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ORIGINAL RESEARCH

RETRACTED ARTICLE: MicroRNA-145-5p inhibits gastric cancer invasiveness through targeting N-cadherin and ZEB2 to suppress epithelial–mesenchymal transition

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Abstract: MicroRNA (miR)-145-5p has been reported to function as a tumor suppressor of cancer and plays an important role in cancer invasiveness. Epithelial–mesenchymal transition (EMT) is an important process in cancer invasion and migration. However, the involvement of miR-145-5p in EMT in human gastric cancer (GC) remains unclear. In this study, we aimed to investigate the molecular mechanisms by which miR-145-5p regulates EMT in GC invasiveness. We used quantitative real-time polymerase chain reaction to investigate the miR-145-5p expression level in GC and matched normal tissues. The effects of miR-145-5p on GC cell invasion and migration abilities were evaluated using Transwell models. The relationships among miR-145-5p and zinc-finger E-box binding homeobox 2 (ZEB2), E-cadherin, and N-cadherin were analyzed by quantitative real-time polymerase chain reaction and Western blot analyses. miR-145-5p levels in primary GC tissues obtained from 60 patients were significantly downregulated, compared to those in paired normal tissues. Lauren classification, depth of tumor invasion, lymph node metastasis, lymphatic invasion, and tumor–node–metastasis stage were associated with miR-145-5p expression. miR-145-5p inhibits the expression of the candidate target gene ZEB2 to delay the invasion and migration of GC cells. ZEB2 acts as transcriptional repressor of E-cadherin, which miR-145-5p is known to suppress N-cadherin directly to regulate EMT. Therefore, we concluded that miR-145-5p may target N-cadherin and ZEB2 directly to influence EMT.

Keywords: miR-145-5p, zinc-finger E-box binding homeobox 2 (ZEB2), epithelial–mesenchymal transition (EMT), gastric cancer

Introduction

Gastric cancer (GC) is one of the most common malignancies of the digestive system in People's Republic of China.[1,2] The majority of GC deaths are caused by cancer cell invasion and metastasis.[3] However, the underlying mechanisms of cancer cell invasion and migration in GC progression remain unclear and further elucidation of the molecular mechanisms underlying these processes is urgently required to improve treatment and prolong survival in patients with advanced GC.

MicroRNAs (miRs) are small noncoding RNAs, which act as posttranscriptional regulators of gene expression during tumor development and carcinogenesis.[4,5] A series of studies have shown that numerous miRs influence the capacity for invasion, migration, and proliferation of cancer cells in GC.[5,6] miR-145-5p has been reported as a tumor suppressor in several types of tumors, such as colon,[7,8] breast,[9] and prostate cancers.[10] Furthermore, previous studies have shown that miR-145-5p is downregulated in GC and may function as a suppressor gene.[11] However, the mechanisms by which miR-145-5p inhibits GC, especially by suppressing epithelial–mesenchymal

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transition (EMT) to inhibit GC metastasis, have not yet been reported.

EMT plays a key role in cancer cell invasion and migration during the development and progression of cancer and metastasis. The concept of EMT was proposed by Greenburg and Hay early in 1982[12] and refers to the loss of polarity and connections between epithelial cells and the acquisition of an interstitial cell phenotype under the influence of a number of factors. The cells then gain the ability to migrate.[13] During the progression of EMT, downregulation of adhesion molecules, such as E-cadherin, and upregulation of mesenchymal markers, such as N-cadherin, decrease epithelial cell–cell adhesion and promote cancer cell invasion and migration.

Gao et al[14] identified the N-cadherin gene as a direct target of miR-145-5p, which is upregulated in GC. Accumulating evidence indicates that zinc-finger E-box binding homeobox 2 (*ZEB2*) is a candidate target gene of miR-145-5p and acts as an EMT-inducing transcription factor, promoting invasion and migration in many tumors.[15–19] Searches of the miRBase Targets, TargetScan Release 5.0 (http://www.targetscan.org/), and PicTar databases and previous reports implicated ZEB2 as the candidate target gene of miR-145-5p in GC. Thus, we speculated that miR-145-5p inhibits metastasis of GC cells by targeting ZEB2, although the specific mechanism remains to be clarified. In this present study, we confirmed that miR-145-5p inhibits GC cell invasion and metastasis through directly targeting N-cadherin and ZEB2 to suppress EMT. Moreover, we investigated the correlation between miR-145-5p expression levels in GC tissues and clinicopathologic parameters.

Materials and methods

Patients and tissue samples

All fresh clinical tissue samples were collected with the written informed consent of 60 patients who underwent gastric resection at the Department of Gastrointestinal Surgery in the People's Hospital of Zhejiang Province (People's Republic of China) from 2012 to 2014. None of the patients received chemotherapy prior to surgery. The tumor pathological type was diagnosed by three independent pathologists, and the matched normal gastric epithelial tissues, which were collected from more than 5 cm away from the tumors, were also verified at the same time. The project was approved by the ethics committee of Zhejiang Provincial People's Hospital.

Cell culture

The human GC cell lines (BGC-823, SGC-7901, MKN-45, AGS, and GES-1) were purchased from the Cell Bank of Shanghai Institute of Cell Biology (Shanghai, People's Republic of China) and cultured in Roswell Park Memorial Institute 1640 (HyClone, Logan, UT, USA) supplemented with 10% fetal bovine serum (Sigma-Aldrich Co., St Louis, MO, USA) at 37°C under a humidified atmosphere containing 5% CO_2.

Cell transfection

AGS and SGC-7901 cells (1×10^5 per well) were seeded in six-well plates. After 24 hours, the cells were transfected with an miR-145-5p mimic, an miR-145-5p mimic negative control, an miR-145-5p inhibitor, or an miR-145-5p inhibitor negative control (Ribo Bio, Guangzhou, People's Republic of China), using Lipofectamine 2000 transfection reagent (Thermo Fisher Scientific, Waltham, MA, USA) and following the manufacturer's protocol. After transfection, the cells were collected for further examination and the effects of miR-145-5p transfection were determined by quantitative real-time polymerase chain reaction (qRT-PCR) at 24 hours posttransfection.

RNA isolation, reverse transcription, and qRT-PCR

Total RNA was isolated from the tissue samples and GC cells using TRIzol reagent (Thermo Fisher Scientific). RNA concentration and purity were determined using Nanodrop 2000 (Thermo Fisher Scientific). Reverse transcription was performed using the One-step PrimeScript miRNA cDNA synthesis kit (D350A; TaKaRa Biotechnology [Dalian] Co., Ltd., Dalian, People's Republic of China). qRT-PCR was carried out on the MX3000P system (Stratagene, La Jolla, CA, USA) using gene-specific primers with the SYBR Premix ExTaq kit (DRR081A; TaKaRa Biotechnology [Dalian] Co., Ltd.) to detect the expression levels of miR-145-5p, ZEB2, E-cadherin, and N-cadherin. All reactions were performed in triplicate. U6 (RNU6B) or glyceraldehyde 3-phosphate dehydrogenase was used as an internal standard for normalization of miR-145-5p, ZEB2, E-cadherin, and N-cadherin expression levels.

The primers of candidate genes were designed using Primer 5.0 software (PREMIER Biosoft International, Palo Alto, CA, USA), and are listed in Table 1. Melting curve analysis was carried out at the end of the PCR cycles to confirm the most suitable amplification condition. The qPCR conditions were as follows: initial denaturation (4 minutes at 95°C) and then 40 cycles of denaturation at 95°C for 10 seconds, annealing at the appropriate temperature for 30 seconds (specific temperatures are shown in Table 1), and extension at 72°C for 30 seconds. The melting curve settings

Table 1 Sequence of primers used in this study

Name	Sequence (5′→3′)	Annealing temperatures (°C)
miR-145-5p	GTCCAGTTTTCCCAGGAATCCCT	60
RNU6B	CGCTTCACGAATTTGCGTGTCAT	60
GAPDH	Forward TGAAGGTCGGAGTCAACGG	55–60
	Reverse TGGAAGATGGTGATGGGATT	
ZEB2	Forward GAAGATGAAATAAGGGAGGG	60
	Reverse CTGGGTAAATAATGGCTGTG	
E-cadherin	Forward CGAGAGCTACACGTTCACGG	56
	Reverse GGGTGTCGAGGGAAAAATAGG	
N-cadherin	Forward TGCGGTACAGTGTAACTGGG	60
	Reverse GAAACCGGGCTATCTGCTCG	
IRS-1	Forward CTGCACAACCGTGCTAAGG	[illegible]
	Reverse CGTCACCGTAGCTCAAGTCC	
FSCN1	Forward CCAGGGTATGGACCTGTCTG	58
	Reverse GTGTGGGTACGGAAGGCAC	
c-Myc	Forward TCCCTCCACTCGGAAGGAC	[illegible]
	Reverse CTGGTGCATTTTCGGTTGTTG	
Ets-1	Forward GATAGTTGTGATCGCCTCACC	60
	Reverse GTCCTCTGAGTCGAAGCTGTC	

were as follows: 95°C for 1 minute, 55°C for 30 seconds, 95°C for 30 seconds. The fluorescence signal was continuously acquired per 0.1°C from 55°C to 95°C. The relative expression levels were calculated using the $2^{-\Delta\Delta ct}$ method.

In vitro cell migration and invasion assays

The migration assay was performed with Transwell plates (3422; Corning Incorporated, Corning, NY, USA) containing a membrane with 8 μm pores. Cell invasion assays were performed using invasion chambers (354480; BD, Franklin Lakes, NJ, USA) precoated with Matrigel. Cells (2×10^5 for invasion assays and 5×10^4 cells for migration assays) were resuspended in serum-free medium and seeded into the upper chamber. Culture medium containing 20% fetal bovine serum was added to the lower chamber as the chemoattractant. The cells were incubated in a humidified incubator at 37°C for 24 hours (migration assays) or 36 hours (invasion assays). Noninvading cells in the upper chambers were removed with cotton swabs. The cells attached to the lower surface were fixed and stained. The number of cells which attached to the lower surface was counted in five random fields under a microscope (×200).

Western blotting

Western blot analysis was performed according to the protocol provided by the manufacturer (Bio-Rad Laboratories Inc., Hercules, CA, USA). Briefly, protein was extracted from cells using radio immunoprecipitation assay (RIPA) lysis buffer (Beyotime, Shanghai, People's Republic of China). Each sample was separated on a sodium dodecyl sulfate-polyacrylamide gel electrophoresis (8%–10% gel) and then transferred onto polyvinylidene difluoride membranes. The polyvinylidene difluoride membranes were blocked with 5% nonfat milk for 2 hours and then incubated with primary rabbit antihuman antibodies for detection of N-cadherin (EPR1791-4 at 1/5,000 dilution; Abcam, San Francisco, CA, USA), E-cadherin (EP700Y at 1/10,000 dilution; Abcam), and ZEB2 (SC-271984 at 1/500 dilution; Santa Cruz Biotechnology Inc., Dallas, TX, USA) overnight at 4°C. The membranes were incubated with a horseradish peroxidase-labeled goat antirabbit IgG antibody for 1 hour. After washing (×4) with Tris-Buffered Saline and Tween 20 Buffer (TBST), the bands were developed using an enhanced chemiluminescence system (GE Healthcare UK Ltd, Little Chalfont, UK). Relative protein expression was normalized to β-actin.

Statistical analyses

All statistical analyses were performed using Statistical Package for the Social Sciences version 13.0 (SPSS Inc., Chicago, IL, USA). Data are presented as mean ± standard deviation. The means of normally distributed data were compared by either paired sample *t*-tests or two independent samples *t*-tests as appropriate. If the results were not normally distributed, Wilcoxon test was used as appropriate. Analysis of variance followed by a posttest was used to assess the different expression levels of miR-145-5p in gastric cell lines. Chi-square or Fisher's exact test was used to assess the statistical significance of the association between miR-145-5p and clinicopathologic parameters. A *P*-value of <0.05 was considered to indicate statistical significance.

Results

miR-145-5p is downregulated in GC tissues and cell lines

miR-145-5p expression in GC tissues was significantly downregulated compared with that in matched normal tissues (Figure 1). Analysis of the expression of miR-145-5p in four human GC cell lines and a normal cell line (GES-1) yielded the following pattern of expression levels: GES-1 > SGC-7901 > BGC-823 > MKN-45 > AGS (Figure 2). Also, miR-145-5p expression was decreased in all four cancer cell lines compared with that in GES-1, with the highest and lowest levels detected in SGC-7901 and AGS, respectively. These two cell lines were, therefore, selected for use in transfection experiments.

Correlation between miR-145-5p expression level and clinicopathologic factors

There was a significant difference in miR-145-5p expression levels between GC tissues and matched normal tissues (3.63±0.67 vs 6.62±0.73) (Figure 1). The miR-145-5p expression levels in GC tissues and normal tissues were evaluated with receiver operating characteristic curve analysis (y-axis, sensitivity; x-axis, [1 − specificity]), and a cut-off value (1.785) was set as the maximum (sensitivity + specificity). Then the expression value that provided the best accuracy was identified and the tumor specimens were classified based on this cut-off into low-expression and high-expression groups. The results showed that low miR-145-5p expression level was significantly related to tumor depth, lymph node

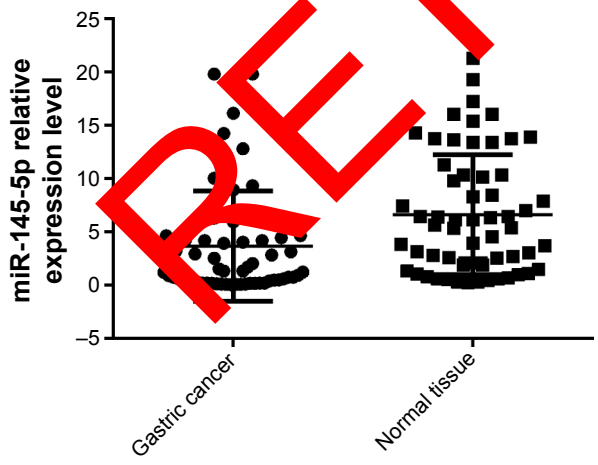

Figure 1 qRT-PCR analysis of miR-145-5p expression in GC tissues.
Notes: miR-145-5p expression was lower in 60 GC tissue samples than in the pair-matched adjacent normal tissues ($P<0.05$). Each sample was analyzed in triplicate and normalized to the endogenous control RNU6B. Data represent the mean ± SD of three individual experiments.
Abbreviations: GC, gastric cancer; miR, microRNA; qRT-PCR, quantitative real-time polymerase chain reaction; SD, standard deviation.

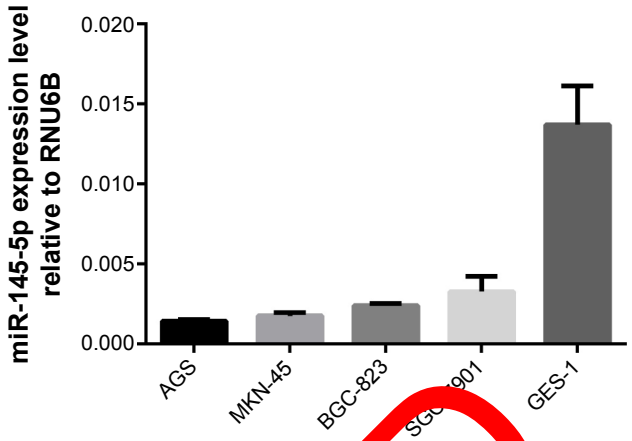

Figure 2 qRT-PCR analysis of miR-145-5p expression in GC cell lines.
Notes: The relative miR-145-5p expression in GC cell lines was much lower than that in the normal control cell line GES-1. The pattern of expression levels was GES-1 > SGC-7901 > BGC-823 > MKN-45 > AGS. Analysis of variance followed by a posttest indicated significantly lower miR-145-5p expression levels in AGS, SGC-7901, MKN-45, and BGC-823 compared with that in GES-1 (all $P<0.05$). The relative expression of miR-145-5p was normalized to the endogenous control RNU6B. Data represent the mean ± SD of three individual experiments.
Abbreviations: GC, gastric cancer; miR, microRNA; qRT-PCR, quantitative real-time polymerase chain reaction; SD, standard deviation.

metastasis, lymphatic invasion, and tumor–node–metastasis (TNM) stage (Table 2).

miR-145-5p suppresses GC cell migration and invasion in vitro

The AGS cell line, expressing relatively low levels of miR-145-5p, was transfected with an miR-145-5p mimic or a negative control. qRT-PCR analysis confirmed that transfection with the miR-145-5p mimic resulted in significant overexpression of miR-145-5p (Figure 3A). As expected, miR-145-5p overexpression significantly suppressed AGS cell migration and invasion ability ($P<0.05$) (Figure 3B).

The SGC-7901 cell line, expressing relatively high levels of miR-145-5p, was also transfected with an miR-145-5p inhibitor or a negative control. qRT-PCR analysis confirmed that transfection with the miR-145-5p inhibitor resulted in significantly reduced expression of miR-145-5p (Figure 3A). The invasion and migration capacity of SGC-7901 cells was significantly increased following transfection with the miR-145-5p inhibitor compared with the inhibitor negative control ($P<0.05$) (Figure 3C). These results confirmed that miR-145-5p suppresses the invasion and migration ability of GC cells.

miR-145-5p inhibits N-cadherin, ZEB2, and EMT to suppress the invasion and metastatic capacity of GC cells

To investigate the possible mechanisms by which miR-145-5p suppresses GC cell invasiveness and EMT, we identified

Table 2 miR-145-5p expression and clinicopathologic factors of gastric cancer

Factor	High expression (n=14)	Low expression (n=46)	*P*-value
Age, years			
<60	7	22	0.887
≥60	7	24	
Sex			
Male	12	41	0.727
Female	2	5	
Lauren classification			
Intestinal type	2	30	0.001*
Diffuse type	12	16	
Tumor diameter (cm)			
<5	7	27	0.565
≥5	7	19	
Depth of tumor invasion			
m, sm, mp	10	7	0.00004*
s, se, si	4	39	
Lymph node metastasis			
Yes	3	35	0.0002*
No	11	11	
Venous invasion			
Yes	2	8	0.785
No	12	38	
Lymphatic invasion			
Yes	4	34	0.002*
No	10	12	
Neural invasion			
Yes	3	10	0.[illegible]
No	11	36	
Distant metastasis			
Yes	1	6	0.547
No	13	40	
TNM stage			
I	6		0.042*
II	5	10	
III	2		
IV	1	6	

Note: *$P<0.05$.

Abbreviations: m, tumor invasion of mucosa; miR, microRNA; mp, muscularis propria; s, subserosa; se, penetration of serosa; si, invasion of serosa; sm, submucosa; TNM, tumor–node–metastasis.

a list of candidate target genes of miR-145-5p, such as IRS-1, FSCN-1, Ets-1, ZEB2, and c-Myc, by searching the miRBase Targets, TargetScan Release 5.0, and PicTar databases, as well as previous reports. The expression of these genes was screened by qRT-PCR in GC cells transfected with an miR-145-5p mimic or inhibitor. In GC cells transfected with miR-145-5p mimic or inhibitor, the changes in ZEB2 expression levels were inversely correlated with miR-145-5p and E-cadherin levels. However, the expression levels of other candidate genes were not correlated with miR-145-5p expression in GC lines (Figure S1). These data indicated that ZEB2 may be a candidate target gene of miR-145-5p involved in the regulation of E-cadherin expression.

Furthermore, qRT-PCR and Western blot analyses showed obvious downregulation of N-cadherin in AGS cells transfected with the miR-145-5p mimic (Figures 4 and 5), while N-cadherin was upregulated in SGC-7901 cells transfected with the miR-145-5p inhibitor compared with the corresponding negative control (Figures 4 and 5).

In this study, qRT-PCR and Western blot analyses confirmed that ZEB2 expression was significantly decreased, while E-cadherin expression was significantly increased in AGS cells transfected with the miR-145-5p mimic, compared to those transfected with the corresponding negative control (NC) (Figures 4 and 5). Opposite patterns of ZEB2 and E-cadherin were detected in SGC-7901 cells transfected with the miR-145-5p inhibitor (Figures 4 and 5). These data indicated that miR-145-5p is an important regulator of the candidate target gene ZEB2, leading to regulation of E-cadherin expression.

Discussion

miRNAs have been reported to function as oncogene or cancer suppressors in many tumors.[5] Approximately one-third of human genes may be regulated by miRNAs, and each miRNA can act on hundreds of target genes.[20] Recent studies have indicated that many miRNAs influence GC invasion and metastasis by targeting specific genes and signaling pathways.[21] For example, miR-199-5p is upregulated in GC and promotes cell migration and invasion by targeting klotho.[22] miR-10b promotes migration and invasion through Hoxd10 in human GC.[23] Low miR-145-5p has been reported in many cancer types such as colon,[7,8] breast,[9] prostate,[17] and ovarian.[24] In addition, many miR-145-5p target genes have been reported, such as p70S6K1 and IRS-1 in colon cancer,[8,25] ER-α and RTKN in breast cancer,[9,26] ZEB2 and DAB2 in prostate cancer,[17,27] and p70S6K1 and MUC1 in ovarian cancer.[28] miR-145-5p also acts as a suppressor in GC by targeting genes such as IRS-1, FSCN-1, N-cadherin, and Ets-1.[11,14,29–31] For example, Zheng et al[31] showed that miR-145-5p targets the 3′-untranslated region of Ets-1 directly, and Ets-1 further regulates the expression of multiple genes, such as MMP1, MMP9, and u-PA, to suppress the invasive and metastatic capacity of GC cells.[32] In this study, we confirmed that miR-145-5p is downregulated in GC tissues, compared with that in adjacent normal tissues. miR-145-5p is significantly related to Lauren classification, depth of tumor invasion, lymph node metastasis, lymphatic invasion, and TNM stage. Thus, further elucidation of the molecular mechanisms by which miR-145-5p affects GC invasion and migration is important.

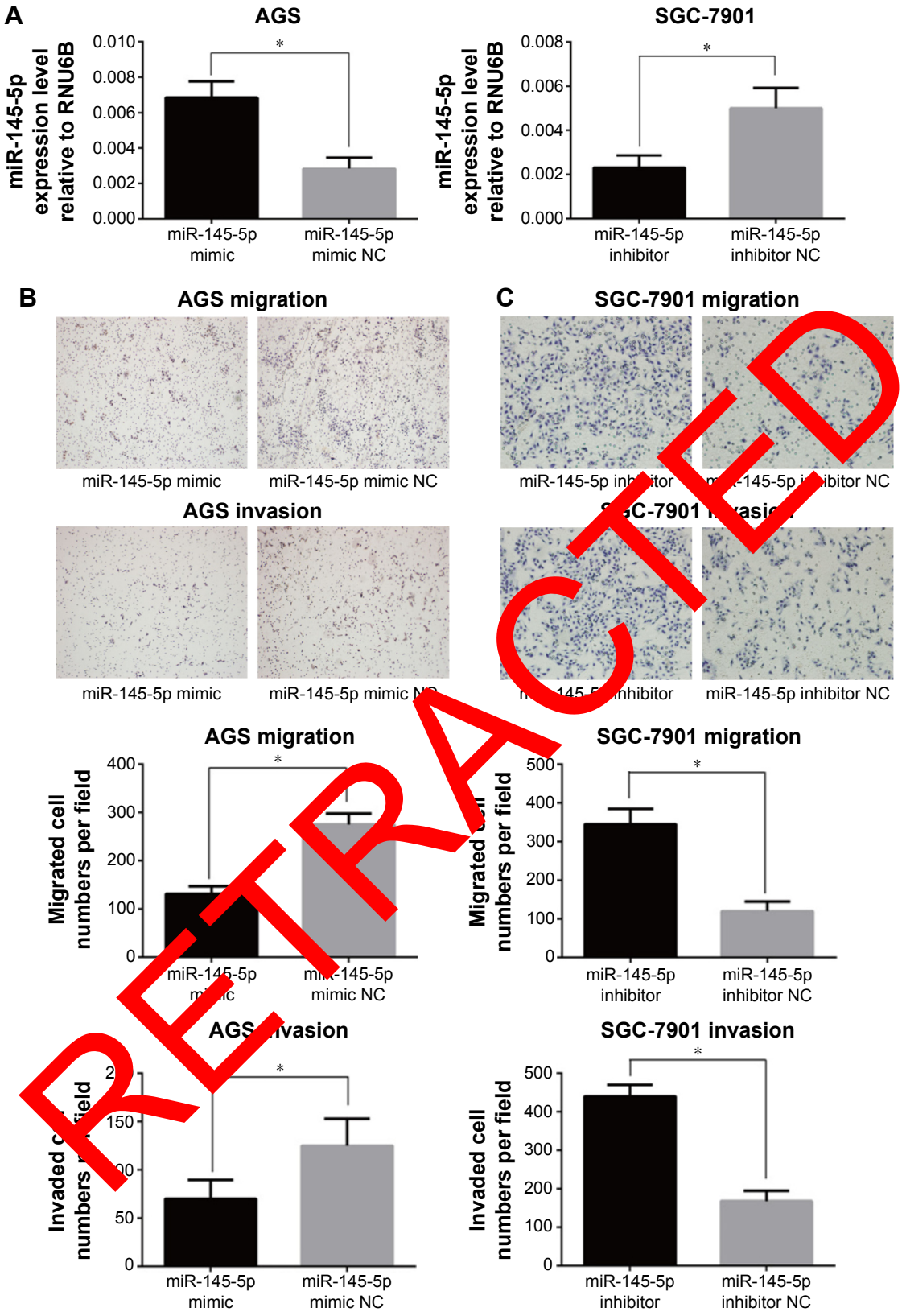

Figure 3 (**A**) miR-145-5p expression in AGS cells transfected with an miR-145-5p mimic was increased, compared with the negative control. miR-145-5p expression in SGC-7901 cells transfected with an miR-145-5p inhibitor was decreased, compared with that in the negative control (*P<0.05). The relative expression of miR-145-5p was normalized to the endogenous control RNU6B. Data represent the mean ± SD of three individual experiments. (**B** and **C**) Transwell assay of miR-145-5p. (**B**) AGS GC cells transfected with an miR-145-5p mimic showed reduced migration and invasion activity, compared with the negative control (*P<0.05). (**C**) SGC-7901 GC cells transfected with an miR-145-5p inhibitor showed increased migration and invasion activity, compared with the negative control (*P<0.05). Data represent the mean ± SD of three individual experiments.

Abbreviations: GC, gastric cancer; miR, microRNA; SD, standard deviation; NC, negative control.

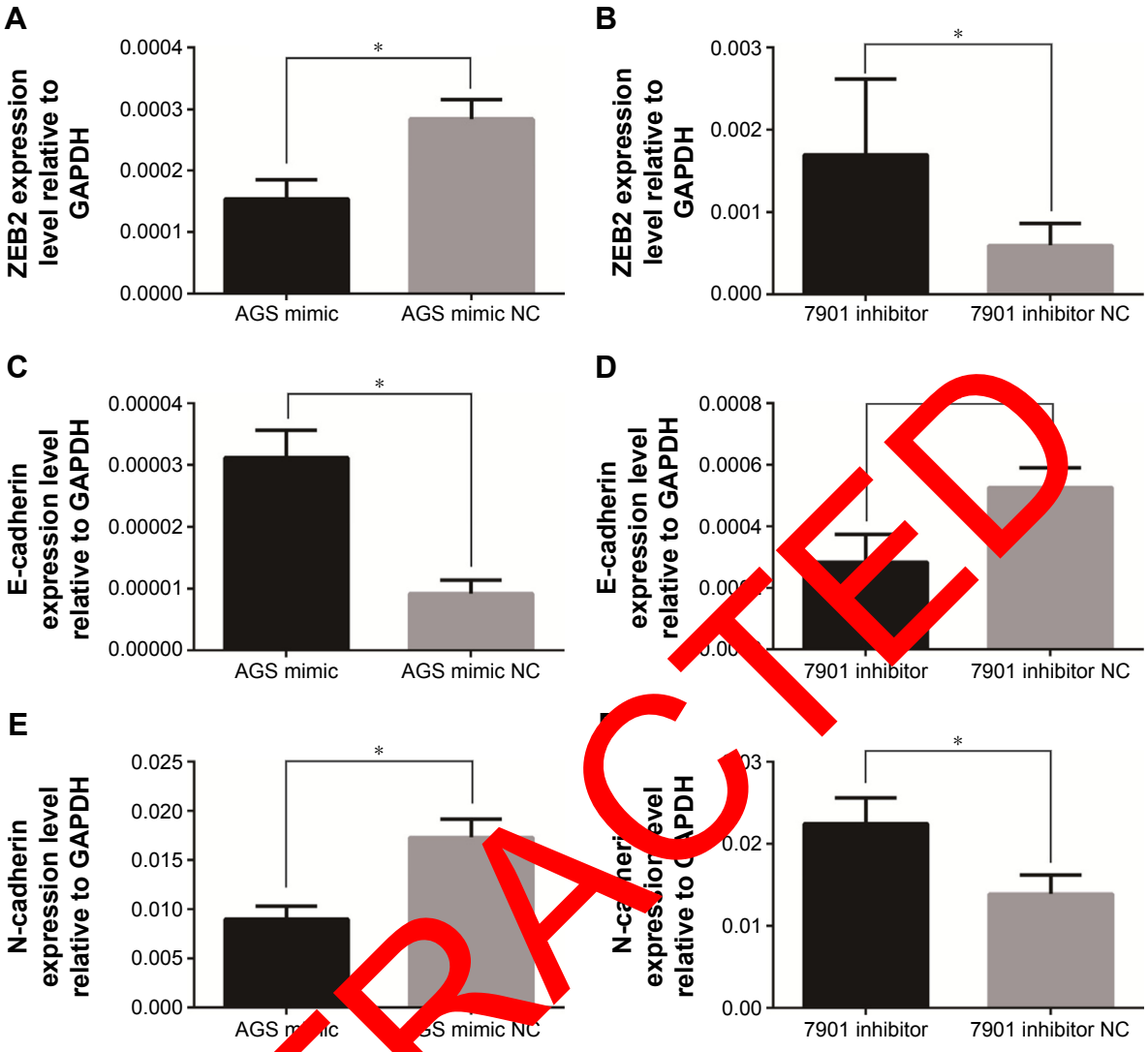

Figure 4 miR-145-5p inhibited N-cadherin, ZEB2 expression and enhanced E-cadherin expression.

Notes: (**A**) AGS GC cells transfected with an miR-145-5p mimic exhibited a significant reduction in ZEB2 expression, compared to those transfected with the miR-145-5p mimic negative control. (**B**) SGC-7901 GC cells transfected with an miR-145-5p inhibitor showed a significant increase in ZEB2 expression, compared to those transfected with the miR-145-5p inhibitor negative control. (**C**) AGS GC cells transfected with an miR-145-5p mimic exhibited a significant increase in E-cadherin expression, compared to those transfected with the miR-145-5p mimic NC. (**D**) SGC-7901 gastric cancer cells transfected with an miR-145-5p inhibitor showed a significant reduction in E-cadherin expression, compared to those transfected with the miR-145-5p inhibitor negative control. (**E**) AGS GC cells transfected with an miR-145-5p mimic exhibited a significant reduction in N-cadherin expression, compared to those transfected with the miR-145-5p mimic negative control. (**F**) SGC-7901 GC cells transfected with an miR-145-5p inhibitor showed a significant increase in N-cadherin expression, compared to those transfected with the miR-145-5p inhibitor negative control (*$P<0.05$). Each sample was analyzed in triplicate, normalized to the endogenous control GAPDH. Data represent the mean ± SD of three individual experiments.

Abbreviations: GAPDH, glyceraldehyde 3-phosphate dehydrogenase; GC, gastric cancer; miR, microRNA; qRT-PCR, quantitative real-time polymerase chain reaction; SD, standard deviation; NC, negative control.

Increasing attention is now focused on the signaling pathways involved in tumor progression. miRNAs are also known to be involved in regulation of the signaling pathways that influence the invasion and migration of tumor cells. For example, Zhang et al[33] found that miR-199 overexpression inhibits SMAD4 gene expression in GC cells, which, in turn, influences cell proliferation and metastasis via the transforming growth factor-beta signaling pathway. Invasion and metastasis are important factors that influence the progression of advanced GC and recurrence after surgery. EMT has an important role in invasion and migration of GC cells, processes which involve multiple molecular mechanisms and levels of gene regulation.[34] Loss of epithelial cell polarity and the acquisition of mesenchymal characteristics are important features of EMT, which are accompanied by changes in epithelial cell and mesenchymal cell markers.[13] Recent studies have confirmed the close relationship between miRNAs and the EMT signaling pathway in regulating the invasive and metastatic ability of tumor cells.[17] Using luciferase assays and Western blot analysis, Gao et al[14] showed that the N-cadherin gene is a direct target of miR-145-5p. In the present study, miR-145-5p upregulation in GC cells also reduced

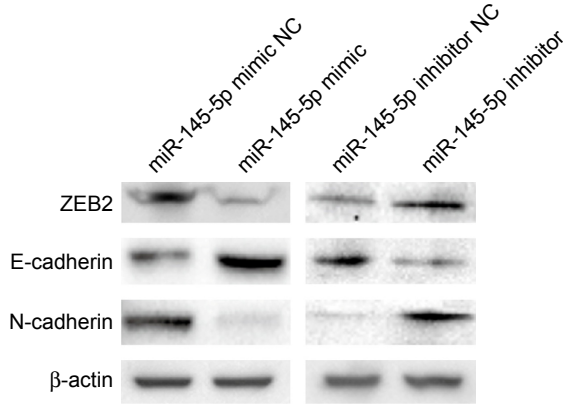

Figure 5 Western blot analysis.
Notes: ZEB2 expression was downregulated in AGS cells transfected with an miR-145-5p mimic and upregulated in SGC-7901 cells transfected with an miR-145-5p inhibitor. E-cadherin expression was upregulated in AGS cells transfected with an miR-145-5p mimic and downregulated in SGC-7901 cells transfected with an miR-145-5p inhibitor. N-cadherin expression was downregulated in AGS cells transfected with an miR-145-5p mimic and upregulated in SGC-7901 cells transfected with an miR-145-5p inhibitor.
Abbreviations: miR, microRNA; NC, negative control.

N-cadherin expression, while miR-145-5p downregulation in GC cells had the opposite effect, which is consistent with previous research. However, immunohistochemistry studies by Kamikihara et al[35] showed only a 21% N-cadherin positive expression rate in GC tissues, indicating the existence of oth molecular mechanisms by which miR-145-5p regulates th EMT signaling pathway in GC.

Ren et al[17] identified ZEB2 as a target gene miR-5p in prostate cancer, and showed that ZEB2 reg tes E-c rin to influence EMT. E-cadherin, which is e key elial cell marker, plays an important role in c er cell EM [36,37] and represents a candidate biomarker n eva ing the metastatic potential of GC.[38,39] ZEB2 ts as transc tional repressor of E-cadherin thro binding the E-BOX sequence in the E-cadherin pro ter, l ding to downregulation of E-cadherin expre n, the y induc g EMT.[16,40] Genetic screening ind ates th ZEB2 e candidate target gene of miR-14 p in r ion to E-cadherin–induced GC cell invasion and m ion. In our study, qRT-PCR and Western blot analyses con med that ZEB2 expression was significantly decreased and E-cadherin expression was increased in GC cells transfected with miR-145-5p mimic, compared to those transfected with the corresponding negative control. In contrast, the opposite pattern of expression was observed following transfection with miR-145-5p inhibitor in GC cells. These observations indicate a significant inverse relationship between miR-145-5p levels and ZEB2 expression, as well as a positive correlation between miR-145-5p levels and E-cadherin.

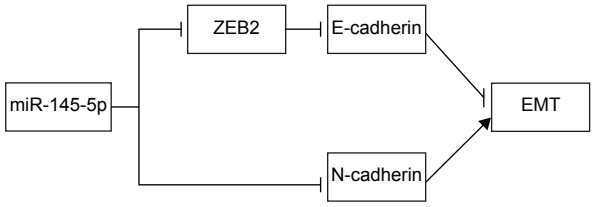

Figure 6 Schematic representation of the interconnections between miR-145-5p, ZEB2, E-cadherin, and N-cadherin in the regulation of epithelial-to-mesenchymal transition.
Abbreviations: EMT, epithelial-to-mesenchymal transition; miR, microRNA.

A number of limitations of this st uld be noted. The sample size is small, and n statistically significant correlation was identified betwee iR-145-5p xpression and patient survival. Our fi ngs ind te that R-145-5p regulates EMT by dire suppr ion o cadherin and indirect induction of E-c herin expression through ZEB2. The proposed rel onships ween m -145-5p and ZEB2, E-cadherin, a cadherin d the regulation of EMT are shown in Figure However, our findings also indicate the ex ce of other pa ways that regulate EMT. Further rese ch into the molecular mechanisms of GC invasion and mig tion will aid early prediction, prognostic analysis, and the gu ance of t atment. Furthermore, miR-145-5p and its downstream EMT signaling pathways are implicated as new tar the prevention and treatment of GC.

Conclusion

In the present study, we confirmed that miR-145-5p inhibits GC cell invasion and metastasis through directly targeting N-cadherin and ZEB2 to suppress EMT. As a suppressor gene in primary GC, miR-145-5p was associated with Lauren classification, depth of tumor invasion, lymph node metastasis, lymphatic invasion, and TNM stage.

Acknowledgments

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Disclosure

The authors report no conflicts of interest in this work.

References

1. Hohenberger P, Gretschel S. Gastric cancer. *Lancet*. 2003;362(9380):305–315.
2. Jemal A, Bray F, Center MM, Ferlay J, Ward E, Forman D. Global cancer statistics. *CA Cancer J Clin*. 2011;61(2):69–90.

3. Terry MB, Gaudet MM, Gammon MD. The epidemiology of gastric cancer. *Semin Radiat Oncol*. 2002;12(2):111–127.
4. Bartel DP. MicroRNAs: target recognition and regulatory functions. *Cell*. 2009;136(2):215–233.
5. Ventura A, Jacks T. MicroRNAs and cancer: short RNAs go a long way. *Cell*. 2009;136(4):586–591.
6. Lu J, Getz G, Miska EA, et al. MicroRNA expression profiles classify human cancers. *Nature*. 2005;435(7043):834–838.
7. Michael MZ, O' Connor SM, van Holst Pellekaan NG, Young GP, James RJ. Reduced accumulation of specific microRNAs in colorectal neoplasia. Molecular cancer research MCR. 2003;1(12):882–891.
8. Xu Q, Liu LZ, Qian X, et al. MiR-145 directly targets p70S6K1 in cancer cells to inhibit tumor growth and angiogenesis. *Nucleic Acids Res*. 2012;40(2):761–774.
9. Spizzo R, Nicoloso MS, Lupini L, et al. miR-145 participates with TP53 in a death-promoting regulatory loop and targets estrogen receptor-alpha in human breast cancer cells. *Cell Death Differ*. 2010;17(2):246–254.
10. Zaman MS, Chen Y, Deng G, et al. The functional significance of microRNA-145 in prostate cancer. *Br J Cancer*. 2010;103(2):256–264.
11. Takagi T, Iio A, Nakagawa Y, Naoe T, Tanigawa N, Akao Y. Decreased expression of microRNA-143 and -145 in human gastric cancers. *Oncology*. 2009;77(1):12–21.
12. Greenburg G, Hay ED. Epithelia suspended in collagen gels can lose polarity and express characteristics of migrating mesenchymal cells. *J Cell Biol*. 1982;95(1):333–339.
13. Thiery JP. Epithelial-mesenchymal transitions in tumour progression. *Nat Rev Cancer*. 2002;2(6):442–454.
14. Gao P, Xing AY, Zhou GY, et al. The molecular mechanism of microRNA-145 to suppress invasion-metastasis cascade in gastric cancer. *Oncogene*. 2013;32(4):491–501.
15. Kurashige J, Kamohara H, Watanabe M, et al. MicroRNA-200b regulates cell proliferation, invasion, and migration by directly targeting ZEB2 in gastric carcinoma. *Ann Surg Oncol*. 2012;19 Suppl 3:S656–S
16. Park SM, Gaur AB, Lengyel E, Peter ME. The miR-200 family determines the epithelial phenotype of cancer cells by targeting the E-cadherin repressors ZEB1 and ZEB2. *Genes Dev*. 2008;22(7):894–907.
17. Ren D, Wang M, Guo W, et al. Double-negative feedback loop between ZEB2 and miR-145 regulates epithelial-mesenchymal transition and stem cell properties in prostate cancer cells. *Cell Tissue Res*. 258(3): 763–778.
18. Ohta H, Aoyagi K, Fukaya M, et al. Cross talk between hedgehog and epithelial-mesenchymal transition pathways in gastric pit cells and in diffuse-type gastric cancers. *Br J Cancer*. 2009;100(2): 9–398.
19. Rosivatz E, Becker I, Specht K, et al. Differential expression of the epithelial-mesenchymal transition regulators snail, SIP1, and twist in gastric cancer. *Am J Pathol*. 2002;161(5):1881–1891.
20. Filipowicz W, Bhattacharyya SN, Sonenberg N. Mechanisms of post-transcriptional regulation by microRNAs: are the answers in sight? *Nat Rev Genet*. 2008;9(2):102–114.
21. Wu HH, Lin WC, Tsai KW. Advances in molecular biomarkers for gastric cancer: miRNAs as emerging novel cancer markers. *Expert Rev Mol Med*. 201
22. He XJ, Ma YY, Yu S, et al. Up-regulated miR-199a-5p in gastric cancer functions as an oncogene and targets klotho. *BMC Cancer*. 2014;14:218.
23. Wang YY, Li L, Ye ZY, Zhao ZS, Yan ZL. MicroRNA-10b promotes migration and invasion through Hoxd10 in human gastric cancer. *World J Surg Oncol*. 2015;13:259.
24. Liang H, Jiang Z, Xie G, Lu Y. Serum microRNA-145 as a novel biomarker in human ovarian cancer. *Tumour Biol*. 2015;36(7):5305–5313.
25. Pekow J, Meckel K, Dougherty U, et al. Tumor suppressors miR-143 and miR-145 and predicted target proteins API5, ERK5, K-RAS, and IRS-1 are differentially expressed in proximal and distal colon. *Am J Physiol Gastrointest Liver Physiol*. 2015;308(3):G179–G187.
26. Wang S, Bian C, Yang Z, et al. miR-145 inhibits breast cancer cell growth through RTKN. *Int J Oncol*. 2009;34(5):1461–1466.
27. Xie S, Xie Y, Zhang Y, Huang Q. [Effects of miR-145 on the migration and invasion of prostate cancer PC3 cells by targeting DAB2]. *Yi chuan*. 2014;36(1):50–57.
28. Wu H, Xiao Z, Wang K, Liu W, Hao Q. MiR-145 is downregulated in human ovarian cancer and modulates cell growth and invasion by targeting p70S6K1 and MUC1. *Biochem Biophys Res Commun*. 2013;441(4): 693–700.
29. Chen JJ, Cai WY, Liu XW, et al. Reverse correlation between MicroRNA-145 and FSCN1 affecting gastric cancer migration and invasion. *PLoS One*. 015;10(5): 012689
30. Xing AY, Wang B, Shi DB, et al. Deregulated expression of miR-145 in manifold human cancer cells. *Exp Mol Pathol*. 2013;95(1):91–97.
31. Zheng L, Bai J, Qi T, et al. miRNA-145 targets v-ets erythroblastosis virus E26 oncogene homolog 1 to suppress the invasion, metastasis, and angiogenesis of gastric cancer cells. *Mol Cancer Res*. 2013;11(2): 182–193.
32. Watson DK. ETS transcription factors and their emerging roles in human cancer. *Eur J Cancer*. 2005;41(16):2462–2478.
33. Zhang Y, Feng XH, KJ, Sun Q, et al. Functional screening for miRNAs targeting Smad4 identified miR-199a as a negative regulator of TGF-beta signalling pathway. *Nucleic Acids Res*. 2012;40(18):9286–9297.
34. Welch DR, Liu ET. Genetic background is an important determinant of metastatic potential. *Nat Genet*. 2003;34(1):23–24; author reply 25.
35. Kamikihara T, Ishigami S, Arigami T, et al. Clinical implications of N-cadherin expression in gastric cancer. *Pathol Int*. 2012;62(3):161–166.
36. Batlle E, Sancho E, Franci C, et al. The transcription factor snail is a repressor of E-cadherin gene expression in epithelial tumour cells. *Nat Cell Biol*. 2000;2(2):84–89.
37. Comijn J, Berx G, Vermassen P, et al. The two-handed E box binding zinc finger protein SIP1 downregulates E-cadherin and induces invasion. *Mol Cell*. 2001;7(6):1267–1278.
38. Lee HS, Lee HK, Kim HS, Yang HK, Kim WH. Tumour suppressor gene expression correlates with gastric cancer prognosis. *J Pathol*. 2003; 200(1):39–46.
39. Yonemura Y, Endou Y, Kimura K, et al. Inverse expression of S100A4 and E-cadherin is associated with metastatic potential in gastric cancer. *Clin Cancer Res*. 2000;6(11):4234–4242.
40. Gregory PA, Bert AG, Paterson EL, et al. The miR-200 family and miR-205 regulate epithelial to mesenchymal transition by targeting ZEB1 and SIP1. *Nat Cell Biol*. 2008;10(5):593–601.

Supplementary material

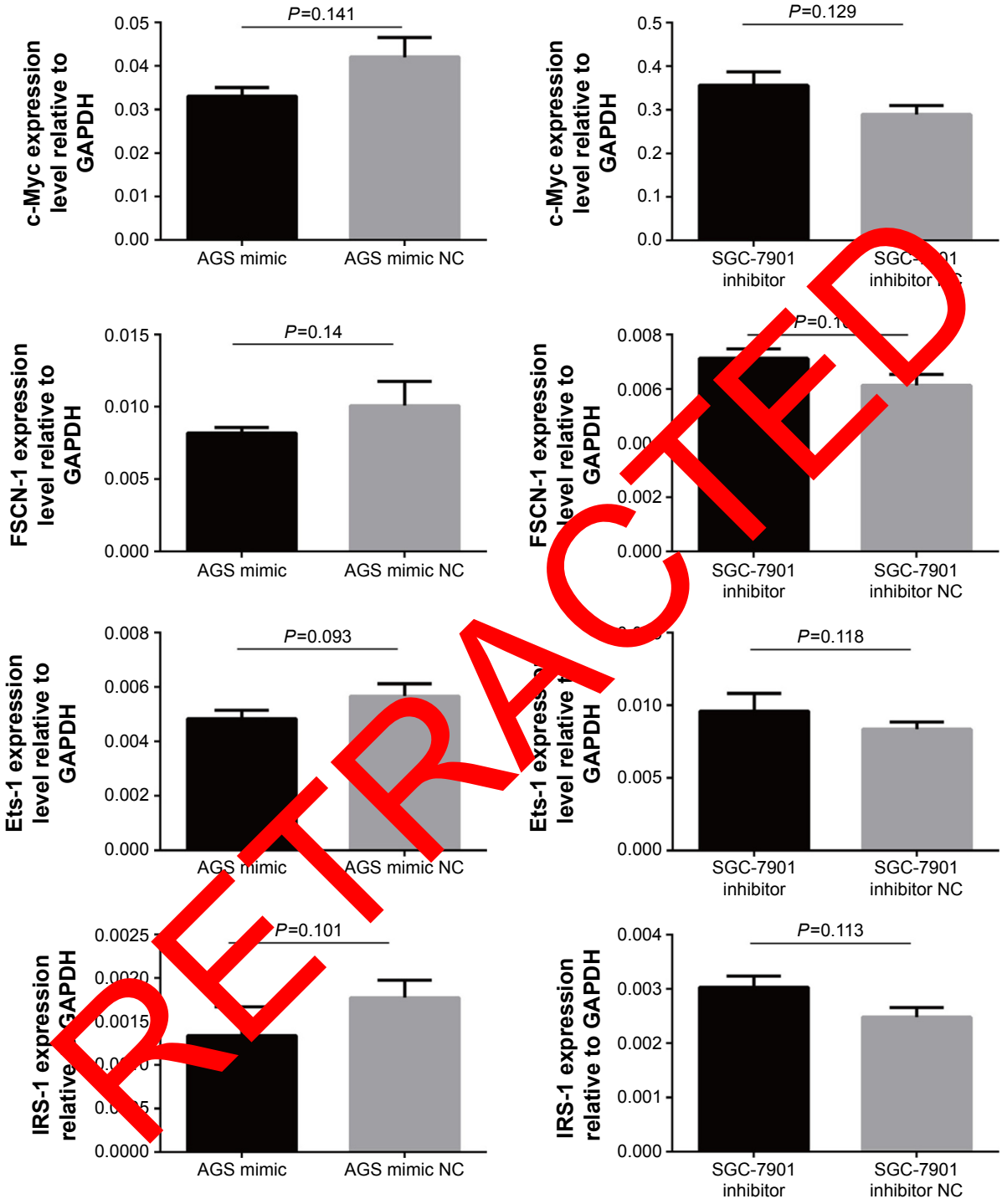

Figure S1 The expression of these genes was screened by qRT-PCR in GC cells transfected with an miR-145-5p mimic or inhibitor.
Notes: The expression levels of these candidate genes were not correlated with miR-145-5p expression in GC lines (all $P>0.05$). Each sample was analyzed in triplicate and normalized to the endogenous control GAPDH. Data represent the mean ± SD of three individual experiments.
Abbreviations: GAPDH, glyceraldehyde 3-phosphate dehydrogenase; GC, gastric cancer; miR, microRNA; qRT-PCR, quantitative real-time polymerase chain reaction; SD, standard deviation; NC, negative control.