

RESEARCH

Open Access

Promoter methylation analysis of WNT/ β -catenin pathway regulators and its association with expression of *DNMT1* enzyme in colorectal cancer

Nader Mansour Samaei¹, Yaghoub Yazdani¹, Reza Alizadeh-Navaei², Hossein Azadeh³ and Touraj Farazmandfar^{1,2,3*}

Abstract

Background: Aberrant DNA methylation as the most important reason making epigenetic silencing of genes is a main mechanism of gene inactivation in patients with colorectal cancer. In this study, we decided to identify promoter methylation status of ten genes encoding WNT negative regulators, and measure the expression of *DNMT1* enzyme in colorectal cancer samples.

Results: Aberrant methylation of *APC* gene was statistically significant associated with age over 50 ($p = 0.017$), *DDK3* with male ($p < 0.0001$), *SFRP4*, *WIF1*, and *WNT5a* with increasing tumor stage ($p = 0.004$, $p = 0.029$, and $p = 0.004$), *SFRP4* and *WIF1* with tumor differentiation ($p = 0.009$ and $p = 0.031$) and *SFRP2* and *SFRP5* with histological type ($p = 0.001$ and $p = 0.025$). The increasing number of methylated genes correlated with the expression levels of the *DNMT1* mRNA.

Conclusions: The rate of gene promoter methylation of WNT pathway regulators is high in colorectal cancer cells. Hyper-methylation is associated with increased expression of the *DNMT1* enzyme.

Keywords: WNT/ β -catenin signaling, Colorectal cancer, Promoter methylation, *DNMT1*

Background

Colorectal cancer (CRC) is the second-leading cause of cancer deaths among adults [1]. Aberrant DNA methylation as the most important reason of epigenetic gene silencing is the main mechanism of gene inactivation in patients with CRC [2,3]. Methylation normally occurs in 5-carbon position of cytosine base within CpG dinucleotide in areas of repetitive DNA outside of exons, introduced by DNA methylases; mainly DNA methyltransferase 1 (*DNMT1*). Although the *DNMT1* enzyme is not the only factor involving in the DNA methylation, but plays a significant role in creating it [4-6]. DNA methylation of CpG islands in promoter regions of tumor suppressor genes and DNA repair genes is now recognized as a prevalent feature of human cancers [2].

The developmental WNT/ β -catenin signaling pathway is one of the well-known signaling pathways involved in embryogenesis and cancer. A common mechanism of carcinogenesis through WNT/ β -catenin signaling is the increased levels of β -catenin protein, which are often results from mutations in the adenomatous polyposis coli (*APC*) gene (encoding a β -catenin inhibitor) or in the *β -catenin* gene. Moreover, other mechanisms like functional reduction or loss of negative regulators by DNA methylation or overexpression of oncogenic ligands may contribute to WNT pathway activation in cancer development [7-9]. In previous studies, DNA methylation of some WNT inhibitors such as *APC*, axis inhibition protein 2 (*AXIN2*), secreted frizzled-related protein (*SFRP*) family and members of the DICKKOPF (*DKK*) have been reported in CRC [10-13].

As of yet, no comprehensive survey on promoter methylation levels of WNT pathway inhibitors in CRC has been performed, while a potential use of promoter methylation in cancer diagnosis and prediction can be highly regarded. In this study, promoter methylation status of ten genes encoding WNT negative regulators

* Correspondence: tourajf@yahoo.com

¹Golestan Research Center of Gastroenterology and Hepatology-GRCGH, Golestan University of Medical Sciences, Gorgan, Iran

²Molecular and Cell Biology Research Center, Mazandaran University of Medical Sciences, P.O. Box: 4817773913, Sari, Iran

Full list of author information is available at the end of the article

was assayed in CRC samples. These genes including extracellular WNT inhibitors [WNT inhibitory factor-1 (*WIF1*), *DKK3*, *SFRP2*, *SFRP4*, *SFRP5*], cytosolic WNT antagonists (*AXIN2*, *APC*), nuclear proteins [sex determining region Y related box 7 (*SOX7*) and 17 (*SOX17*)], and one WNT ligand [wingless-type MMTV integration site family member 5A (*WNT5A*)]. To estimate the association between methylation and expression of the *DNMT1* enzyme, the expression of this enzyme was measured in the samples.

Methods

Subjects

Samples including 125 Formalin-fixed paraffin-embedded (FFPE) cancerous and adjacent normal tissues (normal tissues distances from the tumor were not measured in this study) obtained from the CRC patients who had surgery between 2005 and 2011 from pathology laboratory. Clinical and pathologic features of patients were extracted from medical records and Tumor staging was determined on the basis of the tumor node metastasis (TNM) classification [14]. Samples with mutational familial adenomatous polyposis or hereditary non-polyposis CRC were excluded of this study. This study was approved of the Clinical Research Ethics Committee in Golestan University of Medical Science.

Methylation analysis

Genomic DNA of microdissected tissue samples was extracted and bisulfite treated using the EpiTect Fast Bisulfite Conversion Kit (Qiagen, Hilden, Germany). Methylation specific PCR (MSP) primers of 10 selected candidate genes were prepared as described previously [15]. MSP was performed using 50 nanograms of modified DNA and Taq DNA polymerase (Roche, Woerden, Netherlands) in 7500 Real-Time PCR system (Applied Biosystem, USA). The methylation was calculated from threshold cycles (CT) values. Ten MSPs for the WNT inhibitors were analytically validated using methylated DNA as positive control (CTs \leq 25 cycles) and primary keratinocyte DNA as unmethylated controls (CTs $>$ 35 cycles).

DNMT1 expression assay

The amplification primers for human *DNMT1* and Hypoxanthine-guanine phosphoribosyltransferase (*HPRT*) cDNA designed by GENE RUNNER software and be reviewed in NCBI and BLAST. *DNMT1* Primers sequence including 5'-AGCCAGGTAGCCCTCCTC-3' as forward and 5'-GACAGCTTAACAGAAAAGGAATG-3' as reverse with a 141 base pairs (bp) PCR product (GenBank accession number NM_001379.1) and *HPRT* including 5'-TGGACTAATATGGACAGGACT-3' as forward and 5'-CCTGTTGACTGGTCATTACAAT-3' as reverse with

a 219 bp PCR product (GenBank accession number NM_000194). Total RNA was purified from micro-dissected FFPE tissues using the PureLink FFPE RNA Isolation Kit (Invitrogen, Karlsruhe, Germany). The first strand cDNA was generated using a SuperScript III First-Strand Synthesis SuperMix (Invitrogen, Karlsruhe, Germany). Reverse transcriptase PCR was performed using SYBR Green PCR Master Mix (Fermentas, Lithuania) in triplicate and normalized to *HPRT* in 7500 detection system. Real-Time PCR conditions consist of 40 cycles (95°C for 15 s, 55°C for 30 s, 72°C for 20 s) after one step initial denaturation (95°C for 10 min). The mean and standard deviation (SD) of *DNMT1* mRNA was calculated by $2^{-\Delta CT}$ and the expression fold was calculated by the $2^{-\Delta\Delta CT}$ and a fold change ≥ 1.5 was considered as over-expression [16].

Statistical analysis

Statistical analysis was performed by SPSS (version 17.0). Methylation frequencies associations with clinical and pathologic features were analyzed using chi-squared and fisher's exact test. The survival curves were estimated by the Kaplan-Meier method. Association between promoter methylation status with survival was examined by the log-rank test. Survival time was determined from the diagnosis date to the death date due to CRC. A p-value of less than 0.05 was considered statistically significant.

Results

The promoter methylation status

In this study, the promoter methylation was examined on ten genes encoding the WNT pathway inhibitors in CRC tissue samples. Aberrant promoter methylation was detected in 78.4% of patients (98 of 125) (CTs \leq 25) and none of adjacent non-tumor samples showed methylation (CTs $>$ 35 cycles). The promoter methylation status of the ten genes, including *APC*, *AXIN2*, *DKK3*, *SFRP2*, *SFRP4*, *SFRP5*, *SOX7*, *SOX17*, *WIF1* and *WNT5a* are respectively 44 samples (35.2%), 41 (32.8%), 50 (40%), 58 (46.4%), 38 (28.8%), 33 (26.4%), 40 (32%), 42 (33.6%), 52 (41.6%) and 28 (22.4%) (Table 1).

The correlation with clinical and pathological features

We analyzed methylation status relationship of these genes with some patients' clinical and pathological features. As the results in Table 1 show, *APC* gene methylation is statistically associated with age over 50 ($p = 0.017$). *DDK3* gene methylation is also significantly associated with male ($p < 0.0001$). Methylation of *SFRP4*, *WIF1* and *WNT5a* genes were meaningfully associated with increasing tumor stage ($p = 0.004$, $p = 0.029$ and $p = 0.004$). Moreover, methylation frequency of *SFRP4* and *WIF1* genes were also significantly associated with tumor differentiation ($p = 0.009$ and $p = 0.031$). The *SFRP2* and *SFRP5* genes

Table 1 The association of promoter methylation frequencies and DNMT1 expression with some pathological and clinical features of patients

Clinical and pathological features	N	APC			AXIN2			DKK3			SFRP2			SFRP4			SFRP5		
		N (%)			N (%)			N (%)			N (%)			N (%)			N (%)		
		M	U	p	M	U	P	M	U	p	M	U	p	M	U	p	M	U	p
All cases	125	44 (35.2)	81 (64.8)		41 (32.8)	84 (67.2)		50 (40)	75 (60)		58 (46.4)	67 (53.6)		38 (30.4)	87 (69.6)		33 (26.4)	92 (73.6)	
Age				.017															
<50	18	11 (25)	7 (8.7)		7 (17.1)	11 (13.1)		8 (16)	10 (13.3)		9 (15.5)	9 (13.4)		5 (13.2)	13 (14.9)		8 (24.2)	10 (10.7)	
≥50	107	33 (75)	74 (91.3)		34 (82.9)	73 (86.9)		42 (84)	65 (86.7)		49 (84.5)	58 (86.6)		33 (86.8)	74 (85.1)		25 (75.8)	82 (89.3)	
Sex										<.001									
Female	55	21 (47.7)	34 (42)		16 (39)	39 (46.4)		12 (24)	43 (57.3)		28 (48.3)	27 (40.3)		13 (34.2)	42 (48.3)		17 (51.5)	38 (41.3)	
Male	70	23 (52.3)	47 (58)		25 (61)	45 (53.6)		38 (76)	32 (42.7)		30 (51.7)	40 (59.7)		25 (65.8)	45 (51.7)		16 (48.5)	54 (58.7)	
Tumor location																			
Proximal	58	18 (40.9)	40 (49.2)		19 (46.3)	39 (46.4)		24 (48)	34 (45.3)		32 (55.1)	26 (38.8)		17 (44.7)	41 (47.1)		16 (48.5)	42 (45.7)	
Distal	67	26 (59.1)	41 (50.8)		22 (53.7)	45 (53.6)		26 (52)	41 (54.7)		26 (44.9)	41 (61.2)		21 (55.3)	46 (52.9)		17 (51.5)	50 (54.3)	
TNM stage																			.004
I	17	5 (11.4)	12 (14.8)		6 (14.6)	11 (13.1)		8 (16)	9 (12)		9 (15.5)	8 (11.9)		4 (10.5)	13 (14.9)		5 (15.2)	12 (13)	
II	39	17 (38.6)	22 (27.2)		11 (26.8)	28 (33.3)		15 (30)	24 (32)		18 (31)	21 (31.3)		10 (26.3)	29 (33.3)		12 (36.4)	27 (29.3)	
III	61	18 (40.9)	43 (53.1)		19 (46.4)	42 (50)		22 (44)	39 (52)		25 (43.1)	36 (53.8)		17 (44.7)	44 (50.6)		13 (39.4)	48 (52.2)	
IV	8	4 (9.1)	4 (4.9)		5 (12.2)	3 (3.6)		5 (10)	3 (4)		6 (10.4)	2 (3)		7 (18.5)	1 (1.2)		3 (9)	5 (5.5)	
Tumor differentiation																			.009
Low	11	4 (9.1)	7 (8.7)		5 (12.2)	6 (7.1)		3 (6)	8 (10.7)		4 (6.9)	7 (10.4)		6 (15.8)	5 (5.7)		3 (9.1)	8 (8.7)	
Moderate	89	30 (68.2)	59 (72.8)		27 (65.9)	62 (73.8)		39 (78)	50 (66.7)		43 (74.1)	46 (68.7)		20 (52.6)	69 (79.3)		22 (66.7)	67 (72.8)	
High	25	10 (22.7)	15 (18.5)		9 (21.9)	16 (19.1)		8 (16)	17 (22.6)		11 (19)	14 (20.9)		12 (31.6)	13 (15)		8 (24.2)	17 (18.5)	
Histological type																			.001
Non-mucinous	98	30 (68.2)	68 (84)		34 (82.9)	64 (76.2)		39 (78)	59 (78.7)		53 (91.4)	45 (67.2)		30 (78.9)	68 (78.2)		21 (63.6)	77 (83.7)	.025
Mucinous	27	14 (31.8)	13 (16)		7 (17.1)	20 (23.8)		11 (22)	16 (21.3)		5 (8.6)	22 (32.8)		8 (21.1)	19 (21.8)		12 (36.4)	15 (16.3)	

Clinical and pathological features	SOX7		<i>p</i>	SOX17		<i>p</i>	WIF1		<i>p</i>	WNT5a		<i>p</i>	DNMT1 expression		
	N (%)			N (%)			N (%)			N (%)			Fold change (%)		<i>p</i>
	M	U		M	U		M	U		M	U		≥1.5	<1.5	
All cases	40 (32)	85 (68)		42 (33.6)	83 (66.4)		52 (41.6)	73 (58.4)		28 (22.4)	97 (77.6)		52 (41.6)	73 (58.4)	
Age															
<50	7 (17.5)	11 (12.5)		10 (23.8)	8 (9.6)		5 (9.6)	13 (17.8)		6 (21.4)	12 (12.4)		7 (13.5)	11 (15.1)	
≥50	33 (82.5)	74 (87.5)		32 (76.2)	75 (90.4)		47 (90.4)	60 (82.2)		22 (78.6)	85 (87.6)		45 (86.5)	62 (84.9)	
Sex															
Female	19 (47.5)	36 (42.4)		15 (35.7)	40 (48.2)		23 (44.2)	32 (43.8)		12 (42.8)	43 (44.3)		21 (40.4)	34 (46.6)	
Male	21 (52.5)	49 (57.6)		27 (64.3)	43 (51.8)		29 (55.8)	41 (56.2)		16 (57.2)	54 (55.7)		31 (59.6)	39 (53.4)	
Tumor location															
Proximal	21 (52.5)	37 (43.5)		20 (47.6)	38 (45.8)		27 (51.9)	31 (42.5)		14 (50)	44 (45.4)		28 (53.8)	30 (41.1)	
Distal	19 (47.5)	48 (56.5)		22 (52.4)	45 (54.2)		25 (48.1)	42 (57.5)		14 (50)	53 (54.6)		24 (46.2)	43 (58.9)	
TNM stage									.029			.004			
I	7 (17.5)	10 (11.8)		6 (14.3)	11 (13.3)		12 (23.1)	5 (6.8)		3 (10.7)	14 (14.4)		7 (13.5)	10 (13.7)	
II	13 (32.5)	26 (30.6)		10 (23.8)	29 (34.9)		14 (26.9)	25 (34.3)		5 (17.8)	34 (35.1)		13 (25)	26 (35.6)	
III	16 (40)	45 (52.9)		24 (57.1)	37 (44.6)		25 (48.1)	36 (49.3)		14 (50)	47 (48.4)		27 (51.9)	34 (46.6)	
IV	4 (10)	4 (4.7)		2 (4.8)	6 (7.2)		1 (1.9)	7 (9.6)		6 (21.5)	2 (2.1)		5 (9.6)	3 (4.1)	
Tumor differentiation									.031						
Low	2 (5)	9 (10.6)		7 (16.7)	4 (4.8)		1 (1.9)	10 (13.7)		3 (10.7)	8 (8.2)		4 (7.7)	7 (9.6)	
Moderate	32 (80)	57 (67.1)		30 (71.4)	59 (71.1)		37 (71.2)	52 (71.2)		18 (64.3)	71 (73.2)		36 (69.2)	53 (72.6)	
High	6 (15)	19 (22.3)		5 (11.9)	20 (24.1)		14 (26.9)	11 (15.1)		7 (25)	18 (18.6)		12 (23.1)	13 (17.8)	
Histological type															
Non-mucinous	34 (85)	64 (75.3)		32 (76.1)	66 (79.5)		37 (71.2)	61 (83.6)		19 (67.8)	79 (81.4)		35 (67.3)	63 (86.3)	
Mucinous	6 (15)	21 (24.7)		10 (23.9)	17 (20.5)		15 (28.8)	12 (16.4)		9 (32.2)	18 (18.6)		17 (32.7)	10 (13.7)	

N; Number of cases, M; Methylated, U; Unmethylated, *p*; *p* value.
Only significant *P* values are described.

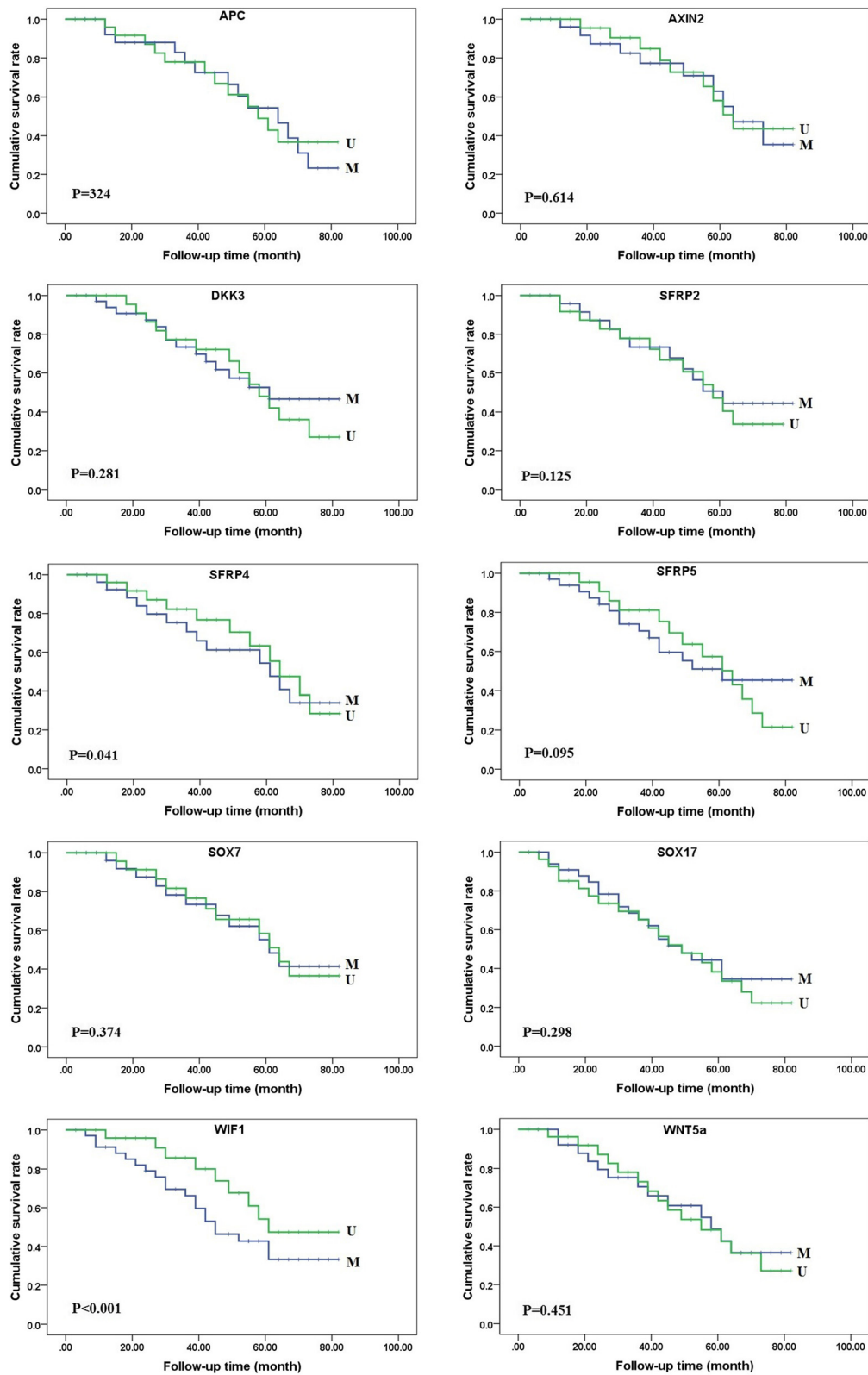


Figure 1 Kaplan-Meier curves for overall survival in colorectal carcinomas. Kaplan-Meier curves for cumulative survival rate of patients according to the promoter methylation in all the colorectal carcinomas. Among the ten genes, only patients with methylated *WIF1* gene promoter had shorter overall survival. M, Methylated; U, Unmethylated.

methylation was correlated with histological type, therefore the frequency of methylation is higher in non-mucinous type ($p = 0.001$ and $p = 0.025$). There is no significant association between genes methylation status and tumor location. There is also no significant association between *DNMT1* expression and clinicopathological features.

Follow-up information was available on 112 CRC patients for 42 ± 25 (3 to 80) months. Univariate analysis by the Kaplan-Meier curves indicated, among the ten genes, only *WIF1* has a negative correlation between promoter methylation and survival in CRC patients ($P < 0.001$) (Figure 1).

Correlation of *DNMT1* overexpression with the increasing number of methylated genes

We assayed the expression levels of *DNMT1* enzyme mRNA in 125 tumor and adjacent normal tissues. As Figure 2 shows, *DNMT1* expression in CRC tissues (2.01 ± 0.82) is statistically higher than the non-tumor mucosa (1.02 ± 0.52) ($P < 0.001$), as well as methylated (2.91 ± 0.95) than non-methylated samples (1.07 ± 0.44) ($P < 0.001$). We also investigated the expression levels of *DNMT1* mRNA within methylated samples and was compared to fold changes of *DNMT1* expression. For this purpose, methylated samples were divided into six groups according to the number of methylated genes. The results show; the expression level of the *DNMT1* mRNA was directly correlated with the increasing number of methylated genes in methylated samples (Table 2).

Discussion

Today, the epigenetic markers of causing changes in the WNT signaling pathways are highly considered, both in the detection and prognosis of the disease process in many

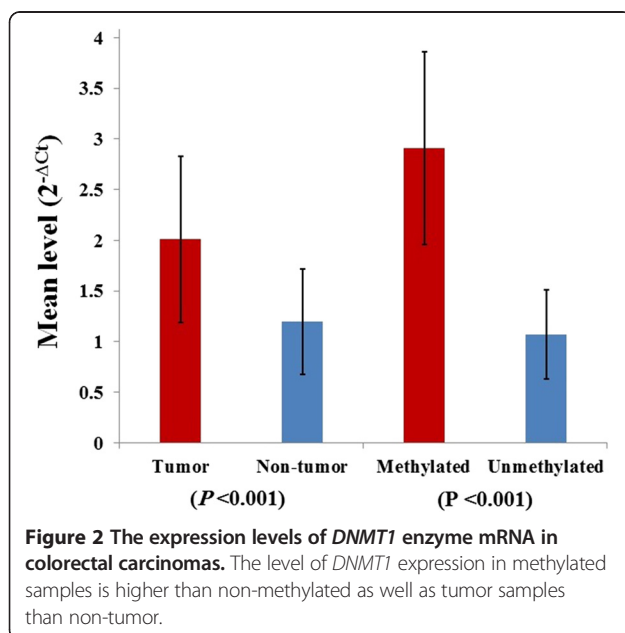


Table 2 The relationship of *DNMT1* expression with the number of methylated genes

Number of methylated genes	<i>DNMT1</i> -overexpressed cases		Odds ratio (CI 95%)
	N (%)	Fold change (mean ± SD)	
1 (n = 35)	13 (37.1)	1.52 ± 1.12	1
2 (n = 19)	11 (57.9)	2.12 ± 1.56	2.3 (0.7-7.2)
3 (n = 16)	9 (56.2)	2.02 ± 1.78	2.1 (0.6-7.2)
4 (n = 10)	6 (60)	3.61 ± 1.89	2.5 (0.6-10.7)
5 (n = 11)	7 (63.6)	3.06 ± 1.55	2.9 (0.7-12.9)
6 (n = 7)	6 (85.7)	4.14 ± 1.28	10.1 (1.1-93.9)*

* p value < 0.05 , CI, confidence interval.

cancers [17]. The study of methylation as a reversible major change during the early stages of tumor angiogenesis is under investigation [18,19]. Hence, we were going to investigate the variability of promoter methylation of WNT negative regulators to estimate these changes in CRC. In this study, the frequency of promoter methylation of *APC* gene (35.2%) is higher than the frequency obtained during the studies of Chen et al. (17.9%), Esteller et al. (18%) and Arnold et al. (28%) [10,20,21]. On the other hand, this frequency is less than the frequencies in Studies of Iacopetta et al. (41.1%) and Fu et al. (41.7%) [22,23]. Because, changes in the *APC* gene are the most common cause of CRC, 35.2% methylation can also be significant. The *AXIN2* methylation frequency of this study (32.8%) compared to prevalence of the Koinuma et al. study (25%) had higher level [11]. It seems that frequency of *DKK3* promoter methylation (40%) is less than Yu et al. study (52%). Unlike Yu et al. study, we reported that the increasing of promoter methylation frequency was significant in men, but we did not find a significant association between promoter methylation frequencies with cancer progression

Table 3 The comparison of promoter methylation of this study and other reports in colorectal carcinomas

Genes	Number of methylated samples (%)	References (frequency of gene)
<i>APC</i>	44 (35.2)	Esteller et al. [21] (18%); Arnold et al. [10] (28%); Chen et al. [20] (17.9%); Iacopetta et al. [22] (41.1%) and Fu et al. [23] (41.7%)
<i>AXIN2</i>	41 (32.8)	Koinuma et al. [11] (25%)
<i>DKK3</i>	50 (40)	Yu et al. [12] (52%)
<i>SFRP2</i>	58 (46.4)	Qi et al. [13] (82.8%)
<i>SFRP4</i>	38 (30.4)	Qi et al. [13] (32.4%)
<i>SFRP5</i>	33 (26.4)	Qi et al. [13] (54.3%)
<i>SOX7</i>	40 (32)	No Reference
<i>SOX17</i>	42 (33.6)	No Reference
<i>WIF1</i>	52 (41.6)	Lee et al. [24] (74%)
<i>WNT5a</i>	28 (22.4)	Rawson et al. [25] (18.8%)

stages [12]. The promoter methylation frequency of *SFRP2*, *4*, *5* genes in this study (46.4%, 28.8%, and 26.4%) compared to the results of Qi et al. study (82.8%, 32.4% and 54.3%) is much lower [13]. Low frequency of *WIF1* promoter methylation in this study (41.6%) compared to the Lee et al. study (74%) was also considerable [24]. There are few differences between frequency of *WNT5a* promoter methylation in this study (22.4%) and Rawson et al. study (18.8%). In both studies, the frequency of promoter methylation is significantly associated with female gender [25] (Table 3). Univariate analysis indicates that *WIF1* promoter methylation is prognostic factors for overall survival in colorectal carcinomas. The results of this study show that *DNMT1* expression levels in methylated samples are higher from unmethylated, unlike Ting et al. study in which they believed the *DNMT1* enzyme has no effect on the maintenance of DNA methylation [26]. The increasing expression of the *DNMT1* enzyme weakly correlates with the increasing number of methylated genes (Table 2). On the other hand, there have not been many studies on correlation between *DNMT1* expression and methylation, which makes it difficult to evaluate our work; Therefore, It needs more study.

Conclusions

We have shown that the rate of gene methylation in cancer cells increases can contribute to cancer development and progression. Methylation may also increase due to increased expression or mutations in the methyltransferase enzyme or their regulatory proteins in cancer cells. Knowing the rate of *DNMT1* enzyme overexpression in human cancers, particularly in cases of hyper-methylated might be useful as part of the diagnostic and prognostic evaluation in human cancers.

Competing interests

The authors declare no conflict of interests.

Authors' contributions

NMS carried out the Real-Time PCR, data analysis and manuscript preparation. YY, RAN and HA participated project design, data analysis and manuscript preparation. TF supervised experimental design, data analysis and reviewed manuscript. All authors read and approved the final manuscript.

Acknowledgments

This study supported by a grant from the Research and Technology Department in Golestan University of Medical Sciences.

Author details

¹Golestan Research Center of Gastroenterology and Hepatology-GRCGH, Golestan University of Medical Sciences, Gorgan, Iran. ²Molecular and Cell Biology Research Center, Mazandaran University of Medical Sciences, P.O. Box: 4817773913, Sari, Iran. ³Cancer Research Center, Mazandaran University of Medical Sciences, Sari, Iran.

Received: 7 June 2014 Accepted: 27 July 2014

Published online: 09 August 2014

References

1. Jemal A, Siegel R, Ward E, Hao Y, Xu J, Murray T, Thun MJ: **Cancer statistics, 2008.** *CA Cancer J Clin* 2008, **58**:71–96.
2. Issa J-P: **CpG island methylator phenotype in cancer.** *Nat Rev Cancer* 2004, **4**:988–993.
3. Kondo Y, Issa J-P: **Epigenetic changes in colorectal cancer.** *Cancer Metastasis Rev* 2004, **23**:29–39.
4. Markowitz SD, Bertagnolli MM: **Molecular origins of cancer: molecular basis of colorectal cancer.** *N Engl J Med* 2009, **361**:2449–2460.
5. Ting AH, Jair K, Schuebel KE, Baylin SB: **Differential requirement for DNA methyltransferase 1 in maintaining human cancer cell gene promoter hypermethylation.** *Cancer Res* 2006, **66**:729–735.
6. Jair K-W, Bachman KE, Suzuki H, Ting AH, Rhee I, Yen R-WC, Baylin SB, Schuebel KE: **De novo CpG island methylation in human cancer cells.** *Cancer Res* 2006, **66**:682–692.
7. Smith JJ, Deane NG, Dhawan P, Beauchamp RD: **Regulation of metastasis in colorectal adenocarcinoma: a collision between development and tumor biology.** *Surgery* 2008, **144**:353–366.
8. Veeck J, Dahl E: **Targeting the Wnt pathway in cancer: the emerging role of Dickkopf-3.** *Biochim Biophys Acta* 1825, **2012**:18–28.
9. Bienz M, Clevers H: **Linking colorectal cancer to Wnt signaling.** *Cell* 2000, **103**:311–320.
10. Arnold CN, Goel A, Niedzwiecki D, Dowell JM, Wasserman L, Compton C, Mayer RJ, Bertagnolli MM, Boland CR: **APC promoter hypermethylation contributes to the loss of APC expression in colorectal cancers with allelic loss on 5q.** *Cancer Biol Ther* 2004, **3**:960–964.
11. Koinuma K, Yamashita Y, Liu W, Hatanaka H, Kurashina K, Wada T, Takada S, Kaneda R, Choi YL, Fujiwara S-I, Miyakura Y, Nagai H, Mano H: **Epigenetic silencing of AXIN2 in colorectal carcinoma with microsatellite instability.** *Oncogene* 2006, **25**:139–146.
12. Yu J, Tao Q, Cheng YY, Lee KY, Ng SSM, Cheung KF, Tian L, Rha SY, Neumann U, Röcken C, Ebert MPA, Chan FKL, Sung JY: **Promoter methylation of the Wnt/beta-catenin signaling antagonist Dkk-3 is associated with poor survival in gastric cancer.** *Cancer* 2009, **115**:49–60.
13. Qi J, Zhu Y-Q, Luo J, Tao W-H: **Hypermethylation and expression regulation of secreted frizzled-related protein genes in colorectal tumor.** *World J Gastroenterol* 2006, **12**:7113–7117.
14. Sobin LH, Fleming ID: **TNM Classification of Malignant Tumors, fifth edition (1997).** Union Internationale Contre le Cancer and the American Joint Committee on Cancer. *Cancer* 1997, **80**:1803–1804.
15. Van der Meide WF, Snellenberg S, Meijer CJLM, Baalbergen A, Helmerhorst TJM, van der Sluis WB, Snijders PJF, Steenbergen RDM: **Promoter methylation analysis of WNT/β-catenin signaling pathway regulators to detect adenocarcinoma or its precursor lesion of the cervix.** *Gynecol Oncol* 2011, **123**:116–122.
16. Schmittgen TD, Livak KJ: **Analyzing real-time PCR data by the comparative C(T) method.** *Nat Protoc* 2008, **3**:1101–1108.
17. Ying Y, Tao Q: **Epigenetic disruption of the WNT/beta-catenin signaling pathway in human cancers.** *Epigenetics* 2009, **4**:307–312.
18. Paluszczak J, Baer-Dubowska W: **Epigenetic diagnostics of cancer—the application of DNA methylation markers.** *J Appl Genet* 2006, **47**:365–375.
19. Kulis M, Esteller M: **DNA methylation and cancer.** *Adv Genet* 2010, **70**:27–56.
20. Chen J, Röcken C, Lofton-Day C, Schulz H-U, Müller O, Kutzner N, Malfertheiner P, Ebert MPA: **Molecular analysis of APC promoter methylation and protein expression in colorectal cancer metastasis.** *Carcinogenesis* 2005, **26**:37–43.
21. Esteller M, Sparks A, Toyota M, Sanchez-Cespedes M, Capella G, Peinado MA, Gonzalez S, Tarafa G, Sidransky D, Meltzer SJ, Baylin SB, Herman JG: **Analysis of adenomatous polyposis coli promoter hypermethylation in human cancer.** *Cancer Res* 2000, **60**:4366–4371.
22. Iacopetta B, Grieu F, Li W, Ruszkiewicz A, Caruso M, Moore J, Watanabe G, Kawakami K: **APC gene methylation is inversely correlated with features of the CpG island methylator phenotype in colorectal cancer.** *Int J Cancer* 2006, **119**:2272–2278.
23. Fu X, Li J, Li K, Tian X, Zhang Y: **Hypermethylation of APC promoter 1A is associated with moderate activation of Wnt signalling pathway in a subset of colorectal serrated adenomas.** *Histopathology* 2009, **55**:554–563.
24. Lee BB, Lee EJ, Jung EH, Chun H-K, Chang DK, Song SY, Park J, Kim D-H: **Aberant methylation of APC, MGMT, RASSF2A, and Wif-1 genes in plasma as a biomarker for early detection of colorectal cancer.** *Clin Cancer Res* 2009, **15**:6185–6191.

25. Rawson JB, Mrkonjic M, Daftary D, Dicks E, Buchanan DD, Younghusband HB, Parfrey PS, Young JP, Pollett A, Green RC, Gallinger S, McLaughlin JR, Knight JA, Bapat B: Promoter methylation of Wnt5a is associated with microsatellite instability and BRAF V600E mutation in two large populations of colorectal cancer patients. *Br J Cancer* 2011, **104**:1906–1912.
26. Ting AH, Jair K, Suzuki H, Yen R-WC, Baylin SB, Schuebel KE: CpG island hypermethylation is maintained in human colorectal cancer cells after RNAi-mediated depletion of DNMT1. *Nat Genet* 2004, **36**:582–584.

doi:10.1186/s12929-014-0073-3

Cite this article as: Samaei *et al.*: Promoter methylation analysis of WNT/ β -catenin pathway regulators and its association with expression of DNMT1 enzyme in colorectal cancer. *Journal of Biomedical Science* 2014 **21**:73.

**Submit your next manuscript to BioMed Central
and take full advantage of:**

- Convenient online submission
- Thorough peer review
- No space constraints or color figure charges
- Immediate publication on acceptance
- Inclusion in PubMed, CAS, Scopus and Google Scholar
- Research which is freely available for redistribution

Submit your manuscript at
www.biomedcentral.com/submit

 **BioMed** Central