Clinical significance and association of RUNX3 hypermethylation frequency with colorectal cancer: a meta-analysis

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Background: The RUNX family, which is composed of RUNX1, RUNX2, and RUNX3, is a sequence-specific transcription factor family and is closely involved in a variety of cellular processes including development, differentiation, participation in the regulation of p53-dependent DNA damage response and/or tumorigenesis. Emerging evidence indicates that RUNX3 is a candidate tumor suppressor in several types of human tumors including colorectal cancer (CRC). However, the correlation of RUNX3 inactivation with CRC remains unclear. In the study reported here, we conducted a systematic review and meta-analysis to quantitatively evaluate the effects of RUNX3 hypermethylation/expression on the incidence of CRC.

Methods: A detailed search of the literature was made using Medline® and Web of Science for related research publications written in English. The methodological quality of the studies was also evaluated. The data were extracted and assessed by two reviewers independently. Analyses of the pooled data were performed. Odds ratios (ORs) and hazard ratios were calculated and summarized, respectively.

Results: A final analysis of 1,427 CRC patients from eleven eligible studies was performed. We observed that RUNX3 hypermethylation was significantly higher in CRC than in normal colorectal mucosa. The pooled OR from six studies comprising 289 CRC and 188 normal colorectal mucosa was OR = 0.07 (confidence interval [CI] = 0.03–0.18, P < 0.00001). Aberrant RUNX3 hypermethylation/expression was significantly higher in advanced CRC than in early staged CRC (OR = 0.54, CI = 0.41–0.71, P < 0.0001). Aberrant RUNX3 hypermethylation/expression was also significantly higher in microsatellite instability (MSI)-positive CRC than in MSI-negative CRC (OR = 0.44, CI = 0.3–0.66, P < 0.0001). In addition, CRC patients with RUNX3 hypermethylation or lacking RUNX3 protein expression had a lower survival rate than those without RUNX3 hypermethylation or those who did not express RUNX3 protein.

Conclusion: The results of this meta-analysis suggest that RUNX3 hypermethylation is associated with an increased risk of CRC, increased risk of progression of CRC, and a poorer CRC survival rate. RUNX3 hypermethylation, which induces the inactivation of RUNX3 gene, plays an important role in colorectal carcinogenesis, high levels of MSI, as well as CRC progression and development.

Keywords: methylation, tumor-suppressor gene, odds ratio, hazard ratio, microsatellite instability

Introduction

Colorectal cancer (CRC) is one of the most malignant types of cancers. In the USA and Europe, CRC is the second most frequent cancer after lung cancer that leads to death.¹ The incidence of CRC in the People’s Republic of China has been reported to increase annually and will continue to rise in the next few years.² Currently, there are
approximately 1.25 million patients diagnosed with CRC, and more than 600,000 patients will die from this disease every year worldwide. Surgical resection can be performed to remove the tumor if no lymph-node or distant metastasis is present, but the recurrence rate after surgery remains high. Therefore, investigation of the mechanism of initiation and progression and identification of prognostic markers are still needed in the treatment of CRC.

A proper DNA damage response has been considered a critical barrier to genetic alterations, preventing tumor initiation and progression. The runt-domain-related (RUNX) family of genes, RUNX1, RUNX2, and RUNX3, have recently come to prominence because of their protein roles as essential regulators of cell fate in development and their paradoxical effects in cancer, as well as in the regulation of p53-dependent DNA damage response and/or tumorigenesis. The RUNX3 gene is one of the most critical members of the runt-domain family and has a crucial role in the regulation of cell proliferation and cell death by apoptosis, and in angiogenesis, cell adhesion, and invasion. The RUNX3 gene, localized to chromosome 1p36, a region that exhibits frequent loss-of-heterozygosity events in colon, gastric, breast, and ovarian cancers, is considered a tumor-suppressor gene involved in the transforming growth factor beta (TGF-β) signaling pathway. Its precise function has been intensively studied in several tumors, with upregulation of the induction of cell-cycle arrest, apoptosis, and downregulation of cyclin D1 expression. Inactivation of RUNX3 by promoter methylation (hypermethylation) has been found to play an important role in colorectal epithelial tumorigenesis. However, its role in CRC and its clinical significance have not been thoroughly investigated. In this study, we review and update the published clinical investigations regarding the effect of RUNX3 on patients with CRC.

Methods
Search strategy and selection criteria
We searched PubMed, Embase, and ISI Web of Knowledge to identify studies from January 1, 1998 to December 2013 using the search terms “colorectal” and “cancer” or “tumor” or “neoplasm” or “carcinoma”, “methylation”, and “RUNX3”. We also manually searched the reference lists of the retrieved articles and reviews for additional articles. Although our search did not initially have language limits, for the full-text reading and final evaluation, we reviewed only studies published in English. Conference abstracts were not selected for our analysis due to their containing insufficient data. After the exclusion of irrelevant and/or redundant publications from the different databases, the full-text versions of the remaining papers were evaluated against inclusion and exclusion criteria (see the following paragraph), their reference lists, and/or bibliographies searched for additional relevant articles. All searched data were retrieved. To avoid duplication, if the same patient population was reported in several publications, the most complete study was chosen for review.

The three inclusion criteria were as follows: 1) RUNX3 methylation and/or expression evaluated in the circulation and/or primary CRC tissues, 2) research revealed the relationship between RUNX3 methylation and/or expression and CRC clinicopathological parameters and prognosis, 3) RUNX3 methylation and/or expression examined by polymerase chain reaction (PCR), 4) sufficient information provided to estimate hazard ratio (HR) concerning overall survival (OS) and 95% confidence interval (CI). The two exclusion criteria were: 1) letters, reviews, case reports, conference abstracts, editorials, expert opinion; and 2) all in vitro/ex vivo studies. Studies on cell lines and human xenografts were also excluded.

Data extraction and methodological assessment
Two authors (WM, JW) independently reviewed and extracted the data from eligible studies. Disagreements were resolved by discussion and consensus. Two authors (QN, NS) reviewed all of articles that fitted the inclusion criteria. The following information was recorded for each study: the first author’s name, year of publication, sample source, number of cases, clinicopathological parameters, cancer tumor-node-metastasis stage, methylation detection method, methylation rate and/or expression, and follow-up. Data for study characteristics and clinical responses were summarized and transferred into table format. The heterogeneity of investigation was evaluated to determine whether the data from the various studies could be analyzed in a meta-analysis.

For the methodological evaluation of the studies, three investigators (WM, JW, and HL) read each publication independently, and assessed and scored them according to Reporting Recommendations for Tumor Marker Prognostic Studies (REMARK) guidelines and the European Lung Cancer Working Party quality scale. The three readers provided the quality scores and compared them, then reached a consensus value for each item.

Statistical analysis
Analysis was conducted using STATA (v 12.0; StataCorp LP, TX, USA) and Review Manager (v 5.2; The Cochrane
Collaboration, Oxford, UK) software. The pooled frequency of RUNX3 hypermethylation and 95% CI were estimated. The frequency of RUNX3 hypermethylation in different tumor characteristics was compared. Heterogeneity among studies was evaluated with Cochran’s Q test and the $I^2$ statistic. When heterogeneity was not an issue ($I^2$ values $<50\%$), a fixed-effects model was used to calculate parameters. If there was substantial heterogeneity ($I^2$ values $\geq 50\%$), a random-effects model was used to pool data and attempt to identify potential sources of heterogeneity based on subgroup analyses. The pooled OR was estimated for the association between RUNX3 hypermethylation and clinicopathological features. $P$-values less than 0.05 were considered statistically significant.

Publication bias was assessed using a method reported by Egger et al. We also explored reasons for statistical heterogeneity using meta-regression, subgroup analysis, and sensitivity analysis. The analysis of meta-regression and publication bias was performed using STATA (v 10.0; StataCorp LP).

**Results**

**Identification of relevant studies**

Sixty-seven publications were identified using the described search method. Of these, 56 were excluded due to being laboratory studies, non-original articles (ie, reviews), or irrelevant to the current analysis. Eventually, eleven studies were included in the final meta-analysis, as shown in Figure 1.

**Study characteristics**

The eleven studies eligible for meta-analysis were published between 2004 and 2013, and between them reported on a total of 1,427 CRC patients from Japan, Singapore, Brazil, Norway, and the USA. The basic characteristics of these patients are summarized in Table 1.

**Correlation of RUNX3 hypermethylation and expression with clinicopathological features**

**Inactivation of RUNX3 through hypermethylation in CRC and adenoma**

The loss of RUNX3 messenger RNA (mRNA) and protein expression was found to be statistically correlated with the promoter hypermethylation in several types of cancer including CRC. RUNX3 hypermethylation was significantly higher in CRC than in normal colorectal mucosa. The pooled OR from six studies of a total of 289 CRC and 188 normal colorectal mucosa, as shown in Figure 2A (OR=0.07, CI=0.03–0.18, $P<0.00001$) indicates that RUNX3

![Figure 1](image_url) Flowchart of study selection.
inactivation through hypermethylation plays an important role in the pathogenesis of CRC. In addition, RUNX3 hypermethylation was found to occur in colorectal adenoma but slightly less so than in CRC, as shown in Figure 2B.

Role of RUNX3 hypermethylation in CRC development

We analyzed 1,059 CRC patients pooled from three studies to assess whether the aberrant RUNX3 hypermethylation/expression in CRC was associated with advanced stage. As shown in Figure 3, aberrant RUNX3 hypermethylation/expression was significantly higher in advanced CRC compared with in early staged CRC (OR =0.54, CI =0.41–0.71, P<0.0001). These results suggest that epigenetic silencing of RUNX3 gene expression by promoter hypermethylation may play an important role in CRC progression and development.

Correlation of RUNX3 hypermethylation/expression with microsatellite instability (MSI) in CRC

We also examined the data for 1,039 CRC patients pooled from four studies to assess whether the aberrant RUNX3 hypermethylation/expression in CRC was associated with MSI. As shown in Figure 4, aberrant RUNX3 hypermethylation/expression was significantly higher in MSI-positive CRC compared with in MSI-negative CRC (OR =0.44, CI =0.3–0.66, P<0.0001). These results suggest that epigenetic silencing of RUNX3 gene expression by promoter hypermethylation may play an important role in high levels of MSI.

Table 1 Basic characteristics of the included studies

| Study               | Patients, N | Method(s)         | Primary aim                                                                 | Methylation site | RUNX3 expression |
|---------------------|-------------|-------------------|-----------------------------------------------------------------------------|------------------|------------------|
| Imamura et al19     | 92          | MSP               | Determination of the methylation status of the RUNX3 gene and correlation of the results with the clinicopathological features of affected patients | Promoter, CpG islands | –                |
| Goel et al20        | 91          | MSP, RT-PCR       | Determination of RUNX3 expression and the frequency of RUNX3 promoter hypermethylation | Promoter, CpG islands | +                |
| Ku al21             | 87          | RT-PCR, MSP       | Determination of whether there is promoter methylation of the RUNX3 gene in CRC | Promoter, CpG islands | +                |
| Ahlquist et al28    | 25          | MSP               | Pinpointing of the epigenetic markers that can discriminate between nonmalignant and malignant tissue from the large bowel | Promoter, CpG islands | –                |
| Soong et al29       | 849         | Immunohistochemistry | Determination of the clinical significance of RUNX3 expression in a large series of CRC patients |                    | +                |
| Ito et al30         | 48          | MSP, RT-PCR       | Investigation of the possible roles of RUNX3 in regulating the Wnt pathway and in intestinal tumorigenesis | Promoter, CpG islands | +                |
| Hibi and Nakao31    | 59          | MSP               | Determination of whether RUNX3 methylation status is correlated with the clinicopathological features of the affected patients | Promoter, CpG islands | –                |
| Ogino et al32       | 30          | MethyLight        | Determination of whether CpG island methylation may predict poor survival in CRC | Promoter, CpG islands | +                |
| Tan et al33         | 17          | MSP               | Determination of the promoter status of RUNX3 in CRC | Promoter, CpG islands | –                |
| Silva et al34       | 10          | Methyl-Profiler™ PCR Array® | Identification of useful epigenetic markers for noninvasive CRC screening | Promoter, CpG islands | –                |
| Nishio et al35      | 119         | MSP               | Analysis of RUNX3 promoter hypermethylation as a novel tumor marker | Promoter, CpG islands | –                |

Note: *Qiagen NV, Venlo, the Netherlands.

Abbreviations: CRC, colorectal cancer; MSP, methylation-specific polymerase chain reaction; PCR, polymerase chain reaction; RT-PCR, reverse transcription followed by conventional polymerase chain reaction.
**RUNX3 hypermethylation/expression as a prognostic factor for CRC**

Only two studies estimated the relationship between OS and RUNX3 hypermethylation/expression in CRC. Ogino et al showed that CRC patients with RUNX3 hypermethylation had a lower 1-year survival than those without RUNX3 hypermethylation (*P*<0.001). Soong et al observed that nuclear RUNX3 expression was associated with significantly better patient survival than no nuclear RUNX3 expression (*P*=0.025). The pooled HR for OS showed that RUNX3 hypermethylation or decreased RUNX3 expression was associated with worse survival in CRC patients, as shown in Figure 5 (HR = 0.44, 95% CI = 0.27–0.70, *P*= 0.0006).

**RUNX3 hypermethylation/expression**

As a prognostic factor for CRC

| Study or subgroup | Normal colorectal cancer | Odds ratio | Intercept |
|------------------|-------------------------|------------|-----------|
|                 | Events | Total | Weight | M-H, fixed, 95% CI | M-H, fixed, 95% CI |
| Ahquist et al    | 0 | 2 | 16 | 2 | 4.8% | 0.12 (0.00, 2.66) |
| Goel et al       | 1 | 21 | 19 | 91 | 11.3% | 0.19 (0.02, 1.50) |
| Hibi et al       | 0 | 59 | 2 | 22 | 37.3% | 0.01 (0.00, 0.24) |
| Ku et al         | 0 | 87 | 16 | 87 | 27.4% | 0.02 (0.00, 0.42) |
| Silva et al      | 4 | 9 | 6 | 10 | 5.3% | 0.53 (0.09, 3.31) |
| Tan et al        | 0 | 10 | 11 | 17 | 13.9% | 0.03 (0.00, 0.54) |
| **Total (95% CI)** | 188 | 289 | 100.0% | 0.07 (0.03, 0.18) |

**Heterogeneity:** χ² = 7.85, df = 5 (*P*= 0.16); I² = 36%

**Test for overall effect:** Z = 5.67 (*P* < 0.00001)

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**RUNX3 hypermethylation/expression**

As a prognostic factor for CRC

| Study or subgroup | Colorectal adenoma | Odds ratio | Intercept |
|------------------|--------------------|------------|-----------|
|                 | Events | Total | Weight | M-H, fixed, 95% CI | M-H, fixed, 95% CI |
| Ahquist et al    | 4 | 8 | 16 | 25 | 40.1% | 0.56 (0.11, 2.81) |
| Ito et al        | 17 | 34 | 14 | 48 | 59.9% | 2.43 (0.97, 6.07) |
| **Total (95% CI)** | 42 | 73 | 100.0% | 1.68 (0.77, 3.68) |

**Heterogeneity:** χ² = 2.40, df = 1 (*P*= 0.12); I² = 58%

**Test for overall effect:** Z = 1.30 (*P*= 0.19)

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**RUNX3 hypermethylation/expression**

As a prognostic factor for CRC

| Study or subgroup | Early stage | Advanced stage | Odds ratio | Intercept |
|------------------|-------------|----------------|------------|-----------|
|                 | Events | Total | Weight | M-H, fixed, 95% CI | M-H, fixed, 95% CI |
| Imamura et al    | 20 | 61 | 11 | 31 | 7.3% | 0.89 (0.36, 2.20) |
| Nishio et al     | 10 | 54 | 37 | 65 | 20.3% | 0.17 (0.07, 0.40) |
| Soong et al      | 118 | 535 | 99 | 313 | 72.4% | 0.61 (0.45, 0.84) |
| **Total (95% CI)** | 650 | 409 | 100.0% | 0.54 (0.41, 0.71) |

**Heterogeneity:** χ² = 8.80, df = 2 (*P*= 0.01); I² = 77%

**Test for overall effect:** Z = 4.36 (*P* < 0.0001)

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**RUNX3 hypermethylation/expression**

As a prognostic factor for CRC

| Study or subgroup | Early stage | Advanced stage | Odds ratio | Intercept |
|------------------|-------------|----------------|------------|-----------|
|                 | Events | Total | Weight | M-H, fixed, 95% CI | M-H, fixed, 95% CI |
| Imamura et al    | 20 | 61 | 11 | 31 | 7.3% | 0.89 (0.36, 2.20) |
| Nishio et al     | 10 | 54 | 37 | 65 | 20.3% | 0.17 (0.07, 0.40) |
| Soong et al      | 118 | 535 | 99 | 313 | 72.4% | 0.61 (0.45, 0.84) |
| **Total (95% CI)** | 650 | 409 | 100.0% | 0.54 (0.41, 0.71) |

**Heterogeneity:** χ² = 8.80, df = 2 (*P*= 0.01); I² = 77%

**Test for overall effect:** Z = 4.36 (*P* < 0.0001)
Sensitivity analyses and publication bias
A “sensitivity analysis”, in which one study was removed at a time, was conducted to assess the stability of the results. The pooled ORs and HRs were not significantly changed, indicating the stability of our analyses. The funnel plots were largely symmetrical (Figure 6), suggesting there were no publication biases in our meta-analysis of RUNX3 methylation/expression and clinicopathological features.

Discussion
“Epigenetics” is the study of heritable and age-related modifications of the genome that occur without a change in the primary DNA sequence. Epigenetic alterations, particularly aberrant DNA methylation, one of the best-characterized epigenetic modifications, contribute to tumor initiation and progression.40,41 RUNX3 belongs to the runt-domain family of transcriptional factors, and its inactivation by promoter hypermethylation plays an important role in the normal development of, and tumorigenesis in, several types of tumors including CRC.14,42–53 To date, there have been some studies describing the precise expression, prognostic impact, and methylation status of RUNX3 in CRC; however, the role of RUNX3 inactivation in CRC and RUNX3 inactivation have not been thoroughly investigated. We conducted the meta-analysis to evaluate the correlation of RUNX3 hypermethylation/low expression with CRC. Analysis of the pooled data showed that: CRC had a higher hypermethylation OR than normal colorectal mucosa; aberrant RUNX3 hypermethylation/expression was significantly higher in advanced CRC compared with in early staged CRC, indicating that epigenetic silencing of RUNX3 gene expression by promoter hypermethylation may play an important role in CRC progression and development; and aberrant RUNX3 hypermethylation/expression was significantly higher in MSI-positive CRC compared with in MSI-negative CRC. In addition, CRC patients with RUNX3 hypermethylation or lacking RUNX3-protein expression had a lower survival rate than those without RUNX3 hypermethylation or with RUNX3-protein

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**Table 1.** Odds ratios for RUNX3 hypermethylation or expression with CRC.*

| Study or subgroup | MSI negative | MSI positive | Odds ratio | Odds ratio |
|-------------------|--------------|--------------|------------|------------|
|                   | Events       | Total        | Weight     | M-H, fixed, 95% CI |
| Ahlquist et al28  | 0            | 1            | 25         | 0.19 (0.01, 5.20) |
| Goel et al20      | 6            | 51           | 40         | 0.28 (0.09, 0.81) |
| Nishio et al35    | 36           | 106          | 13         | 0.09 (0.02, 0.44) |
| Soong et al29     | 176          | 716          | 87         | 0.62 (0.39, 0.99) |
| Total (95% CI)    | 218          | 70           | 100.0%     | 0.44 (0.30, 0.66) |

**Notes:** *OR = 0.44, CI = 0.30–0.66, P < 0.0001.

**Abbreviations:** CI, confidence interval; M-H, Mantel-Haenszel; OR, odds ratio; df, degrees of freedom.

**Figure 4** A total of 1,039 colorectal cancer (CRC) patients pooled in four studies. Aberrant RUNX3 hypermethylation/expression was significantly higher in microsatellite instability (MSI)-positive CRC than in MSI-negative CRC.*

**Notes:** *OR = 0.44, CI = 0.30–0.66, P < 0.0001.

**Abbreviations:** CI, confidence interval; M-H, Mantel-Haenszel; OR, odds ratio; df, degrees of freedom.

**Figure 5** Two studies estimated the relationship between overall survival (OS) and RUNX3 hypermethylation/expression in colorectal cancer (CRC). The pooled hazard ratios (HRs) for OS showed that RUNX3 hypermethylation or decreased RUNX3 expression was associated with worse survival in CRC patients.*

**Notes:** *HR = 0.44, 95% CI = 0.27–0.70, P = 0.0006.

**Abbreviations:** CI, confidence interval; M-H, Mantel-Haenszel; HR, hazards ratio; df, degrees of freedom.
expression. Progression from colorectal adenoma to CRC appears to mirror the accumulation of genetic abnormalities, suggesting a stepwise progression of genetic changes. In fact, the hypermethylation of several tumor suppressors has been reported in colorectal adenoma.\(^{54-56}\) Combining RUNX3 with other genes to develop several gene markers will be a good strategy for risk stratification to predict initial carcinogenesis and neoplastic progression, including in CRC.\(^{54}\)

RUNX3 exerts pleiotropic effects during tumor suppression. RUNX3 inhibits the oncogenic Wnt signaling pathway via the formation of a complex with the TCF4-β-catenin complex and hampers it from binding to target genes such as \(c\)-\(myc\) and \(cyclin\) \(D1.\)\(^{42,57}\) RUNX3 interacts with SMAD3/SMAD4 to activate TGF-β-dependent proliferation inhibition and apoptosis by activation of p21 and Bim. Although only two studies estimated the relationship between OS and RUNX3 hypermethylation/expression in CRC, both showed very similar results. Ogino et al showed that CRC patients with RUNX3 hypermethylation had lower 1-year survival than those without RUNX3 hypermethylation \((P<0.001).\)\(^{32}\) Soong et al observed that nuclear RUNX3 expression was associated with significantly better patient survival than no nuclear RUNX3 expression \((P=0.025).\)\(^{29}\)

In addition, detection of RUNX3 methylation status may predict treatment effects among CRC patients who receive fluorouracil-based and irinotecan-based chemotherapy.\(^{32}\) Consistent results were shown in sensitivity analyses, and no evidence of publication bias was found. This study has several potential limitations. First, the possibility of information and selection biases and unidentified confounders could not be completely excluded, because all of the included studies were observational. Second, the search strategy was restricted to articles published in English. Articles with potentially high-quality data published in other languages were not included because of anticipated difficulties in obtaining accurate medical translation. Hence, caution should be taken in interpreting our findings among the general population.

**Disclosure**
The authors declare no conflicts of interest in this work.

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