Win Fragment analyzer 1.02™ software package (Pharmacia, Tokyo, Japan). LOH was determined by measuring the signal ratio between the opposing alleles and defined as tumor cellularity according to the equation that we previously reported.[4,26,27] Supposing that the A1 allele is lost in a heterozygote carrying A1 and A2 alleles, T is the peak height of the signal from the tumor samples and N is the peak height of the signal from normal control. The tumor cellularity in the sample is thus given as follows:

$$\text{Tumor cellularity}\,(\%) = [(N_{A1}/N_{A2}) - (T_{A1}/T_{A2})]\times 100/(N_{A1}/N_{A2})$$

Genomic DNA from normal PBL was analyzed to set the cutoff values for tumor cellularity. As previously reported, the mean + 3s.d. values of the normal heterozygous DNA were used as a cutoff value for tumor cellularity, and tumor samples showing tumor cellularities above the cutoff level were considered to have LOHs.[4] A104 allele was indistinguishable from B allele in this analysis, while the observed frequency of the A104 allele in the Japanese is reported to be as low as 1.3%. In fact, in all samples tested, the genotypes coincided with the patient's ABO isotypes. In addition, two single base nucleotide polymorphism markers (*ALDOB*, 9q21.3 and *VAV2*, 9q34.1) were used to assess the allelic status on 9q according to the method that we previously reported;[4] the former is centromeric and the latter is telomeric to the *ABO* gene locus, respectively (Figure 4). Nucleotide sequences of the forward and reverse primers for *ALDOB* and *VAV2* were as follows: 5′Cy5-GGGCTTGACTTTC CAACACG-3′ and 5′-TCTAGCCTCAATCCTCATAC-3′ (*ALDOB*), 5′-GTGTCTGCACTGGCCACACT-3′ and 5′Cy5-TCCAAAGGACCTTCTCCAAA-3′ (*VAV2*).

Bisulfite PCR-SSCP Analysis and Methylation-Specific PCR

In cases that underwent TUR, methylation status in the promoter region of the *ABO* gene was analyzed by bisulfite PCR-SSCP (BiPS) and methylation specific PCR (MSP).[24,28,29] Seven primer sets were designed to amplify seven overlapping regions spanning the CpG island located from −765 to +21 relative to the translation start site (Figure 2). Primer sets *re 1* through *re 6* were designed for BiPS analysis and *RE7*.M and *RE7*.UM were for MSP. Bisulfite treatment was performed using the CpGenome DNA Modification Kit (Intergen Co., New York, NY, USA). In all, 1 μg of tumor-derived DNA was treated with Na-bisulfite according to the manufacturer's recommendations. PCRs were performed in 25 μl reaction volumes containing 10 × buffer, 1.0 μl bisulfite-modified DNA corresponding to 50 ng of genomic DNA as a template, 0.2 μmol/l of each primer, 0.125 mmol/l dNTP and 0.25 units of AmpliTaq Gold DNA polymerase. PCR conditions were 95°C for 9 min for heat denaturation, 40 cycles of 94°C for 1 min, 1 min at the different annealing temperatures for each primer set (Table 2), 72°C for 2 min for amplification, followed by a final extension at 72°C for 10 min. The BiPS procedure was performed as previously described.[28,29] Nondenaturing polyacrylamide gels of 8% for *re 2* and *re 6*, 10% for *re 1*, *re 4* and *re 5*, and 15% for *re 3* were used for the analysis. CpGenome™ Universal Methylated DNA (CHEMICON International, Temecula, CA, USA) was used as a positive control, and PBL obtained from healthy control donors were used as a negative control. When extra bands were observed, they were cut from the gels, reamplified and subjected to direct sequencing using ABI 3100 PRISM sequencer with a Big-Dye terminator sequencing kit (Perkin-Elmer). In analysis of cases that underwent radical cystectomy, BiPS analysis was not employed due to the technical difficulty for reliable amplification of relatively long sized DNA fragments from formalin-fixed paraffin-embedded sections. In cases that underwent radical cystectomy, methylation status was assessed by MSP of region 7, the most proximal to the translation start site. The size of the PCR product was as short as 96 bp and amplifiable from archival samples with

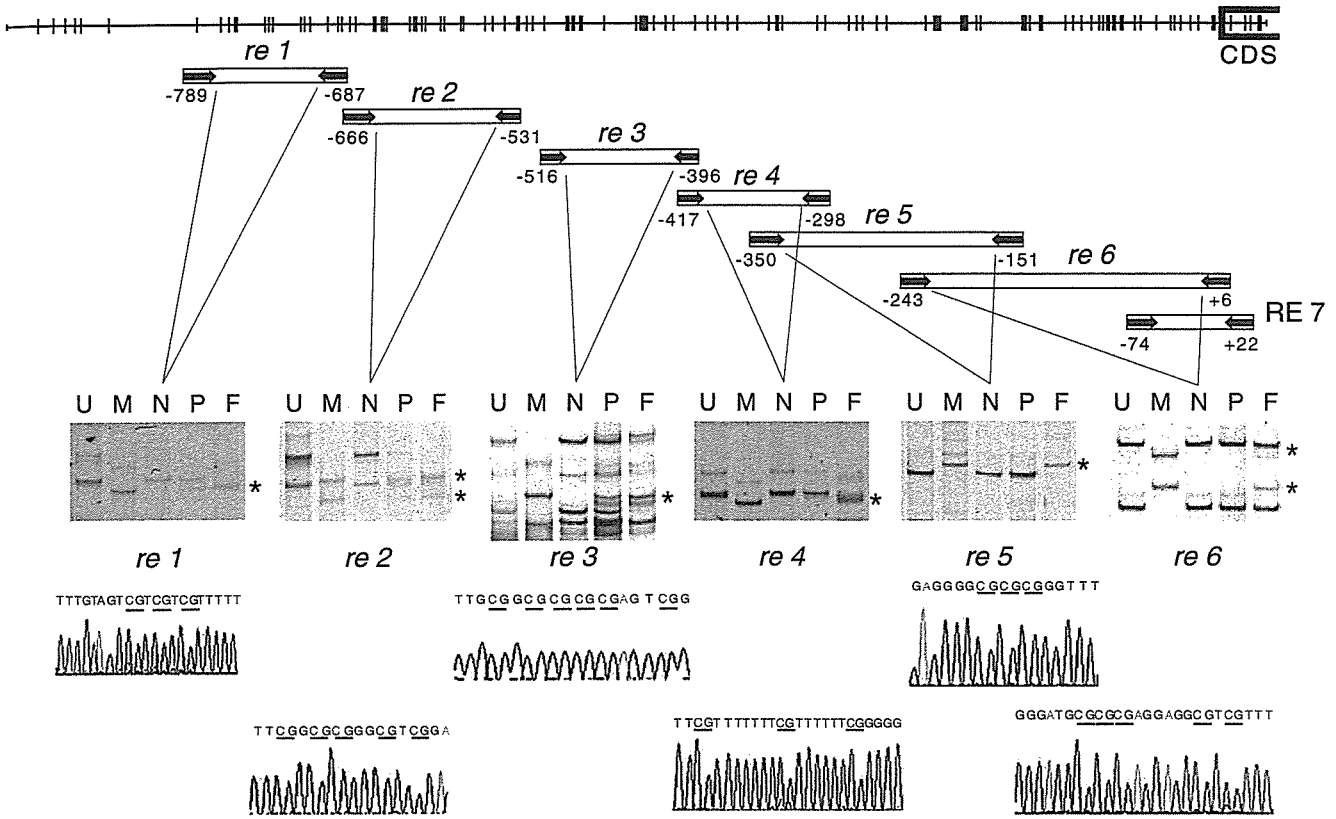


Figure 2 Map of the 5′ CpG island of the *ABO* gene and result of BiPS analysis. (Top) CpG sites in the promoter region of the *ABO* gene are indicated by vertical lines. (Middle) The amplified DNA fragments from regions 1 to 7 are indicated. PCR primer set of each region was indicated by arrows. (Bottom) BiPS analysis of the *ABO* gene. Extra bands are indicated by asterisks. After SSCP analysis, the extra bands were excised from gels, reamplified by PCR, and sequenced. Results of the direct sequencing of the case with full methylation were shown in the lower panel. U: unmethylated control, M: methylated control, N: no methylation, P: partial methylation, F: full methylation, *extra band showing mobility shift.

Table 2 Primer sequences for BiPS analysis and MSP

Primer name	*Forward primer sequence*	*Reverse primer sequence*	*Products length (bp)*	*No. of CpG sites*	*Annealing temperature (°C)*
re 1	5′-TTGGGATTTTTCGGGAGGTAATTT-3′	5′-CCCCGCTACGACCCCCGCCCTTAC-3′	103	11	54
re 2	5′-GGGCGGAGCGGGGTTTTGTTTACG-3′	5′-CGCGACCCCACGAAACTCTACGTC-3′	136	20	48
re 3	5′-AGCGATTTTGTTTAGGGGGA-3′	5′-ACTACGACCCCAAAACCCAC-3′	121	15	59
re 4	5′-TCGTGGGTTTTGGGGTCGTAGTTT-3′	5′-CCCCGTCCCCGAAAACCCCTTAAC-3′	120	11	54
re 5	5′-GGGGGTCGTTTTCGTTCGGGAGAT-3′	5′-CGAATCCCCAAAAACCCCTACTAA-3′	200	19	48
re 6	5′-TAAGGTATTAGGGTTACGAGG-3′	5′-GACCATAACTCCGCGTCTAAT-3′	248	33	49
RE 7.M	5′-GAGGGGGCGTTTCGGGTTTATTTC-3′	5′-ACGTCCGCAACACCTCGACCATAA-3′	96	16	70
RE 7.UM	5′-GGAGGGGGTGTTTTGGGTTTA-3′	5′-ATCCACAACACCTCAACCATAACT-3′	96	13	60

M, methylated; UM, unmethylated.

relative ease; however, five out of 37 cases that underwent radical cystectomy failed in PCR amplification. Methylation status of region 7 was used as the surrogate indicator for extensive methylation of the CpG sites or full methylation.

Statistical Analysis

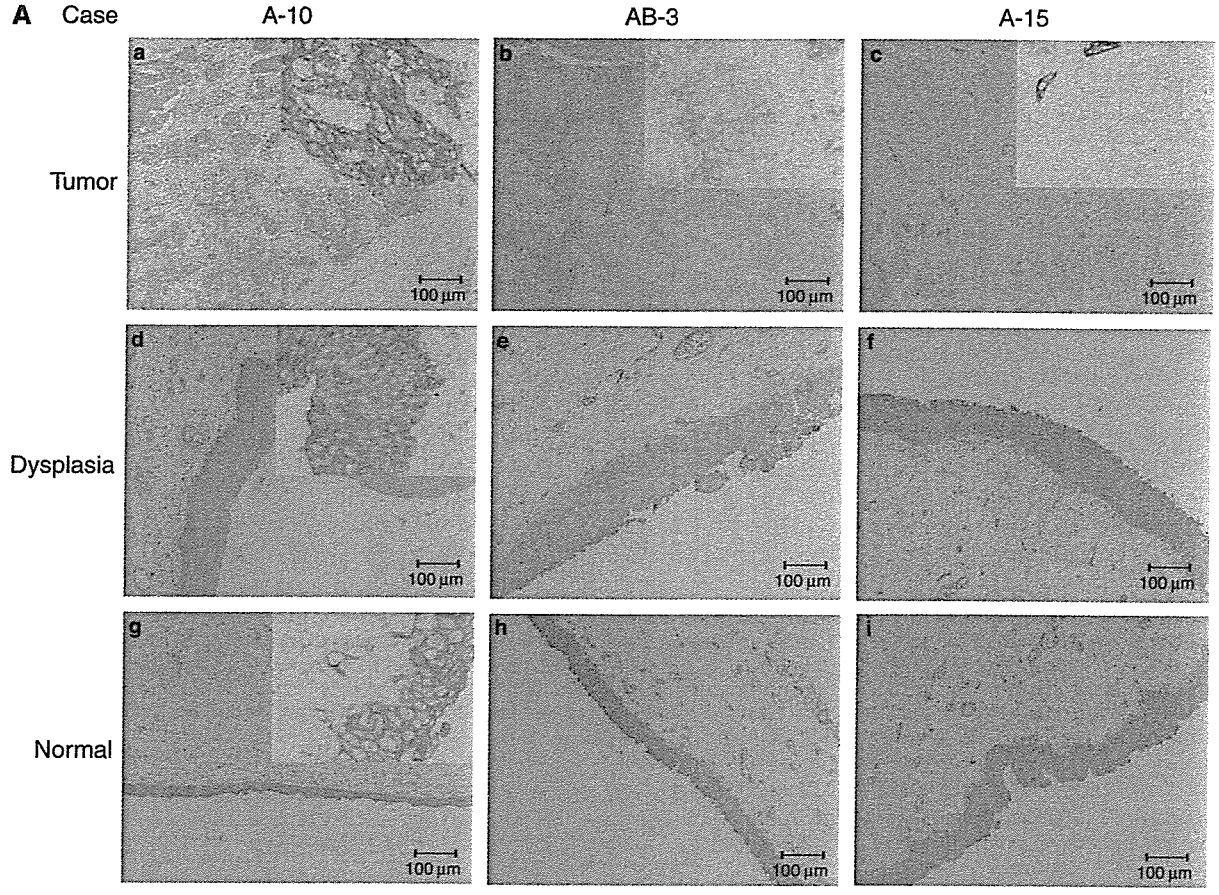
Statistical analysis was performed using a likelihood χ^2 analysis or Fisher's exact test. Probability (P) values of <0.05 were considered to be significant.

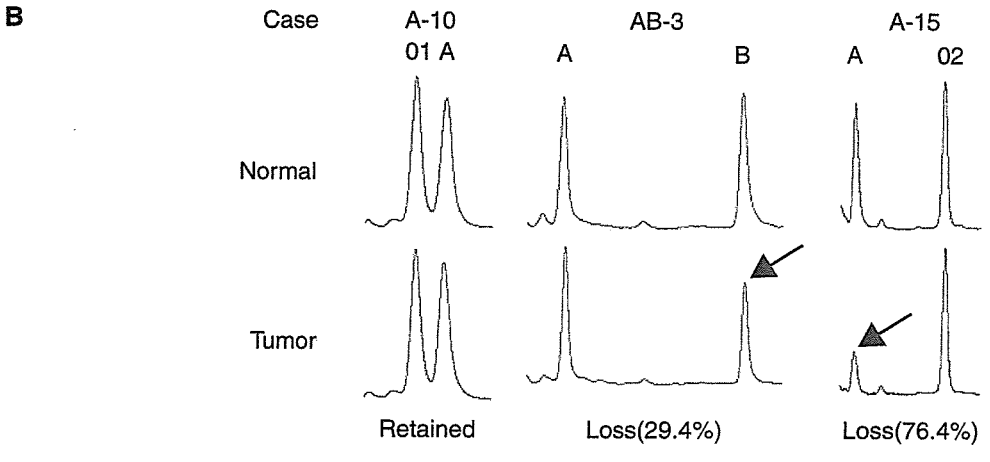
Results

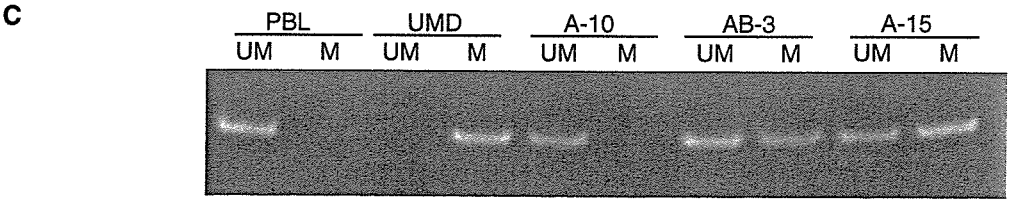
Expression of the A Antigen in TCC of the Bladder by IHC

Expression of the A antigen in tumor and normal urothelium was examined by IHC (Figure 3A). The corresponding staining of A antigen on the normal

urothelium from histo-blood-group B or O donors resulted in background levels only (data not shown). All of the normal urothelium from blood-group A individuals stained positively. The numbers of cases showing positive, heterogeneous and negative staining were 11 (25.0%), 11 (25.0%) and 22 (50.0%) in 44 tumor specimens that underwent TUR, while they were 14 (37.8%), 5 (13.5%) and 18 (48.6%) in 37 tumor specimens that underwent radical cystectomy. The overall frequencies of negative A antigen







expression were 35.7% (5/14) for pTa, 58.3% (21/36) for pT1, 25.0% (3/12) for pT2, 40.0% (4/10) for pT3 and 77.8% (7/9) for pT4 stages, and 71.4% (5/7), 43.5% (10/23) and 49.0% (25/51) for Grade 1, 2 and 3 tumors, respectively. There were no significant differences between A antigen expression and tumor stages or histological grades.

LOH on 9q in TCC of the Bladder

Allelic status of the *ABO* gene and neighboring loci were analyzed by blunt-end SSCP analysis using three polymorphic markers (*ABO* (9q34.1), *ALDOB* (9q21.3-22.2), *VAV2* (9q34.1)) (Figure 4). Heterozygosity of each locus was 87.7% (71/81) for *ABO*, 52.6% (41/78) for *ALDOB* and 48.1% (38/79) for *VAV2*, respectively. As all samples were derived from patients with an A or AB blood group, heterozygosity at the *ABO* locus was highest of all the loci examined. Genotypes of the *ABO* gene were classified into four groups, that is, A/A ($n=10$), A/O1 ($n=34$), A/O2 ($n=26$) and A/B ($n=9$). The cutoff value for tumor cellularity in each genotype was defined as the mean + 3s.d. of the normal DNA samples: 20% for A/O1, 22% for A/O2, 26% for A/B, respectively. In 44 cases that underwent TUR, frequencies of LOH were 53.7% (22/41) for *ABO*, 43.5% (10/23) for *ALDOB* and 50.0% (10/20) for *VAV2*, respectively. Frequencies of allelic loss at the *ABO* locus were 23.1% (9/39), 33.4% (6/18), 33.3% (5/15) and 33.3% (2/6) for A, O1, O2 and B allele, respectively. In 37 cases that underwent radical cystectomy, frequencies of LOH were 76.7% (23/30) for *ABO*, 77.8% (14/18) for *ALDOB* and 83.3% (15/18) for *VAV2*, respectively. Frequencies of allelic loss in the *ABO* locus was 23.3% (7/30), 50.0% (8/16), 54.5% (6/11) and 66.7% (2/3) for A, O1, O2 and B allele, respectively. There were no significant differences as to the frequencies of LOH between three markers and between four alleles of the *ABO* gene. Frequencies of LOH were higher in cases that underwent radical cystectomy as compared to the TUR cases, that is, 76.7% (23/30) *vs* 53.7% (22/41) for *ABO* ($P=0.08$), 77.8% (14/18) *vs* 43.5% (10/23) for *ALDOB* ($P=0.054$) and 83.3% (15/18) *vs* 50.0% (10/20) for *VAV2* ($P=0.043$), among which VAV2 locus showed statistical significance.

Methylation Status of the *ABO* Gene Promoter Region

CpG island of the *ABO* gene extends from 0.7 kb upstream to 0.6kb downstream from the translation start site in exon 1. Reportedly, the promoter region of the *ABO* gene is located between −117 and +31 from the translation start site, of which hypermethylation regulates gene expression.[19,20] In the present study, we divided CpG island spanning −789 to +6 into six regions and examined the methylation status by BiPS analysis (Figure 2). In the preliminary experiment, methylated DNA could be identified as the extra band, if more than 25% of the template DNA was methylated (data not shown). Methylation patterns were defined as follows: full methylation if all regions showed methylation, partial methylation if at least one region showed methylation and no methylation. A total of 44 TUR cases were analyzed, and we assessed the correlation between methylation status and expression levels of the A antigen using a panel of 35 cases, for nine cases showing LOH of the A allele were not included in the first assessment (Tables 3 and 4). Frequencies of methylation in *re 1* through *re 6* were 17.1% (6/35), 28.6% (10/35), 34.3% (12/35), 11.4% (4/35), 14.3% (5/35) and 11.4% (4/35), respectively (Table 4). In *re 4*, *re 5* and *re 6*, methylation was not detected in all cases showing positive or heterogenous expression and expression of the A antigen was negative in four cases showing full methylation. Frequencies of cases showing negative A antigen expression were 100% (4/4) in full methylation, 66.7% (6/9) in partial methylation and 27.3% (6/22) in no methylation and significant association was observed between methylation status (full, partial and no methylation) and expression of the A antigen ($P=0.0093$) (Table 4). In analysis using MSP, methylation of *RE 7* was observed in nine cases, of which six cases showed full or partial methylation in BiPS analysis and the expression of the A antigen was negative in these six cases (Table 3). Discrepancies between MSP and BiPS analysis were shown in three cases, which showed methylation only in MSP and heterogeneous expression of the A antigen. Positive expression of the A antigen was found in 11 cases, in which two cases showed methylation of regions 1 through 3 by BiPS analysis and no cases showed methylation of *RE 7* by MSP (Table 3).

Correlation of the Expression of A Antigen with A Allelic Loss and Hypermethylation of the *ABO* Gene Promoter Region

In analysis of 44 cases that underwent TUR, loss of the A allele was observed in nine cases, among

Figure 3 Expression of the blood-group A antigen, allelic status of the *ABO* gene and MSP of region 7 in cases that underwent radical cystectomy. (**A**) Immunostaining of A antigen in tumor (a, b, c), dysplasia (d, e, f), and corresponding normal urothelium (g, h, I) from cases A-10, AB-3 and A-15, respectively. A-10 showed positive staining in tumor (a), dysplasia (d) and normal urothelium (g), while the tumor section showed heterogeneous staining for the case AB-3 (b), and negative staining for the case A-15 (c). Normal urothelium from cases A-10 (g), AB-3 (h) and A-15 (i) stained positively. Reduced from × 100. High magnification view (× 400) was shown as inset. (**B, C**) Analysis of LOH of the *ABO* gene locus using blunt-end SSCP and methylation status by MSP (*RE 7*). A-10 showed the expression of the A antigen in tumor tissue, no allelic loss and unmethylated CpG sites. AB-3 showed heterogenous expression of the A antigen and methylation of the *ABO* gene, while the A allele was retained. A-15 showed negative expression of the A antigen, loss of A alleles and methylation of the *ABO* gene.

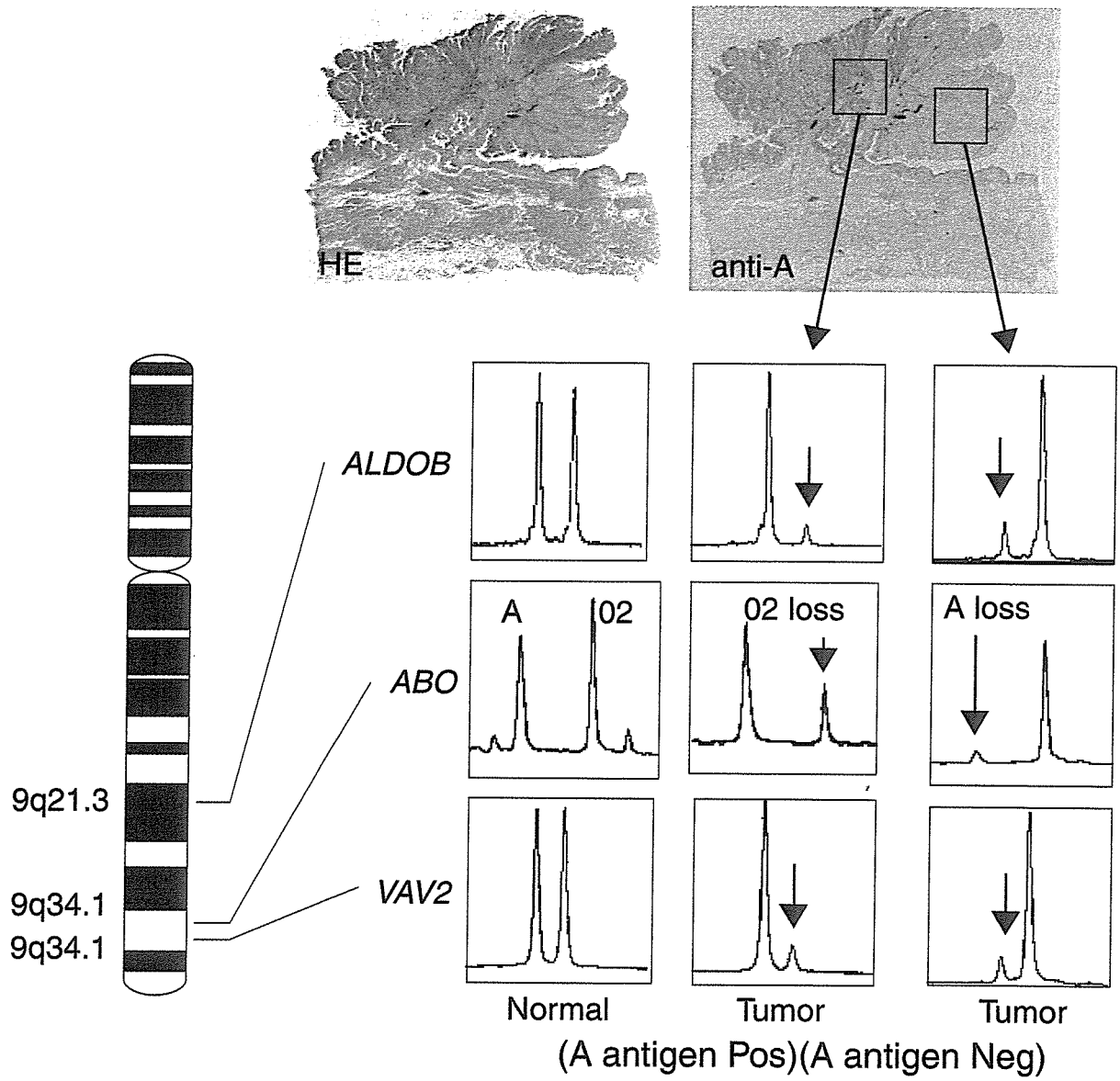


Figure 4 A case of bladder cancer showing chimeric expression of the A antigen. DNA was extracted from areas showing positive or negative A antigen expression and subjected to blunt-end SSCP analysis using three single nucleotide polymorphic markers (*ALDOB*, *ABO* and *VAV2*) on 9q. The patient's genotype was A/O2. A allele was lost in the sample taken from the area showing negative A antigen expression, while O2 allele was lost in the sample taken from the area showing positive A antigen expression. Note that two polymorphic loci (*ALDOB*, 9q21.3 centromeric to the *ABO* locus and *VAV2*, 9q34.1 telomeric to the *ABO* locus) also showed LOH and suggested a large regional chromosome deletion, while the parental origin of the lost allele in these two loci was different between areas showing A-antigen positive or negative expression.

which six cases showed negative and three cases showed heterogenous expression of the A antigen (Table 5). Cases homozygous for A allele were regarded as retaining at least one copy of the *ABO* gene. No statistical association was found between the expression level of the A antigen and A allelic loss ($P=0.26$). In BiPS analysis, expression of the A antigen was negative in all of the four cases with full methylation and statistical association was shown between the expression of the A antigen and methylation status ($P=0.035$). Taking A allelic loss or full methylation in combination, 76.9% (10/13) cases with A allelic loss and/or full methylation showed negative A antigen expression, while the expression of the A antigen was negative in 38.7% (12/31) of cases that retained A allele and showed partial or no methylation. Cases with A allelic loss and/or full methylation showed significant correlation with negative A antigen expression ($P=0.02$) (Table 5). In analysis of 37 cases that underwent radical cystectomy, A allelic loss was observed in seven cases and they all showed negative A antigen expression in the tumor (Table 6). Compared with 30 cases that retained the A allele (including A/A

Table 3 Methylation status in the *ABO* gene promoter region and expression of A antigen

No.	*Case*	*Genotype*	*LOH*[a]	*Methylation status*[b]	*Methylation status (%)*[c]						*RE 7*[d]	*Expression of A antigen*
					re 1	*re* 2	*re* 3	*re* 4	*re* 5	*re* 6		
1	37	A/O2	O2	Full	+(100)	+(100)	+(100)	+(100)	+(100)	+(71)	+	−
2	65	A/B	B	Full	+(100)	+(100)	+(100)	+(86)	+(100)	+(97)	+	−
3	72	A/O1	O1	Full	+(70)	+(62)	+(85)	+(57)	+(87)	+(61)	+	−
4	228	A/B	Ret	Full	+(100)	+(100)	+(100)	+(100)	+(100)	+(100)	+	−
5	85	A/O1	O1	Partial	−	+(85)	+(69)	−	+(100)	+(100)	+	−
6	235	A/O1	O1	Partial	−	+(85)	+(100)	−	−	−	+	−
7	10	A/O2	Ret	Partial	−	−	+(23)	−	−	−	−	−
8	186	A/O2	Ret	Partial	−	+(62)	+(38)	−	−	−	−	−
9	220	A/O1	O1	Partial	−	−	+(62)	−	−	−	−	−
10	229	A/O1	O1	Partial	−	−	+(46)	−	−	−	−	−
11	226	A/O2	Ret	Partial	−	−	+(62)	−	−	−	−	+/−
12	40	A/O1	Ret	Partial	+(100)	+(100)	+(100)	−	−	−	−	+
13	141	A/O2	O2	Partial	+(100)	+(100)	+(100)	−	−	−	−	+
14	5	A/O2	O2	No	−	−	−	−	−	−	−	−
15	43	A/O1	O1	No	−	−	−	−	−	−	−	−
16	77	A/O2	O2	No	−	−	−	−	−	−	−	−
17	97	A/O2	O2	No	−	−	−	−	−	−	−	−
18	195	A/O1	Ret	No	−	−	−	−	−	−	−	−
19	7	A/A	NI	No	−	−	−	−	−	−	−	−
20	71	A/B	B	No	−	−	−	−	−	−	+	+/−
21	184	A/O2	O2	No	−	−	−	−	−	−	+	+/−
22	183	A/B	Ret	No	−	−	−	−	−	−	+	+/−
23	212	A/O2	Ret	No	−	−	−	−	−	−	−	+/−
24	225	A/B	Ret	No	−	−	−	−	−	−	−	+/−
25	3	A/A	NI	No	−	−	−	−	−	−	−	+/−
26	98	A/A	NI	No	−	−	−	−	−	−	−	+/−
27	78	A/O2	Ret	No	−	−	−	−	−	−	−	+
28	79	A/O2	Ret	No	−	−	−	−	−	−	−	+
29	94	A/O1	Ret	No	−	−	−	−	−	−	−	+
30	185	A/O2	Ret	No	−	−	−	−	−	−	−	+
31	193	A/B	Ret	No	−	−	−	−	−	−	−	+
32	221	A/O1	Ret	No	−	−	−	−	−	−	−	+
33	222	A/O2	Ret	No	−	−	−	−	−	−	−	+
34	45	A/A	NI	No	−	−	−	−	−	−	−	+
35	80	A/A	NI	No	−	−	−	−	−	−	−	+

[a]The cases in which A allele was retained were shown.
[b]Full methylation indicates all the regions were methylated, Partial; at least one regions were methylated, No; all the regions were ummethylated by SSCP analysis.
[c]Numbers in parentheses indicate the proportion of CpG sites methylated in the amplified DNA fragments.
[d]Methylation was analyzed using MSP.

Table 4 Correlation of the expression of A antigen with methylation status in 35 cases underwent TUR

Expression of A antigen	*Each locus (Nos. methylated/nos. unmethylated)*						*All loci*			P
	re 1	*re* 2	*re* 3	*re* 4	*re* 5	*re* 6	*Full*	*Partial*	*None*	
Positive/Hetero	2/17	2/17	3/16	0/16	0/16	0/16	0	3	16	0.0093
Negative	4/12	8/8	9/7	4/12	5/11	4/12	4	6	6	

Among 44 cases that underwent TUR, nine cases showing loss of A allele were not included in Table 4.
Hetero: heterogenous expression.

homozygotes), the frequency of A antigen expression was significantly low in those showing A allelic loss ($P=0.003$) (Table 6). MSP of *RE 7* showed methylation in seven cases (18.9%) in which the expression of the A antigen was negative in six cases. Methylation status was significantly correlated with negative expression of the A antigen ($P=0.03$). Taking A allelic loss and methylation in combination, 91% (10/11) of cases with A allelic loss and/or methylation were negative for the A antigen expression, while the expression of the A antigen was negative in 23.8% (5/21) of cases

Table 5 Correlation of the expression of A antigen with A alleleic loss and hypermethylation of the *ABO* gene promoter region in 44 cases that underwent TUR

Expression of A antigen	*A allele*		P	*Full methylation*	*Partial or no methylation*	P	*A loss and/or full methylation*[a]	*A retained and partial/ no methylation*	P
	Loss	*Retain*							
Positive/ Hetero	3	19	0.26	0	22	0.035	3	19	0.02
Negative	6	16		4	18		10	12	

[a]The cases that showed loss of A allele and/or full and partial methylation.
Hetero: heterogenous expression.

Table 6 Correlation of the expression of A antigen with A allele loss and/or hypermethylation of the *ABO* gene promoter region in 37 cases that underwent radical cystectomy

Expression of A antigen	*A allele*		P	*MSP (RE 7)*		P	*A loss and/or methylated*	*A retain and unmethylated*	P
	Loss	*retain*		*M*	*UM*				
Positive/heterogenous	0	19	0.003	1	16[a]	0.03	1	16	0.0005
Negative	7	11		6	9[b]		10	5	

[a]Two cases were not available.
[b]Three cases were not available.
M, methylated; UM, unmethylated.

showing retained A allele and no methylation. A allelic loss and methylation were significantly correlated with the expression level of the A antigen ($P=0.0005$) (Table 6). In one case, the expression of the A antigen was chimeric and the tumor was divided into areas showing positive or negative expression (Figure 4). This case was an A/O2 heterozygote, and the allelic status was determined from the dissected specimen. O2 allele was lost in the area showing positive staining, while the A allele was lost in the area showing negative staining. Allelic status was also examined in the *ALDOB* and *VAV2* loci, where the parental origin of the lost allele was different between positively and negatively stained areas, indicating that allelic loss in the tumor involved large chromosomal region between 9q21.3 and 9q34.1.

Expression of the A Antigen in Dysplasia and Normal Urothelium

A total of 23 cases that underwent radical cystectomy were examined for expression of the A antigen in concomitant dysplastic lesions and normal urothelium (Table 7). In analysis of 13 cases showing positive A antigen expression in the tumor, A allele was retained in all cases and only one case showed hypermethylation together with normal expression of the A antigen in the dysplasia specimen. In analysis of 10 cases showing negative expression of the A antigen in the tumor, eight showed A allelic loss and/or methylation. Abnormal expression of the A antigen was observed only in one case (A-9), in which dysplasia specimen showed heterogeneous expression but A allelic loss and methylation were not observed in the tumor.

Discussion

Previously, we reported that LOH on chromosome 9 was a frequent genetic event in TCCs of the bladder and its detection in urine samples would be an useful indicator for tumor recurrence in patients with TCC that underwent TUR.[4] Frequencies of LOH of the *ABO* locus examined in this study seems higher than those reported previously.[17,18] In previous studies, allelic status of the *ABO* gene was examined by PCR/RFLP; however, LOH is barely detectable by PCR/RFLP if the proportion of tumor cells in the sample is below 60%, due to the formation of heteroduplex dimers that are resistant to the restriction enzyme digestion.[30] Blunt-end SSCP analysis is a sensitive method to detect an LOH from clinical samples, of which the proportion of tumor cells is as low as 10–20%.[26] However, LOH study from small lesions such as concomitant dysplasia was still difficult due to technical problems. Slebos *et al*[31] reported that the lower the amount of DNA in the PCR, the greater the risk for allele ratios that were abnormal due to a chance distribution of alleles in the reaction and the DNA equivalent of a minimum of about 100 cells is required for a full representation of both alleles in the analysis. Furthermore, DNAs extracted from formalin-fixed paraffin-embedded sections often harbor degradation and fail in the PCR amplifica-

Table 7 Correlation of the expression of A antigen in the tumor, dysplasia and normal urothelium specimens with the genetic and epigenetic changes in the primary tumor

Case	*Genotype*	*Tumor*			*Dysplasia expression*	*Urothelium expression*
		Expression	*LOH*	*Methylation status*		
A-22	A/O1	Positive	O1	M	Positive	Positive
A-1	A/O2	Positive	O2	UM	Positive	Positive
A-10	A/O2	Positive	O2	UM	Positive	Positive
A-3	A/O2	Positive	O2	UM	Positive	Positive
A-46	A/O2	Positive	O2	UM	Positive	Positive
A-5	A/O1	Positive	Ret	UM	Positive	Positive
A-43	A/O1	Positive	Ret	UM	Positive	Positive
AB-5	A/B	Positive	Ret	UM	Positive	Positive
A-5	A/O1	Positive	Ret	UM	Positive	Positive
A-18	A/O1	Positive	Ret	NA	Positive	Positive
A-29	A/A	Positive	NI	UM	Positive	Positive
A-47	A/A	Positive	NI	UM	Positive	Positive
A-14	A/A	Positive	NI	NA	Positive	Positive
A-15	A/O2	Negative	A	M	Positive	Positive
A-16	A/O2	Negative	A	M	Positive	Positive
A-48	A/O2	Negative	A	M	Positive	Positive
A-2	A/O2	Negative	A	UM	Positive	Positive
A-31	A/O1	Negative	A	UM	Positive	Positive
A-6	A/O1	Negative	A	NA	Positive	Positive
A-13	A/O1	Negative	O1	M	Positive	Positive
A-9	A/O1	Negative	O1	UM	Hetero	Positive
A-33	A/O2	Negative	O2	NA	Positive	Positive
AB-2	A/B	Negative	B	M	Positive	Positive

UM and M indicate whether the *RE 7* sequences were unmethylated and methylated, respectively; Hetero: heterogenous expression; NA: not applicable.

tion, suggesting potential difficulty in assessing the allelic status of small lesions from archival materials. The aim of the present study was to elucidate the underlying mechanisms of reduced expression of the histo-blood group A antigen in bladder cancer, and to determine if IHC of the A antigen expression could be available as a hallmark to determine the allelic loss and/or epigenetic alterations of the *ABO* gene on a cell-to-cell basis.

In cases with radical cystectomy, allelic status was examined using DNAs extracted from histological slides and directly comparable with the A antigen expression in the same specimen and expression of the A antigen was negative in all cases showing A allelic loss. In cases that underwent TUR, three cases showed heterogenous expression of the A antigen, regardless of A allelic loss in the sample. In TUR cases, DNAs were extracted from fresh frozen samples obtained by cold-cup biopsies, while the expression of the A antigen was examined in formalin-fixed paraffin-embedded sections of the resected tumors. Discrepancies between A allelic loss and A antigen expression in TUR cases may be explained by the difference of materials subjected to analysis. As we indicated in Figure 4, some tumors show polyclonal development as to the allelic loss of chromosome 9 and direct comparison between biopsies and resected specimen may be difficult in such cases. In BiPS analysis, full methylation was observed in four cases and they all showed negative expression of the A antigen (Table 5). CpG islands were densely methylated in full methylation and they were closely correlated with the transcriptional silencing of the *ABO* gene. In cases with partial methylation, A antigen expression was also negative in 66.7% (6/9) of cases. Although partial methylation may play some role in transcriptional silencing, we used full methylation as an indicator of methylation in this study. As methylation extended to the most downstream of the *ABO* gene promoter region (*re 6*) in full methylation, we designed a primer set for MSP spanning region 7, which overlapped the downstream of region 6. The size of the amplified DNA fragment in MSP was as short as 96 bp and we used it as an indicator of full methylation in analysis of DNAs extracted from formalin-fixed paraffin-embedded sections. As MSP amplifies methylated DNA sequences selectively, its sensitivity is much higher than that of BiPS analysis and may have a risk of overestimation. In fact, MSP showed methylation in three cases that showed no methylation in BiPS analysis and the expression of the A antigen in these three cases were heterogenous. This may indicate the heterogeneity of the methylation status, suggesting only small number of cells harbored methylation (Table 3). In cases that underwent TUR, negative A antigen expression was signifi-

cantly correlated with full methylation ($P=0.035$), but not with A allelic loss ($P=0.26$) (Table 5). In cases that underwent radical cystectomy, both methylation and A allelic loss were significantly correlated with the expression of the A antigen ($P=0.003$ for A allelic loss, $P=0.03$ for MSP, respectively). Using these two indices in combination, 29.5% (13/44) of the cases that underwent TUR and 29.7% (11/37) of cases that underwent radical cystectomy showed loss of the A allele and/or hypermethylation of the *ABO* gene. They were significantly correlated with the expression of the A antigen ($P=0.02$ for TUR cases, $P=0.0005$ for radical cystectomy cases) (Tables 5 and 6). Negative A antigen expression was observed in 50.0% (22/44) in TUR cases and 48.6% (18/37) in cases that underwent radical cystectomy, which was attributable to genomic deletion and/or hypermethylation of the *ABO* gene in at least 45% (10/22) of cases that underwent TUR and 66.7% (10/15) of cases that underwent radical cystectomy. It is apparent that A allelic loss and/or hypermethylation of the *ABO* gene could not be the sole cause for negative A antigen expression. As the antigenic determinant of the A antigen is the terminal structure of the carbohydrate chains, incomplete synthesis of carbohydrate chains associated with oncogenesis may also be concerned with the reduced expression of the A antigen. Methylation seems to be more predominant than loss of the A allele in cases that underwent TUR. This might be explained by the observation that superficial papillary tumors such as pTa or pT1 stages comprised most of the TUR cases, while more than 70% of them were invasive cancers above Stage pT2 in cases that underwent radical cystectomy. In our previous study, frequencies of LOH on chromosome 9 were 67% in pTa, 71% in pT1 and 80% in tumors ≧pT2 stages.[4] As for the putative tumor suppressors found on chromosome 9, p16 and $p14^{ARF}$ are located on 9p21.[32,33] And an area on 9q31–34 is most prone to be deleted in TCC of the bladder,[34,35] which is also a candidate locus for a putative tumor suppressor gene. Reportedly, deletion of chromosome 9 is an early genetic event in the development of bladder cancers.[1] However, there is not enough evidence to support this hypothesis regarding the occurrence of chromosome 9 deletion in preneoplastic lesions. In a few studies using microsatellite markers from microdissected specimens, allelic loss on chromosome 9 was observed in bladder dysplasia.[3,7] We studied the expression of the A antigen on the dysplasia specimens by IHC, aiming at screening genetic alterations in precancerous lesions of the bladder. Expression of the A antigen was examined in 23 cases of bladder cancer comprising dysplasia, among which the numbers of tumors showing positive or negative expression were 13 and 10, respectively. All of the cases showing positive expression retained the A allele in the tumor and only one case showed hypermethylation, while the expression of the A antigen was preserved in dysplasia and normal urothelium in all cases. In the analysis of 10 cases showing negative A antigen expression in the tumor, loss of the A allele and/or the hypermethylation was observed in eight cases. Expression of the A antigen was preserved in normal urothelium and dysplasia in all but one case showing heterogenous expression in the dysplasia. This case did not exhibit LOH or hypermethylation in the tumor. These results suggested that LOH and/or hypermethylation of the *ABO* gene were infrequent genetic and epigenetic alterations in dysplasia and normal urothelium of the bladder bearing TCC. Furthermore, one case showed chimeric expression of the A antigen in the tumor, among which the expression of the A antigen coincided with loss or retention of the A allele (Figure 4). Analysis of two polymorphic markers in the vicinity of *ABO* gene locus also showed LOHs and the parental origin of the lost allele in these two loci was opposite as was shown in analysis of the *ABO* gene locus. Previously, we reported loss of chromosome 9 was observed in 71% of TCCs of the bladder and nearly 50% of them involved both 9p and 9q, suggesting monosomy or uniparental aneusomy of chromosome 9.[4] Thus, the deletion was considered to involve large chromosomal regions at least between 9q21.3 and 9q34.1 and possibly on the same allele. This finding may suggest the idea that the tumor showed polyclonal development as to the deletion of the 9q allele and that the loss of chromosome 9 might not be an early genetic event associated with tumorigenesis.

In conclusion, reduced expression of the A antigen in bladder cancer reflects allelic loss of the *ABO* gene assigned to 9q34.1 and/or hypermethylation of its promoter region, which is a specific marker for genetic and epigenetic alterations in bladder cancer but not in dysplasia.

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References

1 Dalbagni G, Presti J, Reuter V, *et al.* Genetic alterations in bladder cancer. Lancet 1993;342:469–471.
2 Knowles MA, Elder PA, Williamson M, *et al.* Allelotype of human bladder cancer. Cancer Res 1994;54:531–538.
3 Spruck III CH, Ohneseit PF, Gonzalez-Zulueta M, *et al.* Two molecular pathways to transitional cell carcinoma of the bladder. Cancer Res 1994;54:784–788.
4 Shigyo M, Sugano K, Fukayama N, *et al.* Allelic loss on chromosome 9 in bladder cancer tissues and urine

samples detected by blunt-end single-strand DNA conformation polymorphism. Int J Cancer 1998;78: 425–429.
5 Czerniak B, Li L, Chaturvedi V, *et al.* Genetic modeling of human urinary bladder carcinogenesis. Genes Chromosomes Cancer 2000;27:392–402.
6 Muto S, Horie S, Takahashi S, *et al.* Genetic and epigenetic alterations in normal bladder epithelium in patients with metachronous bladder cancer. Cancer Res 2000;60:4021–4025.
7 Hartmann A, Schlake G, Zaak D, *et al.* Occurrence of chromosome 9 and p53 alterations in multifocal dysplasia and carcinoma in situ of human urinary bladder. Cancer Res 2002;62:809–818.
8 Richie JP, Blute Jr RD, Waisman J. Immunologic indicators of prognosis in bladder cancer: the importance of cell surface antigens. J Urol 1980;123:22–24.
9 Abel PD, Thorpe SJ, Williams G. Blood group antigen expression in frozen sections of presenting bladder cancer: 3-year prospective follow-up of prognostic value. Br J Urol 1989;63:171–175.
10 Newman Jr AJ, Carlton Jr CE, Johnson S. Cell surface A, B, or O(H) blood group antigens as an indicator of malignant potential in stage A bladder carcinoma. J Urol 1980;124:27–29.
11 Yamada T, Fukui I, Kobayashi T, *et al.* The relationship of ABH(O) blood group antigen expression in intraepithelial dysplastic lesions to clinicopathologic properties of associated transitional cell carcinoma of the bladder. Cancer 1991;67:1661–1666.
12 Orntoft TF, Wolf H. Blood group ABO and Lewis antigens in bladder tumors: correlation between glycosyltransferase activity and antigen expression. APMIS 1988;4(Suppl):126–133.
13 Yamamoto F, Clausen H, White T, *et al.* Molecular genetic basis of the histo-blood group ABO system. Nature 1990;345:229–233.
14 Yamamoto F, Marken J, Tsuji T, *et al.* Cloning and characterization of DNA complementary to human UDP-GalNAc: Fuc alpha 1-2Gal alpha 1-3GalNAc transferase (histo-blood group A transferase) mRNA. J Biol Chem 1990;265:1146–1151.
15 Ogasawara K, Bannai M, Saitou N, *et al.* Extensive polymorphism of ABO blood group gene: three major lineages of the alleles for the common ABO phenotypes. Hum Genet 1996;97:777–783.
16 Ogasawara K, Yabe R, Uchikawa M, *et al.* Molecular genetic analysis of variant phenotypes of the ABO blood group system. Blood 1996;88:2732–2737.
17 Meldgaard P, Johnson PH, Langkilde NC, *et al.* Loss of ABH antigen expression in bladder cancer is not caused by loss of heterozygosity of the ABO locus. Int J Cancer 1995;63:341–344.
18 Orlow I, Lacombe L, Pellicer I, *et al.* Genotypic and phenotypic characterization of the histoblood group ABO(H) in primary bladder tumors. Int J Cancer 1998; 75:819–824.
19 Kominato Y, Hata Y, Takizawa H, *et al.* Expression of human histo-blood group ABO genes is dependent upon DNA methylation of the promoter region. J Biol Chem 1999;274:37240–37250.
20 Kominato Y, Hata Y, Takizawa H, *et al.* Alternative promoter identified between a hypermethylated upstream region of repetitive elements and a CpG island in human ABO histo-blood group genes. J Biol Chem 2002;277:37936–37948.
21 Iwamoto S, Withers DA, Handa K, *et al.* Deletion of A-antigen in a human cancer cell line is associated with reduced promoter activity of CBF/NF-Y binding region, and possibly with enhanced DNA methylation of A transferase promoter. Glycoconj J 1999;16: 659–666.
22 Gao S, Worm J, Guldberg P, *et al.* Genetic and epigenetic alterations of the blood group ABO gene in oral squamous cell carcinoma. Int J Cancer 2004; 109:230–237.
23 Habuchi T, Luscombe M, Elder PA, *et al.* Structure and methylation-based silencing of a gene (DBCCR1) within a candidate bladder cancer tumor suppressor region at 9q32–q33. Genomics 1998;48:277–288.
24 Horikawa Y, Sugano K, Shigyo M, *et al.* Hypermethylation of an E-cadherin (CDH1) promoter region in high grade transitional cell carcinoma of the bladder comprising carcinoma *in situ*. J Urol 2003;169:1541–1545.
25 Preece AF, Strahan KM, Devitt J, *et al.* Expression of ABO or related antigenic carbohydrates on viral envelopes leads to neutralization in the presence of serum containing specific natural antibodies and complement. Blood 2002;99:2477–2482.
26 Sugano K, Nakashima Y, Yamaguchi K, *et al.* Sensitive detection of loss of heterozygosity in the TP53 gene in pancreatic adenocarcinoma by fluorescence-based single-strand conformation polymorphism analysis using blunt-end DNA fragment. Genes Chromosomes Cancer 1996;15:157–164.
27 Sugano K, Tsutsumi M, Nakashima Y, *et al.* Diagnosis of bladder cancer by analysis of the allelic loss of the p53 gene in urine samples using blunt-end single-strand conformation polymorphism. Int J Cancer 1997; 74:403–406.
28 Maekawa M, Sugano K, Kashiwabara H, *et al.* DNA methylation analysis using bisulfite treatment and PCR-single-strand conformation polymorphism in colorectal cancer showing microsatellite instability. Biochem Biophys Res Commun 1999;262: 671–676.
29 Miyakura Y, Sugano K, Konishi F, *et al.* Extensive methylation of hMLH1 promoter region predominates in proximal colon cancer with microsatellite instability. Gastroenterology 2001;121:1300–1309.
30 Ganly PS, Jarad N, Rudd RM, *et al.* PCR-based analysis allows genotyping of the short arm of chromosome 3 in small biopsies from patients with lung cancer. Genomics 1992;12:221–228.
31 Slebos RJ, Umbach DM, Sommer CA, *et al.* Analytical and statistical methods to evaluate microsatellite allelic imbalance in small amounts of DNA. Lab Invest 2004;84:649–657.
32 Williamson MP, Elder PA, Shaw ME, *et al.* p16 (CDKN2) is a major deletion target at 9p21 in bladder cancer. Hum Mol Genet 1995;4:1569–1577.
33 Cairns P, Polascik TJ, Eby Y, *et al.* Frequency of homozygous deletion at p16/CDKN2 in primary human tumours. Nat Genet 1995;11:210–212.
34 Habuchi T, Yoshida O, Knowles MA. A novel candidate tumour suppressor locus at 9q32–33 in bladder cancer: localization of the candidate region within a single 840 kb YAC. Hum Mol Genet 1997;6: 913–919.
35 Hornigold N, Devlin J, Davies AM, *et al.* Mutation of the 9q34 gene TSC1 in sporadic bladder cancer. Oncogene 1999;18:2657–2661.

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Randomized trial of dietary fiber and *Lactobacillus casei* administration for prevention of colorectal tumors

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The epidemiologic evidence that dietary fiber protects against colorectal cancer is equivocal. No large-scale clinical study of the administration of *Lactobacillus casei* has been reported. We examined whether dietary fiber and *L. casei* prevented the occurrence of colorectal tumors. Subjects were 398 men and women presently free from tumor who had had at least 2 colorectal tumors removed. Subjects were randomly assigned to 4 groups administered wheat bran, *L. casei,* both or neither. The primary end point was the presence or absence of new colorectal tumor(s) diagnosed by colonoscopy after 2 and 4 years. Among 380 subjects who completed the study, 95, 96, 96 and 93 were assigned to the wheat bran, *L. casei,* both and no treatment groups, respectively. Multivariate adjusted ORs for occurrence of tumors were 1.31 (95% CI 0.87–1.98) in the wheat bran group and 0.76 (0.50–1.15) in the *L. casei* group compared to the control group. There was a significantly higher number of large tumors after 4 years in the wheat bran group. The occurrence rate of tumors with a grade of moderate atypia or higher was significantly lower in the group administered *L. casei.* No significant difference in the development of new colorectal tumors was observed with administration of either wheat bran or *L. casei.* However, our results suggest that *L. casei* prevented atypia of colorectal tumors.

Key words: colorectal cancer; *Lactobacillus casei*; dietary fiber; probiotic

The incidence of colon cancer is rapidly increasing in Japan.[1] It has been suggested that this trend is caused by the high-fat, low-dietary fiber diet resulting from Westernization of the lifestyle among Japanese. Indeed, intake of dietary fiber by the Japanese has decreased significantly over the past 10 years.[2]

Since Burkitt[3] proposed that a diet high in dietary fiber prevented colorectal cancer, basic studies have suggested the possibility of prevention of colorectal cancer by dietary fiber, through actions including absorption of carcinogens by insoluble dietary fiber[4] and dilution of bile acids and decrease of mutagenicity due to the increase in stool volume.[5,6]

A large number of case-control studies have suggested that dietary fiber may prevent the development of colorectal cancers.[7] However, reports of large-scale cohort studies have failed to show a preventive effect of dietary fiber against colorectal cancer, causing controversy.[8–11]

Randomized clinical trials have been conducted in Western countries[12–16] to evaluate the effectiveness of dietary fiber, using the development of colorectal adenoma as an end point. Many of these studies failed to prove that dietary fiber prevented the development of colorectal adenoma. No intervention study on dietary fiber has been reported in Asians.

It has been shown that *Lactobacillus casei* strain Shirota reduces DNA damage induced by chemical carcinogens in laboratory studies[17] and prevents carcinogenesis in animal experiments.[18,19] In addition, it has been reported, in humans, that lactobacilli reduce the level of mutagens in stool.[20] Furthermore, oral administration of *L. casei* strain Shirota preparation decreased the recurrence of superficial bladder cancer after transurethral resection,[21,22] and habitual intake of a fermented product with *L. casei* strain Shirota reduced the risk of bladder cancer in an epidemiologic study.[23] Thus, we decided to use a *L. casei* strain Shirota preparation in the present study. It has been suggested that high intake of yogurt and fermented milk is responsible for the low incidence of colon cancer in Finland, where consumption of fat is higher than in other countries.[24] Two case-control studies have shown that yogurt[25] and fermented milk[26] prevent colon cancer. In the Netherlands Cohort Study, it was reported that fermented milk intake showed an inverse relationship with the development of colon cancer, although there was no statistical significance.[27]

In 1993, we initiated a randomized clinical trial to determine whether dietary fiber from wheat bran and *L. casei* prevented the occurrence of colorectal tumors.

Material and methods

Study design and subjects

Part of the study design and methods have been previously described in detail.[28] Subjects were recruited at the Osaka Medical Center for Cancer and Cardiovascular Diseases between June 1993 and September 1997. The study protocol was approved by the Ethics Committee of the Osaka Medical Center for Cancer and Cardiovascular Diseases. Written informed consent was obtained from all subjects.

Inclusion criteria were men and women aged 40–65 years who had had at least 2 colorectal tumors (adenomas and/or early cancers) removed endoscopically within 3 months before recruitment. Endoscopic examination had been conducted twice, to detect and resect polyps, respectively. It must have been performed on the entire large intestine, and the subjects must have had an adequate nutritional status. Excluded were subjects with other malignant tumors, a history of intestinal or gastric resection (except appendectomy), familial adenomatous polyposis and severe illness.

Four regimens were incorporated for prevention of colorectal cancer: A, dietary instruction and regular intake of wheat bran biscuits; B, dietary instruction and regular intake of *L. casei* preparation; C, dietary instruction and regular intake of wheat bran biscuits and *L. casei* preparation; and D, dietary instruction alone.

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One of the 4 regimens was assigned randomly in advance each week. Physicians recruited subjects according to the regimen decided at the beginning of the week. Patients received consultation, including histologic diagnosis of the resected polyp, from group physicians as soon as possible from 1 week following endoscopic treatment. Since the regimen assignment could not be changed by the physicians or participants or arbitrarily manipulated by the authors, it was regarded as random. Trial physicians recruited all outpatients who met the inclusion criteria.

The amount of wheat bran biscuits and *L. casei* preparation to be consumed in 1 month was given to the participant at the start of the trial, and thereafter the amount for 3 months was given. The trial was started after confirming that the subject understood the procedure of the regimen. During the trial, consultation was performed every 3 months to check the participant's physical condition and to confirm the intake of wheat bran biscuits and the *L. casei* preparation. The regimen was continued for 4 years. Participants' compliance with taking wheat bran biscuits and/or the *L. casei* preparation was assessed at the consultations performed every 3 months. At each consultation, the numbers of unconsumed biscuit packages and silver packages of *L. casei* preparation were estimated by verbal inquiry of the patients, and the amounts of wheat bran biscuits and *L. casei* preparation taken in the past 3 months were calculated as the percentage of the target intake. Consultations were performed 16 times, every 3 months for 4 years, and the average at those 16 consultations was taken as the compliance over 4 years.

The target number of subjects was 100 in each group, for a total of 400 subjects. As the incidence of tumors in the control group can be estimated to be about 60%, a significant difference would be obtained if the occurrence rate of tumors could be reduced to 50% (suppression rate 17%) by administration of wheat bran or *L. casei* preparation. No midpoint analysis was performed.

Tumors discovered by colonoscopy performed at the end of the 2nd and 4th years were included in the analysis. The analysis included subjects with poor compliance with the regimen for intake of wheat bran biscuits and *L. casei* preparation on an intention-to-treat basis. For patients with early colorectal cancers resected during colonoscopy before entry in the trial, colonoscopy was performed 6 months after entry (35, 29, 25 and 24 subjects of groups A, B, C and D, respectively). Tumors discovered by colonoscopy performed at 6 months were excluded from analysis. Subjects who refused participation and dropouts were excluded from analysis.

Dietary instruction

The core purpose of the dietary instruction was to restrict fat intake so that the energy from fat constituted 18–22% of total energy intake. Subjects were asked to record, on a diet record form, the contents of their meals for the 3 days before consultation; and nutritionists calculated, from these records, the total energy intake and intake of fat and oil. Compliance with the dietary instructions on the restriction of fat intake was evaluated at dietary checkups 3 months and 4 years after beginning the regimen, and, when necessary, instruction was given again.

Wheat bran biscuits

Biscuits containing wheat bran at 30% of dry weight were prepared.[29] Patients were instructed to eat 25 g/day wheat bran biscuits (7.5 g as wheat bran) before each meal. Biscuits were developed by Ezaki Glico (Osaka, Japan) and Horii Pharmaceutical Industry (Osaka, Japan). The components and contents of the wheat bran biscuits were as follows: energy, 454 kcal/day; protein, 2.9 g/day; lipid, 3.3 g/day; and nonfibrous carbohydrate, 17.5 g/day.

L. casei *preparation*

The *L. casei* strain Shirota preparation was a powder containing approximately 10^{10} viable cells/g. It was stored in a refrigerator, and 1 g was taken after every meal. The *L. casei* preparation was provided by Yakult Honsha (Tokyo, Japan). The viable cell count of *L. casei* and absence of bacterial contamination were confirmed for all lots every 6 months during the 2-year storage period. To confirm the viable cell count of *L. casei,* MRS agar medium for detection of *L. casei* was used. It has been confirmed in previous studies that the number of bacteria per 1 g of *L. casei* preparation remained in the range of 1.5×10^9 to 2.1×10^{10} during 24 months when stored in a cool place (15°C). In addition, the average number of bacteria is 8.0×10^9 after 24 months.

Colonoscopy

The main end point of the trial was the presence or absence of new colorectal tumor(s). Colonoscopy was performed 2 and 4 years after the start of the regimen. The entire large intestine, from the anus to the cecum, was examined. Examinations for detection of new lesions were performed by 2 physicians. All lesions, except hyperplastic polyps clearly evaluated by colonoscopy, were examined histologically on the basis of the guidelines of the Japanese Society for Cancer of the Colon and Rectum.[30] All histologic diagnoses (inflammatory polyp; hyperplastic polyp; adenoma with mild atypia, with moderate atypia, with severe atypia; early cancer) were performed blindly without identification of the participant's dietary regimen.

In patients with early colorectal cancer, which was diagnosed from tumor tissue resected by colonoscopy before entry in the trial, colonoscopy was performed to detect local recurrence after 6 months of participation. All colorectal tumors discovered with this procedure were resected.

Statistical analysis

All colorectal tumors discovered at the end of the 2nd and 4th years were defined as "new". Analyses at years 2 and 4 were performed separately, and 2×2 contingency table analysis was performed. Comparison of baseline characteristics of subjects with or without wheat bran biscuits or *L. casei* intake was performed by appropriate tests such as *t*-test and the χ^2 test. Logistic regression models were used to estimate the odds ratio (OR) adjusted for covariates such as age and sex. Confidence intervals (CIs) based on Wald statistics were used to assess significance.

Results

Enrollment and randomization

The number of patients who met the inclusion criteria during the screening period was 470 (Fig. 1). All were invited to participate in the trial, but 60 patients (13%) declined. Of 410 patients who agreed to participate, 12 were excluded because of incompatibility with the protocol, including detection of cholangiocarcinoma and gastric cancer in 4, history of gastrectomy in 3, colectomy in one, familial adenomatous polyposis in one, advanced age in one, young age in one and more than 3 months after endoscopic treatment in one. Thus, 398 patients were assigned to the 4 groups.

Baseline characteristics of subjects

Table I shows the baseline characteristics of the 398 patients randomly assigned and the number of dropouts. There was no difference in baseline characteristics of subjects such as dietary content among the 4 groups. A total of 18 patients (4.5%) did not complete endoscopic examinations. The reasons for not receiving endoscopic examinations were death in 2 patients (from lung cancer and cerebral hemorrhage), serious illness in 5 patients and trial discontinuation in 11 patients. There was no difference in the rate of dropouts among all groups. Excluding 18 dropouts, 380 patients were included in the analysis.

Colonoscopy

Colonoscopic examination was possible throughout the length of the large intestine, up to the cecum, in all cases. There was no difference in the intervention period among groups (Table II).

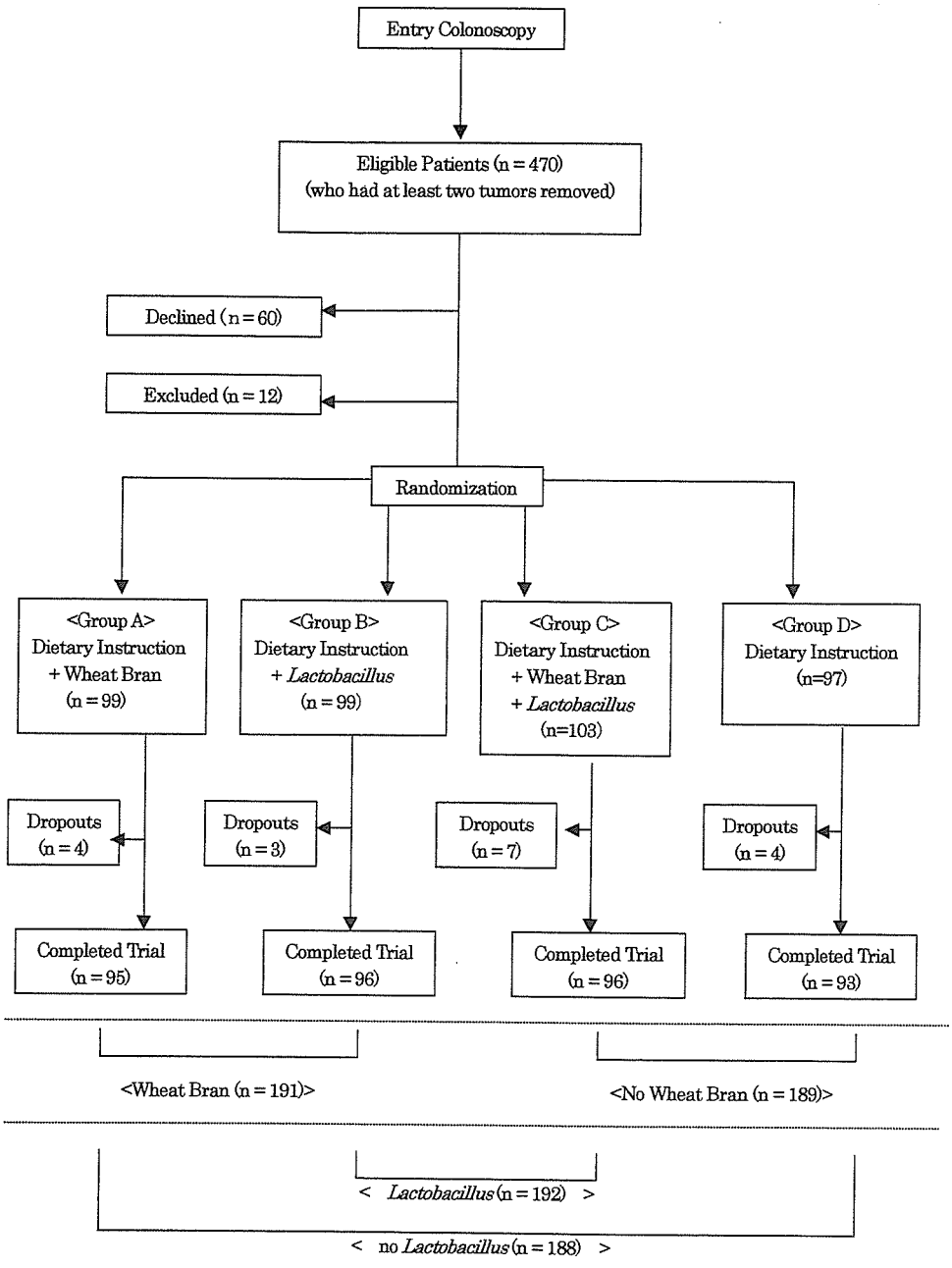

FIGURE 1 – Study participant data.

There was no difference in the time required for insertion into and removal from the cecum in all groups. No difference was found in the proportion of nonneoplastic lesions (inflammatory polyps and hyperplastic polyps).

Compliance

Compliance with intake of wheat bran biscuits was over 90% in 77 persons (40%) and over 70% in 135 persons (71%) for the entire 4 years. Compliance with intake of the *L. casei* preparation was over 90% in 130 persons (68%) and over 70% in 168 persons (88%).

Occurrence of tumors

The results after intake of wheat bran biscuits are shown in Table III. The wheat bran biscuit administration group included 191 persons, while the nonadministration group included 189 persons. The adjusted OR of developing at least one tumor was 1.31 (95% CI 0.87–1.98) after 2 years in the administration group compared to the nonadministration group. It was 1.31 (95% CI 0.87–1.97) after 4 years, showing some increase in adjusted OR, although not statistically significant. The adjusted OR for developing tumors larger than 3 mm was 1.14 (95% CI 0.76–1.72) in the administration group compared to the nonadministration group after 2 years and 1.57 (95% CI 1.04–2.37) after 4 years, showing a significant increase. In particular, the occurrence of tumors larger than 10 mm after 2 years showed no difference between the wheat bran administration and nonadministration groups. However, after 4 years, these tumors did not occur in the nonadministration group while they occurred in 7 patients (3.7%) in the administration group, showing a significant increase. There was no difference in the occurrence of more than one or more than 3 tumors with moderate or severe atypia.

Table IV shows the results after *L. casei* administration. The *L. casei* administration group included 192 persons and the nonad-

TABLE I – BASELINE CHARACTERISTICS OF SUBJECTS[1]

	Group A: wheat bran (n = 99)	Group B: *Lactobacillus* (n = 99)	Group C: wheat bran + *Lactobacillus* (n = 103)	Group D: no treatment (n = 97)
Age (years)	54.7±6.1	54.8±6.5	54.9±6.2	55.5±6.2
Male sex, number (%)	83 (83.8)	79 (79.8)	80 (77.7)	83 (85.6)
Height (cm)	164.6±8.4	164.6±7.3	163.0±7.1	164.1±7.6
Weight (kg)	66.1±10.5	64.6±10.5	62.7±8.7	63.2±9.4
Dietary intake				
Energy (kcal/day)	2,075±368	2,066±411	2,058±402	2,163±404
Total fat (g/day)	54.6±15.2	53.0±13.5	52.8±16.7	56.6±14.9
Dietary fiber (g/day)	15.1±3.9	14.5±3.9	15.4±4.7	15.5±4.0
Calcium (mg/day)	635.4±237.1	638.7±218.4	636.6±246.7	661.4±247.7
Alcohol drinking every day, number (%)	50 (50.5)	37 (37.4)	49 (47.6)	48 (49.5)
Current smoker, number (%)	47 (47.5)	41 (41.4)	43 (41.7)	44 (45.4)
Tumors before recruitment				
Total tumors	5.9±4.3	5.8±5.6	5.2±3.6	5.0±3.4
Adenomas with mild atypia	2.8±2.9	2.7±3.9	2.5±2.6	2.0±2.7
Adenomas with moderate atypia	2.1±2.2	2.4±2.1	1.9±1.8	2.0±1.9
Adenomas with severe atypia	0.6±0.8	0.4±0.7	0.5±1.1	2.0±1.9
Early cancers, number (%)	37 (37.4)	31 (31.3)	29 (28.2)	28 (28.9)
History of colorectal cancer in one parent or sibling, number (%)	15 (15.2)	8 (8.1)	15 (14.6)	11 (11.3)
Dropped out, number (%)	4 (4.0)	3 (3.0)	7 (6.8)	4 (4.1)

[1]Values are means ± SD.

TABLE II – INTERVENTION PERIOD OF COLONOSCOPY

Intervention period	Group A: wheat bran (n = 95)	Group B: *Lactobacillus* (n = 96)	Group C: wheat bran + *Lactobacillus* (n = 96)	Group D: no treatment (n = 93)
Period of 2nd year from entry (days)				
Mean ± SD	679.4±60.8	674.2±31.0	672.1±27.6	680.3±56.9
Maximum	1,009	827	778	925
Minimum	568	617	600	617
Period of 4th year from entry (days)				
Mean ± SD	1,339.6±46.9	1,339.7±51.1	1,338.1±40.5	1,367.4±120.4
Maximum	1,611	1,660	1,617	2,129
Minimum	1,275	1,275	1,233	1,201

ministration group, 188 persons. The adjusted OR of developing at least one tumor was 0.76 (95% CI 0.50–1.15) in the administration group compared to the nonadministration group after 2 years. After 4 years, it was 0.85 (95% CI 0.56–1.27), showing a decrease after both 2 and 4 years, although not statistically significant. For the occurrence of tumors with moderate or severe atypia, the adjusted OR was 0.80 (95% CI 0.52–1.22) in the administration group compared to the nonadministration group after 2 years and 0.65 (95% CI 0.43–0.98) after 4 years, showing a significant decrease after 4 years. There was no difference in the size and number of new tumors that developed.

When the results were examined separately for the different levels of compliance, they were similar to those described above.

Synergistic effects

Tumor occurrence in the group administered both wheat bran and *L. casei* was higher than that in the groups administered wheat bran or *L. casei* and lower than that in the nonadministered group (data not shown). No notable synergistic effects between the treatments were observed.

Adverse events

During the study period, colorectal cancers were discovered in 4 persons by endoscopy, including one person each in groups B, C and D after 2 years and one person in group B after 4 years. There was no bias in their occurrence among the groups. All were cancer invasion of mucosa and were completely resected endoscopically, not requiring colectomy. During the study period, 2 patients died, one of lung cancer in group A and one of cerebral hemorrhage in group C. One person each in groups A and C underwent surgery for peritonitis resulting from acute appendicitis. There was no other serious adverse event.

Discussion

It was found that *L. casei* intake appeared to suppress the development of colorectal tumors; in particular, it prevented, with statistical significance, the development of tumors with moderate and severe atypia. This large-scale randomized clinical study shows that an *L. casei* preparation prevented the development of colorectal tumors.

Since our study was performed at one hospital, the evaluations of endoscopic findings were thought to be consistent. All patients who satisfied the conditions for participation were asked to participate, and the rate of consent to participation was extremely high at 88%, supporting the high validity of the results. The reasons for the high rate of consent could be that a special organization was instituted in this hospital for this trial and that all participants were offered dietary instruction. In addition, the dropout rate was low at 4.5% and compliance was high, indicating that the results were highly reliable. Endoscopic examination was conducted twice before entry so that we could minimize oversights.

In our previous prevention studies, subjects were patients with at least one tumor, whereas the present study included patients with at least 2 tumors. It is known that patients with at least 2 tumors in the large intestine have a higher risk of colon cancer than those with only one tumor. It is difficult to apply the results of our clinical study to the general population. Many of the patients participating in this trial, different from other reports in the past, had a larger number of colorectal tumors together with a history of cancer. This difference appears to have resulted from the background of the population, who had a higher risk of colorectal cancer than those participating in previous clinical trials. Accordingly, our results should be discussed not on the basis of the general population but on the basis of a population with a high risk of colorectal cancer. Nonetheless, our study included patients

TABLE III – RISK OF TUMOR OCCURRENCE WITH WHEAT BRAN BISCUITS

	Year	Wheat bran (groups A + C) (n = 191)	No treatment (groups B + D) (n = 189)	Crude		Adjusted	
				relative risk	(95% CI)	OR	(95% CI)[1]
Number of tumors							
At least one	2	119 (62.3%)	106 (56.1%)	1.11	(0.94–1.31)	1.31	(0.87–1.98)
	4	106 (55.5%)	93 (49.2%)	1.13	(0.93–1.37)	1.31	(0.87–1.97)
≥ 2	2	57 (29.8%)	60 (31.7%)	0.94	(0.70–1.27)	0.92	(0.60–1.43)
	4	51 (26.7%)	53 (28.0%)	0.95	(0.69–1.32)	0.95	(0.60–1.50)
≥ 4	2	11 (5.8%)	14 (7.4%)	0.78	(0.36–1.67)	0.78	(0.34–1.76)
	4	11 (5.8%)	12 (6.3%)	0.91	(0.41–2.00)	0.91	(0.39–2.13)
Size of largest tumor (mm)							
≥ 3	2	95 (49.7%)	88 (46.6%)	1.07	(0.87–1.32)	1.14	(0.76–1.72)
	4	97 (50.8%)	76 (40.2%)	1.26	(1.01–1.58)	1.57	(1.04–2.37)
≥ 4	2	51 (26.7%)	52 (27.5%)	0.97	(0.70–1.35)	0.97	(0.61–1.54)
	4	52 (27.2%)	51 (27.0%)	1.01	(0.73–1.40)	1.02	(0.65–1.60)
≥ 10	2	4 (2.1%)	4 (2.1%)	0.99	(0.25–3.90)	1.00	(0.25–4.06)
	4	7 (3.7%)	0 (0.0%)	—	$p < 0.01$[2]		
Atypia of tumors							
≥ With moderate	2	64 (33.5%)	66 (34.9%)	0.96	(0.73–1.27)	0.94	(0.61–1.44)
	4	77 (40.3%)	74 (39.2%)	1.03	(0.80–1.32)	1.06	(0.70–1.60)

[1]OR of recurrent tumors in the wheat bran biscuits group compared to the no treatment group, adjusted for age, sex and *Lactobacillus* group.–[2]χ^2 test.

TABLE IV – RISK OF TUMOR OCCURRENCE WITH *LACTOBACILLUS* PREPARATION

	Year	*Lactobacillus* (groups B + C) (n = 192)	No treatment (groups A + D) (n = 188)	Crude		Adjusted[1]	
				relative risk	(95% CI)	OR	(95% CI)
Number of tumors							
At least one	2	107 (55.7%)	118 (62.8%)	0.89	(0.75–1.05)	0.76	(0.50–1.15)
	4	96 (50.0%)	103 (54.8%)	0.91	(0.75–1.11)	0.85	(0.56–1.27)
≥ 2	2	56 (29.2%)	61 (32.4%)	0.90	(0.66–1.22)	0.88	(0.57–1.36)
	4	53 (27.6%)	51 (27.1%)	1.02	(0.73–1.41)	1.08	(0.68–1.71)
≥ 4	2	10 (5.2%)	15 (8.0%)	0.65	(0.30–1.42)	0.67	(0.29–1.53)
	4	15 (7.8%)	8 (4.3%)	1.84	(0.79–4.23)	1.98	(0.81–4.83)
Size of largest tumor (mm)							
≥ 3	2	86 (44.8%)	97 (51.6%)	0.87	(0.70–1.07)	0.77	(0.51–1.15)
	4	83 (43.2%)	90 (47.9%)	0.90	(0.72–1.13)	0.85	(0.56–1.28)
≥ 4	2	41 (21.4%)	62 (33.0%)	0.65	(0.46–0.91)	0.56	(0.35–0.89)
	4	58 (30.2%)	45 (23.9%)	1.26	(0.90–1.76)	1.38	(0.87–2.19)
≥ 10	2	4 (2.1%)	4 (2.1%)	0.98	(0.45–3.86)	1.01	(0.25–4.12)
	4	4 (2.1%)	3 (1.6%)	1.31	(0.30–5.75)	1.29	(0.28–6.00)
Atypia of tumors							
≥ With moderate	2	61 (31.8%)	69 (36.7%)	0.87	(0.65–1.14)	0.80	(0.52–1.22)
	4	66 (34.4%)	85 (45.2%)	0.76	(0.59–0.98)	0.65	(0.43–0.98)

[1]OR of recurrent tumors in the *Lactobacillus* group compared to the no treatment group, adjusted for age, sex and wheat bran biscuit group.

with at least 2 tumors for the following reasons: *(i)* it is more efficient for the analysis of preventive methods against colon cancer to use subjects in higher-risk groups and *(ii)* since the occurrence rates of colon tumors after 2 and 4 years were higher in patients in the high-risk group, a preventive effect would be more prominent in this group.

The weak point of this trial is that it was not a double-blind study. Therefore, there could be bias from the fact that the participants and medical professionals did know the group to which each participant belonged. However, since it is widely believed in Japan that dietary fiber prevents colorectal cancer and nobody would think that dietary fiber would cause tumors to enlarge, it is highly unlikely that the unexpected results obtained in this study were biased. Histologic evaluations were performed blindly, without group identification, by pathologists. Therefore, there is unlikely to be a bias resulting from this not being a double-blind study in the result that administration of *L. casei* prevented the development of tumors with moderate or severe atypia.

The occurrence of tumors larger than 4 mm was significantly suppressed by *L. casei* administration after 2 years but not after 4 years. This might have resulted from a suppressive effect of *L. casei* administration against enlargement of colon tumors lasting for only a limited period. At the present time, it is not clear how *L. casei* influences the early stages of tumor development. We are planning to examine the effect of *L. casei* administration on cellular proliferation histopathologically, to find the best administration method that will clearly show a suppressive effect on tumor development.

Although clinical studies on the administration of *L. casei* for the prevention of colorectal tumors have not been reported, there are a few reports of clinical studies aimed at changing the intestinal flora. Roncucci *et al.*[31] reported that lactulose appeared to slightly suppress the development of colorectal tumors, although without statistical significance.

The *L. casei* preparation used in our study was a quality-controlled homogeneous live preparation. *L. casei* survives well in gastric acid[32] and is used as an intestinal conditioning agent in Japan. It is known to augment immunity[33] and inhibit enzyme activity involved in carcinogenesis.[17] It has been reported to suppress the development of colorectal tumors in rats.[34]

The mechanism of the suppression by *L. casei* of the development of colorectal tumors with moderate or severe atypia is not clear. Further analyses are in progress examining stools, colonic mucous membrane and serum collected from patients who participated in this study.

Several similar studies from Western countries have reported that dietary fiber supplementation did not prevent or promote the

development of colorectal tumors. In the clinical study by Bonithon-Kopp *et al.*,[16] dietary fiber-rich psyllium significantly increased the development of adenomas after 3 years as analyzed by endoscopy (OR = 1.67), consistent with our results. Alberts *et al.*[15] reported, from a clinical study with large and small quantities of wheat bran cereal, that there was no difference in the development of adenomas but that the number of patients who developed at least 3 adenomas was significantly higher in the high-dietary fiber group. Since it was found in a previous study[29] that the diets of participants were changed by administration of a large quantity of dietary fiber, the quantity of dietary fiber was lower in the present study than that used in other studies. To target the high-risk group for colorectal cancer, patients with multiple colorectal tumors were included as subjects. In spite of these differences from previous studies, the development of colorectal tumors was not prevented by dietary fiber also in this study.

Thus, there has been no consensus on the efficacy of dietary fiber against colorectal cancer. From the results of our study as well as the previous results of supplementation studies, it is not recommended to take supplements containing a high concentration of dietary fiber for the prevention of colorectal cancer.

References

1. Research Group for Population-Based Cancer Registration in Japan. Cancer incidence in Japan in 1990: estimates based on data from population-based cancer registries. Jpn J Clin Oncol 1998;28:450–3.
2. Munakata A, Iwane S, Ohta M, Nakaji S, Sugawara K, Mori B. Time trend of dietary fiber intake in Japan,1917–1991. J Epidemiol 1995;5:205–10.
3. Burkitt DP. Epidemiology of cancer of the colon and rectum. Cancer 1971;28:3–13.
4. Eastwood MA, Passmore R. Dietary fiber. Lancet 1983;23:202–5.
5. Alberts DS, Ritenbaugh C, Story JA, Story JA, Aickin M, Rees-McGee S, Buller MK, Atwood J, Phelps J, Ramanujam PS, Bellapravalu S, Patel J, et al. Randomized, double-blinded, placebo-controlled study of wheat bran fiber and calcium on fecal bile acids in patients with resected adenomatous colon polyps. J Natl Cancer Inst 1996;88:81–92.
6. Cummings JH, Bingham A, Heaton KW, Eastwood MA. Fecal weight,colon cancer risk, and dietary intake of nonstarch polysaccharides (dietary fiber). Gastroenterology 1992;103:1783–9.
7. Howe GR, Benito E, Castelleto R, Ornee J, Esteve J, Gallagher RP, Iscovich JM, Deng-ao J, Kaaks R, Kune GA, Kune S, L'Abbe KA, et al. Dietary intake of fiber and decreased risk of cancers of the colon and rectum: evidence from the combined analysis of 13 case-control studies. J Natl Cancer Inst 1992;84:1887–96.
8. Heilbrun LK, Nomura A, Hankin JH, Stemmermann GN. Diet and colorectal cancer with special reference to fiber intake. Int J Cancer 1989;44:1–6.
9. Fuchs CS, Giovannucci EL, Colditz GA, Hunter DJ, Stampfer MJ, Rosner B, Speizer FE, Willett WC. Dietary fiber and the risk of colorectal cancer and adenoma in women. N Engl J Med 1999;340:169–76.
10. Michels KB, Giovannucci EL, Joshipura KJ, Rosner BA, Stampfer MJ, Fuchs CS, Colditz GA, Speizer FE, Willett WC. Prospective study of fruit and vegetable consumption and incidence of colon and rectum cancers. J Natl Cancer Inst 2000;92:1740–52.
11. Bingham SA, Day NE, Luben R, Ferrari P, Slimani N, Norat T, Clavel-Chapelon F, Kesse E, Nieters A, Boeing H, Tjonneland A, Overvad K, et al. Dietary fiber in food and protection against colorectal cancer in the European Prospective Investigation into Cancer and Nutrition (EPIC): an observational study. Lancet 2003;361:1496–501.
12. McKeown-Eyssen GE, Bright-See E, Bruce R, Jazmaji V, Toronto Polyp Prevention Group. A randomized trial of a low fat high fiber diet in the recurrence of colorectal polyps. J Clin Epidemiol 1994;47:525–36.
13. MacLennan R, Macrae F, Bain C, Battistutta D, Chapuis P, Gratten H, Lambert J, Newland RC, Ngu M, Russell A, Ward M, Wahlqvist ML, et al. Randomized trial of intake of fat, fiber, and beta carotene to prevent colorectal adenomas. J Natl Cancer Inst 1995;87:1760–6.
14. Schatzkin A, Lanza E, Corle D, Lance P, Iber F, Caan B, Shike M, Weissfeld J, Burt R, Cooper M, Kikendall JW, Cahill J, et al. Lack of effect of a low-fat, high-fiber diet on the recurrence of colorectal adenomas. N Engl J Med 2000;342:1149–55.
15. Alberts DS, Martinez ME, Roe DJ, Guillen-Rodriguez JM, Marshall JR, van Leeuwen JB, Reid ME, Ritenbaugh C, Vargas PA, Bhattacharyya AB, Earnest DL, Sampliner RE, et al. Lack of effect of a high-fiber cereal supplement on the recurrence of colorectal adenomas. N Engl J Med 2000;342:1156–62.
16. Bonithon-Kopp C, Kronborg O, Giacosa A, Rath U, Faivre J, European Cancer Prevention Organisation Study Group. Calcium and fiber supplementation in prevention of colorectal adenoma recurrence: a randomized intervention trial. Lancet 2000;356:1300–6.
17. Morotomi M, Mutai M. In vitro binding of potent mutagenic pyrolysates to intestinal bacteria. J Natl Cancer Inst 1986;77:195–201.
18. Takagi A, Matsuzaki T, Sato M, Nomoto K, Morotomi M, Yokokura T. Inhibitory effect of oral administration of *Lactobacillus casei* on 3-methylcholanthrene-induced carcinogenesis in mice. Med Microbiol Immunol (Berl) 1999;188:111–6.
19. Takagi A, Matsuzaki T, Sato M, Nomoto K, Morotomi M, Yokokura T. Enhancement of natural killer cytotoxicity delayed murine carcinogenesis by a probiotic microorganism. Carcinogenesis 1991;22:599–605.
20. Lidbeck A, Nord CE, Gustasson JA, Rafter J. Lactobacilli, anticarcinogenic activities and human intestinal microflora. Eur J Cancer Prev 1992;1:341–53.
21. Aso Y, Akaza H. Prophylactic effect of a *Lactobacillus casei* preparation on the recurrence of superficial bladder cancer. BLP Study Group. Urol Int 1992;49:125–9.
22. Aso Y, Akaza H, Kotake T, Tsukamoto T, Imai K, Naito S. Preventive effect of a *Lactobacillus casei* preparation on the recurrence of superficial bladder cancer in a double-blind trial. The BLP Study Group. Eur Urol 1995;27:104–9.
23. Ohashi Y, Nakai S, Tsukamoto T, Masumori N, Akaza H, Miyanaga N, Kitamura T, Kawabe K, Kotake T, Kuroda M, Naito S, Koga H, et al. Habitual intake of lactic acid bacteria and risk reduction of bladder cancer. Urol Int 2002;68:273–80.
24. Malhotra SL. Dietary factors in a study of colon cancer from cancer registry,with special reference to the role of saliva, milk, and fermented milk products and vegetable fiber. Med Hypotheses 1977;3:122–34.
25. Peters RK, Pike MC, Garabrant D, Mack TM. Diet and colon cancer in Los Angeles County, California. Cancer Causes Control 1992;3:457–73.
26. Young TB, Wolf DA. Case-control study of proximal and distal colon cancer and diet in Wisconsin. Int J Cancer 1988;42:167–75.
27. Kampman E, Goldbohm RA, van den Brandt PA, van't Veer P. Fermented dairy products, calcium, and colorectal cancer in the Netherlands Cohort Study. Cancer Res 1994;54:3186–90.
28. Ishikawa H, Akedo I, Suzuki T, Otani T, Sobue T. Interventional trial for colorectal cancer prevention in Osaka: an introduction to the protocol. Jpn J Cancer Res 1995;86:707–10.
29. Ishikawa H, Akedo I, Nakamura T, Kimura K, Takimoto Y, Suzuki T, Sato S, Tanaka Y, Otani T. Effects of the administration of wheat bran biscuit: changes in the diet. Biofactors 2000;12:299–303.
30. Japanese Society for Cancer of the Colon and Rectum. Japanese classification of colorectal carcinoma. Tokyo: Kanehara, 1997.
31. Roncucci L, Di Donato P, Carati L, Ferrari A, Perini M, Bertoni G, Bedogni G, Paris B, Svanoni F, Girola M, Ponz de Leon M. Antioxidant vitamins or lactulose for the prevention of the recurrence of colorectal adenomas. Dis Colon Rectum 1993;36:227–34.
32. Kobayashi Y, Tohyama K, Terashima T. Studies on biological characteristics of *Lactobacillus* [in Japanese]. Jpn J Bacteriol 1974;29:691–7.
33. Nagao F, Nakayama M, Muto T, Okumura K. Effects of a fermented milk drink containing *Lactobacillus casei* strain Shirota on the immune system in healthy human subjects. Biosci Biotechnol Biochem 2000;64:2706–8.
34. Yamazaki K, Tsunoda A, Sibusawa M, Tsunoda Y, Kusano M, Fukuchi K, Yamanaka M, Kushima M, Nomoto K, Morotomi M. The effect of an oral administration of *Lactobacillus casei* strain Shirota on azoxymethane-induced colonic aberrant crypt foci and colon cancer in the rat. Oncol Rep 2000;7:977–82.

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Cisplatin-incorporating polymeric micelles (NC-6004) can reduce nephrotoxicity and neurotoxicity of cisplatin in rats

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In spite of the clinical usefulness of cisplatin (CDDP), there are many occasions in which it is difficult to continue the administration of CDDP due to its nephrotoxicity and neurotoxicity. We examined the incorporation of CDDP into polymeric micelles to see if this allowed the resolution of these disadvantages. Cisplatin was incorporated into polymeric micelles through the polymer–metal complex formation between polyethylene glycol poly(glutamic acid) block copolymers and CDDP (NC-6004). The pharmacokinetics, pharmacodynamics, and toxicity studies of CDDP and NC-6004 were conducted in rats or mice. The particle size of NC-6004 was approximately 30 nm, with a narrow size distribution. In rats, the area under the curve and total body clearance values for NC-6004 were 65-fold and one-nineteenth the values for CDDP ($P<0.001$ and 0.01, respectively). In MKN-45-implanted mice, NC-6004 tended to show antitumour activity, which was comparable to or greater than that of CDDP. Histopathological and biochemical studies revealed that NC-6004 significantly inhibited the nephrotoxicity of CDDP. On the other hand, blood biochemistry revealed transient hepatotoxicity on day 7 after the administration of NC-6004. Furthermore, rats given CDDP showed a significant delay ($P<0.05$) in sensory nerve conduction velocity in their hind paws as compared with rats given NC-6004. Electron microscopy in rats given CDDP indicated the degeneration of the sciatic nerve, but these findings were not seen in rats given NC-6004. These results were presumably attributable to the significantly reduced accumulation of platinum in nerve tissue when NC-6004 was administered ($P<0.05$). NC-6004 preserved the antitumour activity of CDDP and reduced its nephrotoxicity and neurotoxicity, which would therefore seem to suggest that NC-6004 could allow the long-term administration of CDDP where caution against hepatic dysfunction must be exercised.

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Cisplatin (*cis*-dichlorodiammineplatinum (II): CDDP) is a key drug in the chemotherapy for cancers, including lung, gastrointestinal, and genitourinary cancer (Roth, 1996; Boulikas and Vougiouka, 2004). However, we often find that it is necessary to discontinue treatment with CDDP due to its adverse reactions, for example, nephrotoxicity and neurotoxicity, despite its persisting effects (Pinzani *et al*, 1994). Platinum (Pt) analogues, for example, carboplatin and oxaliplatin (Cleare *et al*, 1978), have been developed to date to overcome these CDDP-related disadvantages. Consequently, these analogues are becoming the standard drugs for ovarian cancer (du Bois *et al*, 2003) and colon cancer (Cassidy *et al*, 2004). However, those regimens including CDDP are considered to constitute the standard treatment for lung cancer, stomach cancer, testicular cancer (Horwich *et al*, 1997), and urothelial cancer (Bellmunt *et al*, 1997). Therefore, the development of a drug delivery system (DDS) technology is anticipated, which would offer the better selective accumulation of CDDP into solid tumours while lessening its distribution into normal tissue.

Drug delivery system targeting involves two concepts: active targeting and passive targeting. Active targeting aims drug targeting through antigen–antibody reactions and specific bindings between molecules, for example, receptor and ligand. On the other hand, passive targeting is an approach in which the drug accumulates in tumour tissue using the pathophysiological characteristics of solid tumours such as the hyperplasia of tumour vasculature which generally occurs in solid tumours, but which is not seen in a comparable way in lymph nodes. Marked vascular hyperpermeability is also found in the tumour vasculature, and the combination of hyperplasia and hyperpermeability facilitate the extravasation of high-molecular-weight polymers or nanoparticles, which are less prone to leak from intact vasculature, and which can be retained in solid tumour tissue for a longer time (enhanced permeability and retention effect (EPR) effect) (Matsumura and Maeda, 1986; Maeda and Matsumura, 1989; Maeda, 2000, 2001). This effect allows passive targeting of macromolecules with a high blood retention profile into the site of tumour.

Simple polymerisation only is not sufficient to bring about the EPR effect, and strategies are also required to suppress trapping by

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the reticuloendothelial system (RES) and to enhance the blood retention profile (Klibanov *et al*, 1990, 1991; Allen, 1994; Gabizon *etal*, 1996; Lasic, 1996). Polyethylene glycol-tagged liposomal adriamycin (Doxil®) has recently been reported as a clinical success (Orditura *etal*, 2004). We have recently been conducting research dedicated to the development of polymeric micelles capable of incorporating anticancer drugs (Yokoyama *et al*, 1990, 1991, 1999). The Phase I clinical trial of adriamycin-incorporating polymeric micelles has been completed (Matsumura *et al*, 2004). Furthermore, in an animal model, the plasma and tumour area under the curve (AUC) values for taxol-incorporating polymeric micelle (NK105) showed 85- and 25-fold increases, respectively, as compared with those for taxol. Therefore, NK105 showed significant enhancement ($P<0.001$) of the antitumour activity of free taxol and a significant reduction ($P<0.05$) in its neurotoxicity (Hamaguchi *et al*, 2005). Based on these results, the Phase I clinical trial of NK105 is currently being conducted at the National Cancer Center Hospital, Tokyo. We have also been conducting research dedicated to the development of CDDP-incorporating polymeric micelles and have made a number of improvements, in the *in vivo* antitumour activity, reduction of nephrotoxicity, particle size, and particle size distribution as variables (Nishiyama and Kataoka, 2001; Nishiyama *et al*, 2001). Consequently, we discovered that block copolymers, which react with CDDP, acquire a long blood retention profile with the use of polyethylene glycol poly(glutamic acid) block copolymers (PEG–P(Glu)) (Nishiyama *et al*, 2003). In the present study, we used the final development of the technology to prepare CDDP-incorporating polymeric micelles (NC-6004) in an attempt to investigate the following objectives: (1) calculation of pharmacokinetic (PK) parameters in a detailed PK study of CDDP and NC-6004 in rats; (2) a comparison between CDDP and NC-6004 with respect to their antitumour activity in a human cancer cell line; and (3) a detailed comparison between CDDP and NC-6004 with respect to nephrotoxicity and neurotoxicity, which constitute the dose-limiting factors of CDDP.

MATERIALS AND METHODS

Materials

Cisplatin was purchased from WC Heraeus GmbH & Co., KG (Hanau, Germany). γ-Benzyl-L-glutamate *N*-carboxy anhydride was purchased from a supplier. *N,N*-dimethylformamide and 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide were purchased from Wako Pure Chemical Co., Inc. (Osaka, Japan). α-Methoxy-ω-aminopropyl polyethylene glycol ($CH_3O-PEG-CH_2CH_2CH_2-NH_2$; MW = 12 000) was purchased from NOF Corporation (Tokyo, Japan).

Following cell lines, MKN-45, MKN-28, EJ-1, J82, MBT-2, colo201, colo320, HT-29, A549, EBC-1, PC-14, and MCF-7 cells were purchased from the American Type Culture Collection.

Female BALB/*c nu/nu* mice were purchased from SLC (Shizuoka, Japan). Female Sprague–Dawley rats were purchased from Charles River Japan (Kanagawa, Japan). All animal procedures were performed in compliance with the guidelines for the care and use of experimental animals, which had been drawn up by the Committee for Animal Experimentation at the National Cancer Center; these guidelines meet the ethical standards required by law and also comply with the guidelines for the use of experimental animals in Japan and the UKCCCR guidelines (UKCCCR, 1998).

Preparation of PEG-P(Glu) and preparation of CDDP-incorporating polymeric micelles (NC-6004)

Polyethylene glycol–P(Glu) block copolymers were synthesised according to the slightly modified procedure of the previously reported synthetic method of PEG-P(Asp) (Nishiyama and Kataoka, 2001). γ-Benzyl L-glutamate *N*-carboxy anhydride was polymerised in *N,N*-dimethylformamide, initiated with the NH_2 amino group of $CH_3O-PEG-CH_2CH_2CH_2NH_2$, to obtain PEG–poly(γ-benzyl L-glutamate) block copolymers (PEG–PBLG). The polymerisation degree of PBLG was determined to be 40 by comparing proton ratios between PEG ($-OCH_2CH_2-$: $\delta = 3.7$ p.p.m.) and phenyl groups of PBLG ($-CH_2C_6H_5$: $\delta = 7.3$ p.p.m.) in ^{1}H NMR measurement (Mercury plus 300 (Varian Technologies); solvent: DMSO-d_6; and temperature: 25°C). The benzyl group was deprotected by mixing with 0.5 N NaOH at ambient temperature to obtain PEG–P(Glu) as a sodium salt.

Cisplatin-incorporating polymeric micelles (NC-6004) were prepared according to the slightly modified procedure of the previously reported synthetic method of CDDP-incorporating polymeric micelles (Nishiyama *et al*, 2003). Briefly, the sodium salt of PEG–P(Glu) and CDDP were dissolved in distilled water ([Glu] = 4.7 mmol l^{-1}; [CDDP]/[Glu] = 1.0) and were allowed to react for 72 h. NC-6004 thus prepared was purified with ultrafiltration (molecular weight cutoff size: 100 000). The size distribution of NC-6004 was evaluated by dynamic light scattering (DLS) at 23°C using the NICOMP 380 ZLS particle sizer (Particle Sizing Systems, Santa Barbara, CA).

Release of CDDP from NC-6004 dissolved in saline

NC-6004 was dissolved in saline and was then incubated at 37°C. In all, 80 μl of the solution was then harvested at 3, 6, 24, and 96 h after the onset of incubation. The release of CDDP from NC-6004 in the solution harvested at 37°C was quantified by gel permeation chromatography (column: Waters Ultrahydrogel 500 (ϕ7.8 × 300 mm); Waters GPC system equipped with a UV detector (310 nm); and eluent: 10 mmol l^{-1} phosphate-buffered 50 mmol l^{-1} NaCl solution).

In vitro cytoxicity

Various human cancer cell lines were evaluated in the present study. The cell lines were maintained in monolayer cultures in Dulbecco's modified Eagle's medium containing 10% (v v^{-1}) focal calf serum and 600 mg l^{-1} glutamine. WST-8 Cell Counting kit-8 (Dojindo, Kumamoto, Japan) was used for cell proliferation assay. In all, 2000 cells of each cell line in 90 μl of culture medium were plated in 96-well plates and were then incubated for 24 h at 37°C. Serial dilutions of CDDP and NC-6004 in a volume of 10 μl were added, and the cells incubated for 48 or 72 h. All dates were expressed as mean ± s.e. of triplicate of the date triplicate cultures. The data were then plotted as a percentage of the data from the control cultures, which were treated identically to the experimental cultures, except that no drug was added.

Pharmacokinetics and pharmacodynamics of CDDP and NC-6004

Under isoflurane anaesthesia, a polyethylene catheter was inserted into the right internal jugular vein of female Sprague–Dawley female rats. Rats ($n = 3$) were given a single intravenous (i.v.) injection of CDDP (5 mg kg^{-1}) or NC-6004 (an equivalent dose of 5 mg kg^{-1} CDDP) via the tail vein. At 5, 15, and 30 min, as well as at 1, 4, 12, 24, and 48 h after injection of each drug, blood (0.2 ml) was collected into a heparinised microtube via the polyethylene catheter. The blood samples were centrifuged (1000 g) for 10 min at room temperature to obtain the plasma. The plasma samples were stored below −80°C until the analysis. In a tissue distribution study, rats were injected i.v. with CDDP (5 mg kg^{-1}) or NC-6004 (an equivalent dose of 5 mg kg^{-1} CDDP) via the tail vein, and were then killed in groups of three animals at 10 min, at 1, 6, 24, and 48 h, and on day 7 day after injection of each drug under intraperitoneal pentobarbital anaesthesia (50 mg kg^{-1}). Various organs (kidney, liver, spleen, heart, lung, small intestine, colon,

and stomach) were dissected. The organ samples were stored below −80°C until the analysis. Female BALB/*c* mice were inoculated subcutaneously on the back with 10^6 MKN-45 cells (UKCCCR, 1998). After 10 days, when the tumour size had reached approximately 50 mm^2, mice were injected i.v. with CDDP (5 mg kg^{-1}) or NC-6004 (an equivalent dose of 5 mg kg^{-1} CDDP) via the tail vein and were then killed in groups of three animals at 10 min, at 1, 6, 24, and 48 h, and on day 7 after injection of each drug. The tumours were dissected and stored below −80°C until the analysis. The plasma samples were diluted with 0.1 N HCl, vortexed, and analysed for elemental Pt by frameless atomic absorption spectrophotometry (FAAS). The tissue samples were decomposed by heating in concentrated nitric acid, evaporated to dryness, and redissolved in 0.1 N HCl. Elemental Pt was measured by FAAS.

The PK parameters were calculated using noncompartmental analysis (WinNonlin standard software, version 3.1; Pharsight Corporation, Palo Alto, CA, USA). The following PK parameters were obtained: AUC, maximum Pt concentration (C_{max}), time to obtain C_{max} (T_{max}), total body clearance (CL_{tot}), terminal half-life of Pt ($t_{1/2}z$), and steady-state volume of distribution (V_{ss}). The area under the tumour concentration–time curve (tumour AUC) was calculated based on the trapezoidal rule up to 48 h. The parameters were calculated using the following equations:

$$AUC_{0-t}$$

was calculated by the trapezoidal rule to the last measurable data point:

$$AUC_{0-inf.} = \int_0^\infty C(t)dt$$

$$t_{1/2}z(\text{terminal half-life}) = 0.693/\lambda z$$

λz: first-order rate constant associated with terminal portion of the curve)

$$CL_{tot} = \text{Dose}/AUC_{0-inf.}$$

$$V_{ss} = MRT \times CL_{tot}(MRT : \text{mean residence time})$$

In vivo antitumour activity

Antitumour activity was evaluated using nude mice implanted with a human gastric cancer cell line MKN-4. BALB/*c nu/nu* female mice (aged 6 weeks) were inoculated subcutaneously with 10^6 MKN-45 cells on the right dorsal skin. After 3 days, when tumour diameter had reached approximately 3 mm, tumour-bearing mice were allocated randomly to drug administration groups of six animals each. The drugs were administered as follows: animals in the CDDP group were given doses of 0.5, 2.5, 5 mg kg^{-1}; animals in the NC-6004 group were given doses of 0.5, 2.5, and 5 mg kg^{-1}; and animals in the control group were given the 5% glucose solution. Cisplatin or NC-6004 was administered to mice at any of the above dose levels per dose every 3 days. Antitumour activity was evaluated in terms of tumour size by measuring two orthogonal diameters ($a \times b$: a, long diameter; b, short diameter) at various time points. Animals were killed by cervical dislocation when the tumour size reached approximately 15 mm (UKCCCR, 1998). Changes in body weight were also monitored for the mice which were used in the present study.

Nephrotoxicity and hepatotoxicity of CDDP and NC-6004

Under isoflurane anaesthesia, five groups of Sprague–Dawley female rats (aged 6 weeks; 185–215 g initial body weight) were given a single i.v. injection of 5% glucose ($n=8$), CDDP at a dose of 10 mg kg^{-1} ($n=12$), NC-6004 at a dose of 10 mg kg^{-1} on a CDDP basis ($n=13$), or NC-6004 at a dose of 15 mg kg^{-1} on a CDDP basis ($n=8$). Samples of blood and major organs were taken on day 7 after administration (UKCCCR, 1998). In the case of administering NC-6004 at a dose of 10 mg kg^{-1} on a CDDP basis, five samples of blood and major organs were taken on day 14 after administration. The organs were immersed in 10% formalin solution. In each blood sample, plasma concentrations of blood urea nitrogen (BUN), creatinine, glutamic oxaloacetic transaminase (GOT), and glutamic pyruvic transaminase (GPT) were measured by SRL Laboratories (Tokyo, Japan). In addition, WBC and platelet were counted for blood samples 7 and 14 days after each drug administration in SRL Laboratories (Tokyo, Japan).

Evaluation of neurotoxicity

The severity of neurotoxicity was assessed by electrophysiological and histopathological procedures. Under isoflurane anaesthesia, rats ($n=5$) were given CDDP (2 mg kg^{-1}), NC-6004 (an equivalent dose of 2 mg kg^{-1} CDDP), or 5% glucose, all i.v., twice a week, to a total of 11 administrations. Electrophysiological measurements were conducted at week 6 after the first administration, using the method described previously (McKeage *et al*, 1994; Screnci *et al*, 2000). Under light anaesthesia with phenobarbital, responses were evoked by stimulating the sciatic nerve at its notch and the tibial nerve at the ankle of the right hind paw, using a percutaneous needle electrode. The plantar muscle H- and M-waves were recorded using a pair of superficial silver–silver chloride electrodes applied to the sole and dorsum of the hind paw. H-response-related sensory nerve conduction velocity (SNCV) was calculated by dividing the distance between the stimulation sites at the sciatic notch and ankle by the difference in H-response latency after stimulation at the ankle and sciatic notch. M-response-related motor nerve conduction velocity (MNCV) was calculated by dividing the distance between the stimulation sites at the sciatic notch and ankle by the difference in M-response latency after stimulation at the sciatic notch and ankle. At week 7 after the initial administration, rats under deep anaesthesia with phenobarbital were subjected to intracardiac catheterisation and were rinsed with saline, followed by perfusion with 4% glutaraldehyde in 0.12 M PBS. Subsequently, a segment of the sciatic nerve was carefully removed. One part of the sciatic nerve was post-fixed with 4% glutaraldehyde in 0.12 M PBS for 24 h and was then embedded in epoxy resin as described previously (Cavaletti *et al*, 1992). The remaining parts of the sciatic nerve were immersed in a 10% formalin solution. Semi-thin (1 μm thick) and thin sections were prepared from the resin-embedded sciatic nerve for light microscopic observation and electron microscopic observation, respectively.

To determine the Pt concentration in the sciatic nerve, rats were given CDDP (5 mg kg^{-1}, $n=5$), NC-6004 (an equivalent dose of 5 mg kg^{-1} CDDP, $n=5$), or 5% glucose ($n=2$), all i.v. twice a week, to a total of four administrations. On day 3 after the final administration, a segment of the sciatic nerve was removed. The removed sciatic nerve was prepared for ICP-MS analysis as described previously (Screnci *et al*, 2000). Briefly, the nerve was immersed in 1 ml of 70% nitric acid overnight. On the next day, the nerve was digested for 2 h at 90°C and Milli-Q was then added to a final volume of 5 ml. Finally, the Pt concentration in the sample solution was analysed with an ICP-MS spectrometer (SPQ 9000; Seiko Instruments Inc., Tokyo, Japan).

Statistical analysis

Data on therapeutic efficacy and body weight change were expressed as the mean ± s.e. The other data were expressed as the mean ± s.d. The statistical significance of differences in therapeutic efficacy and body weight change between two administration groups was calculated by repeated-measured