

MicroRNA-490-3p regulates cell proliferation and apoptosis in gastric cancer via direct targeting of AKT1

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Abstract. microRNA (miRNA) expression profiles of gastric cancer (GC) and adjacent healthy gastric mucosa tissue were used to search for differentially expressed miRNAs, identifying downregulated miRNA-490-3p in GC. The present study aimed to investigate the cellular function of miRNA-490-3p and its underlying mechanism in the occurrence and progression of GC. Reverse transcription-quantitative polymerase chain reaction was used to measure miRNA-490-3p expression levels in GC tissue and adjacent healthy tissue samples. The regulatory effect of miRNA-490-3p on the proliferation and apoptosis of GC cells was detected by cell counting kit-8, colony formation assay and flow cytometry. Bioinformatic methods were used to predict AKT1 as the target of miRNA-490-3p and this was verified by a dual-luciferase reporter assay. Furthermore, western blot analysis was used to measure protein expression of AKT1 in GC cells following overexpression or knockdown of miRNA-490-3p. The present study demonstrated that miRNA-490-3p expression was downregulated in GC tissue, compared with adjacent healthy tissue. In particular, miRNA-490-3p expression levels were significantly decreased in GC tissue samples from patients with advanced cancer (stage III+IV) compared with samples from patients with early-stage (stage I+II) cancer. Additionally, miRNA-490-3p expression levels were significantly decreased in GC tissue samples from patients whose tumor size was >3 cm, compared with those <3 cm. *In vitro*, downregulation of miRNA-490-3p promoted cell proliferation and suppressed apoptosis. In addition, rescue experiments demonstrated that overexpression of AKT1 partially reversed the effect of miRNA-490-3p on cell proliferation and apoptosis. The present study demonstrated that

miRNA-490-3p regulated proliferation and apoptosis in gastric cancer cells via direct targeting of AKT1.

Introduction

Gastric cancer (GC) is one of the most common types of gastrointestinal cancer. Mortality and morbidity rates vary between countries (1). In China, the prevalence of GC is relatively high (1,2). The development of genetics and molecular biology has enabled considerable progress in understanding the pathogenesis of GC (2). In recent years, there has been a growing interest in the association between microRNA (miRNA) expression and tumor development (3,4). Differentially expressed miRNAs have been identified in a number of cancers, including GC, providing potential therapeutic targets in GC (5).

miRNAs are small non-coding, single-stranded RNAs 18-25 nucleotides in length (6). miRNAs can negatively regulate post-transcriptional gene expression by pairing with complementary binding sites in the 3'-untranslated region (3'UTR) directly cleaving mRNA or inhibiting translation (7,8). Previous studies have revealed that miRNAs can regulate multiple cellular processes, including proliferation, apoptosis, migration and immune response (9-11). Additionally, the occurrence and progression of tumors can be associated with the dysregulation of specific miRNAs (12). Previous studies have revealed that miRNA-490-3p is involved in the pathogenesis of ovarian, esophageal, lung, bladder and liver cancer (3,4,6-8). In the present study, a GC miRNA microarray dataset was used to identify differentially expressed miRNAs between GC tissue and adjacent healthy tissue samples. miRNA-490-3p was identified as being downregulated in GC tissues compared with healthy mucosa. The molecular mechanism through which miRNA-490-3p is involved in regulating GC, remains largely unknown.

The protein kinase B (AKT1) signaling pathway regulates cell proliferation, growth, apoptosis and glucose metabolism (13-15). Although mutant AKT1 has been identified in a number of diseases, AKT1 mutation sites in tumors have not been previously known (16). Studies have revealed that AKT1 is differentially expressed between human breast, colorectal, and ovarian cancers (13-15). The current study investigated the regulatory effect of miRNA-490-3p on proliferation and apoptosis in GC cells via regulation of AKT1 expression.

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Materials and methods

Acquisition and analysis of microarray data. The miRNA microarray dataset GSE93415 (Platform: GPL10971) was downloaded from the National Center of Biotechnology Information (NCBI) Gene Expression Omnibus database (GEO; www.ncbi.nlm.nih.gov/geo) and the miRNA expression data were processed with the limma package in R (version 3.0.2; Bioconductor, Munich, Germany). This dataset comprised the miRNA expression profiles of 20 pairs of tissue samples collected during operative procedures from patients diagnosed with GC. Each pair included resected primary tumor (GC tissue) and adjacent healthy gastric mucosa (normal tissue). TargetScan (http://www.targetscan.org/vert_71/) was used to predict the potential target genes. In the present study, this GC miRNA microarray dataset was used to search for differentially expressed miRNAs with a threshold of \log_2 fold change > 1.0 and $P < 0.05$. A total of 130 differentially expressed miRNAs were identified between GC and adjacent normal tissues, including 22 downregulated miRNAs and 108 upregulated miRNAs. miRNA-490-3p demonstrated a decrease in gastric cancer; following a review of previous reports, the authors selected miRNA-490-3p as the target for the present study.

Sample collection. Tissue samples were surgically resected from 259 male and 118 female patients (aged 59–81 years old) pathologically diagnosed with GC without an apparent family history in Yantai Yuhuangding Hospital (Yantai, China) from July 2012 to 2017. A total of 17 (4.5%) of patients were in stage I, 83 (22.0%) were in stage II, 108 (28.6%) were in stage III and 169 (44.9%) were in stage IV when diagnosed with GC. All enrolled patients did not receive preoperative treatment. GC tissue (tumor necrosis areas were avoided) and adjacent healthy tissue (5 cm away from tumors) samples were collected and preserved in liquid nitrogen. This study was approved by the Medical Ethics Committee at Yantai Yuhuangding Hospital and written consent was obtained from each patient enrolled in the study.

Cell culture. The human gastric epithelial cell line (GES-1) and gastric cancer (GC) cell lines (SNU-1 and N87) were obtained from the Institute of Biochemistry and Cell Biology (Beijing, China). Cells were cultured in Dulbecco's modified Eagle medium (DMEM) supplemented with 10% fetal bovine serum (FBS), 100 U/ml penicillin and 100 μ g/ml streptomycin (HyClone; GE Healthcare Life Sciences, Logan, UT, USA). Cells were maintained at 37°C in a 5% CO₂-humidified incubator and culture medium was replaced every 2 days.

Cell transfection. miRNA-490-3p mimic (50 nM; cat. no B03001), miRNA-490-3p inhibitor (50 nM; cat. no B01001), pcDNA-AKT1 (1 μ g/ μ l; cat. no B02001), 5 μ l inhibitor negative controls (50 nM; cat. no B01003) and 5 μ l mimic negative controls (50 nM; cat. no B1012) were purchased from GenePharma (Shanghai GenePharma Co., Ltd., China). SNU-1 and N87 cells were seeded in six-well plates until 60–80% confluence was reached. Cells were transfected using Lipofectamine® 2000 (Invitrogen; Thermo Fisher Scientific, Inc., Waltham, MA, USA), according to the manufacturer's protocol. Cells were collected 48 h post-transfection for subsequent experimentation.

Reverse transcription-quantitative polymerase chain reaction (RT-qPCR). Total RNA was extracted from miRNA-490-3p mimic, miRNA-490-3p inhibitor, mimics-NC and inhibitor-NC-transfected SNU-1 and N87 cells using TRIzol® reagent (Invitrogen; Thermo Fisher Scientific, Inc.) according to manufacturer's protocol. Total RNA was reverse transcribed into cDNA using the PrimeScript RT reagent kit (Takara Biotechnology Co., Ltd., Dalian, China), according to the manufacturer's protocol. qPCR was subsequently performed with three replicates in each group, using the SYBR® Premix Ex Taq™ (Takara Biotechnology Co., Ltd.), according to the manufacturer's protocol. The following primer pairs were used for the PCR: miRNA-490-3p forward, 5'-CGGCGGTCAACC TGGAGGACTCC-3' and reverse, 5'-CCAGTGCAGGGTCCG AGGTAT-3'; AKT1 forward, 5'-AGCGACGTGGCTATTGTG AAG-3' and reverse, 5'-GCCATCATTCTTGAGGAGGAA GT-3'; GAPDH forward, 5'-AGCCACATCGCTCAGACAC-3' and reverse, 5'-GCCCAATACGACCAAATCC-3'; U6 forward, 5'-CTCGCTTCGGCAGCAGCACATATA-3' and reverse, 5'-AAATATGGAACGCTTCACGA-3'. The following thermo-cycling conditions were used for the PCR: Initial denaturation at 94°C for 30 sec; 40 cycles of 55°C for 30 sec and 72°C for 90 sec. miRNA-490-3p was normalized to U6 and AKT1 was normalized to GAPDH. The 2^{- $\Delta\Delta C_q$} method was used for quantification (17).

Cell proliferation assay. miRNA-490-3p mimic, miRNA-490-3p inhibitor, mimics-NC and inhibitor-NC-transfected SNU-1 and N87 cells were seeded into 96-well plates at a density of 1 × 10⁴/ μ l and cultured for 0, 24, 48, 72 and 96 h. Cells were incubated with 10 μ l of cell counting kit-8 reagent (CKK-8; Dojindo Molecular Technologies, Inc., Kumamoto, Japan). The absorbance was measured at a wavelength of 450 nm using a microplate reader (Bio-Rad Laboratories, Inc., Hercules, CA, USA).

Colony formation assay. miRNA-490-3p mimic, miRNA-490-3p inhibitor, mimics-NC and inhibitor-NC-transfected SNU-1 and N87 cells in the logarithmic growth phase were washed with PBS, digested with trypsin and centrifuged at 10 × g for 3 min at 4°C. After cell density was adjusted to 1 × 10⁴/l, cells were seeded in six-well plates at a density of 2 × 10³ cells/well. Cells were fixed with 4% methanol for 30 min at 20°C and stained with 0.1% crystal violet (Sigma-Aldrich; Merck KGaA, Darmstadt, Germany) for 30 min at 20°C. Colony formation was observed and images were captured using a light microscope (Olympus Corporation, Tokyo, Japan).

Cell apoptosis detection by flow cytometry. miRNA-490-3p mimic, miRNA-490-3p inhibitor, mimics-NC and inhibitor-NC-transfected SNU-1 and N87 cells were collected by centrifugation at 100 × g for 5 min at 4°C. Cells were resuspended in 100 μ l 1X Annexin (Annexin V-FITC/PI Apoptosis Detection kit; Nanjing Jiancheng Bioengineering Institute, Nanjing, China) at a density of 1 × 10⁵ cells/ml. The cells were subsequently stained with 5 μ l Annexin V-fluorescein isothiocyanate and 1 μ l propidium iodide in 100 μ l cell suspension, and incubated at room temperature in darkness for 15 min. Apoptotic cells were subsequently analyzed using a flow cytometer. Apoptotic cells were subsequently analyzed using a flow cytometer (FACSCalibur; BD Biosciences, San Jose, CA, USA).

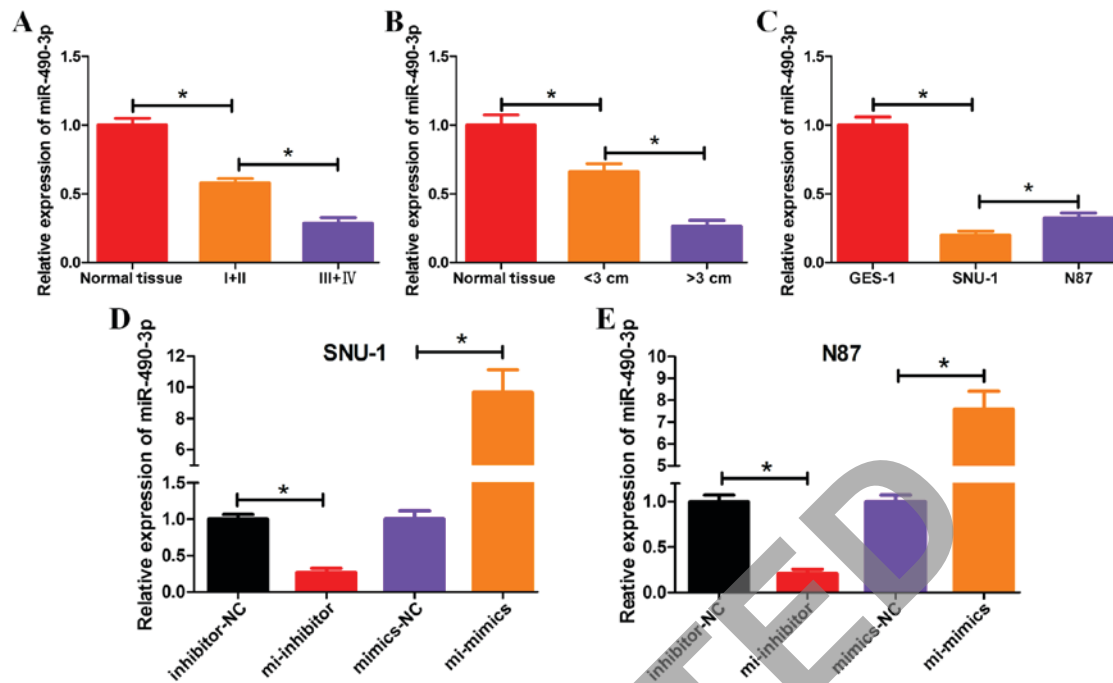


Figure 1. miRNA-490-3p is downregulated in GC. The mRNA expression level of miRNA-490-3p was determined by reverse transcription-quantitative polymerase chain reaction using tissue samples from patients with GC according to (A) stage of cancer and (B) size of tumor. (C) The mRNA expression level of miRNA-490-3p was determined in GC cell lines. The mRNA expression levels of miRNA-490-3p in GC cell lines (D) SNU-1 and (E) N87 were analyzed following transient transfection with miRNA-490-3p mimic, inhibitor and NCs. * $P < 0.05$. NC, negative control; GC, gastric cancer; normal tissue, adjacent healthy tissue; I+II, GC tissue samples from patients with stage I and II cancer; III+IV, GC tissue samples from patients with stage II and IV cancer; GES-1, human gastric epithelial cell line; SNU-1 and N87, GC cell lines; inhibitor-NC and mimics-NC, GC cell lines (SNU-1 or N87) transfected with miRNA-NC; mi-inhibitor, GC cell line (SNU-1 or N87) transfected with miRNA-490-3p inhibitor; mi-mimics, GC cell line (SNU-1 or N87) transfected with miRNA-490-3p mimic.

CellQuest™ software (version 3.3; BD Biosciences) was used for data analysis.

Dual-luciferase reporter assay. Galaxy software (version 2.0; <https://galaxyproject.org>) was used to predict AKT1 as a theoretical target of miRNA-490-3p and this was verified by dual-luciferase reporter gene assay. The AKT1-3'UTR sequence of AKT1 was downloaded from NCBI. Wild-type AKT1 (WT AKT1) and mutant-type AKT1 (MUT AKT1) were constructed. The AKT luciferase reporter plasmid (Shanghai Yeasen Biotechnology Co., Ltd) was used. Cells were co-transfected with 50 pmol/l miRNA-490-3p mimic or negative control and 80 ng WT AKT1 or MUT AKT1, respectively, using Lipofectamine 2000. Following incubation for 48 h at 20°C, cells were collected and luciferase activity was detected. The firefly luciferase reporter gene assay kit (Shanghai Kangnian Biotechnology Co., Ltd.) was used for activity measurement. The normalization was performed through the comparison of firefly luciferase activity with Renilla luciferase activity.

Western blot analysis. Total protein was extracted from treated cells using radioimmunoprecipitation assay lysis buffer (Shanghai Yeasen Biotech Co., Ltd., Shanghai, China). The BCA method was used to quantify protein concentration. Protein samples (10 μ l/lane) were separated by SDS-PAGE (10% gel). The separated proteins were subsequently transferred onto a polyvinylidene difluoride membrane and blocked with 5% skimmed milk at 20°C for 2 h. The membranes were incubated with primary antibodies, including AKT1 (cat. no. 2938),

GAPDH (cat. no. 5174; both 1:500; Cell Signaling Technology, Inc., Danvers, MA, USA) overnight at 4°C. Membranes were washed with Tris-buffered saline with Tween® 20, before incubation with a biotinylated secondary antibody (cat. no. 14708; 1:1,000; Cell Signaling Technology, Inc.) for 1 h at room temperature. AKT1 was normalized to GAPDH. Protein bands were visualized using an enhanced chemiluminescence (Immobilon Western Chemiluminescent HRP Substrate; EMD Millipore, Billerica, MA, USA).

Statistical analysis. The results are reported as the mean \pm standard deviation. Statistical analysis was performed using SPSS statistical software (version 19.0; IBM Corp., Armonk, NY, USA). All experimental data were analyzed using one-way analysis of variance followed by Fisher's Least Significant Difference post hoc test. $P < 0.05$ was considered to indicate a statistically significant difference. Each experiment was repeated three times.

Results

miRNA-490-3p is downregulated in GC. The mRNA expression levels of miRNA-490-3p significantly decreased in GC tissue samples compared with normal tissue samples from patients with GC (Fig. 1A and B). In particular, miRNA-490-3p expression levels were significantly decreased in GC tissue samples from patients with advanced cancer (stage III+IV), compared with GC tissue samples from patients with early-stage (stage I+II) cancer (Fig. 1A). Additionally, miRNA-490-3p expression levels were significantly decreased in GC tissue samples from patients

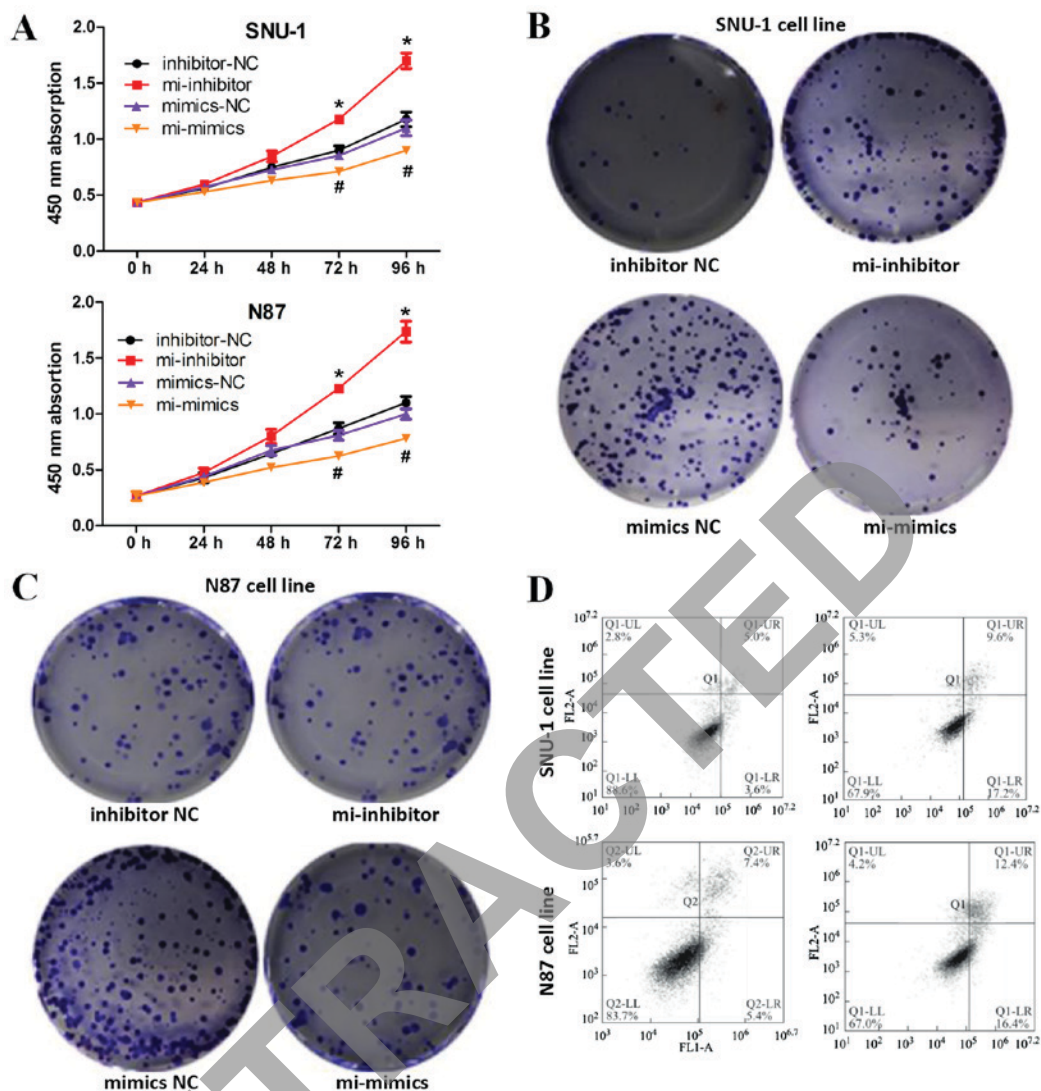


Figure 2. miRNA-490-3p induces apoptosis and inhibits proliferation of GC cells. (A) The effect of miRNA-490-3p overexpression and knockdown on both SNU-1 and N87 cell growth was analyzed by cell counting kit-8 assay. The effect of miRNA-490-3p overexpression and knockdown on (B) SNU-1 and (C) N87 colony formation was analyzed. (D) The effect of miRNA-490-3p overexpression and knockdown on apoptosis in GC cells was detected by flow cytometry. * $P < 0.05$ vs. inhibitor-NC, # $P < 0.05$ vs. mimics-NC. NC, negative control; GC, gastric cancer; SNU-1 and N87, GC cell lines; inhibitor-NC and mimics-NC, GC cell line (SNU-1 or N87) transfected with miRNA-NC inhibitor; mi-inhibitor, GC cell line (SNU-1 or N87) transfected with miRNA-490-3p inhibitor; mi-mimics, GC cell line (SNU-1 or N87) transfected with miRNA-490-3p mimic.

with tumor size >3 cm, compared with GC tissue samples from patients with tumor size <3 cm (Fig. 1B). The mRNA expression levels of miRNA-490-3p significantly decreased in GC cell lines SNU-1 and N87, compared with the control GES-1 cell line (Fig. 1C). miRNA-490-3p mimic, miRNA-490-3p inhibitor and miRNA-negative control (miRNA-NC) were transiently transfected into GC cell lines (SNU-1 and N87) and the expression levels of miRNA-490-3p were detected by RT-qPCR. Relative expression of miRNA-490-3p was calculated to give an indication of transfection efficiency in GC cell lines (Fig. 1D and E).

Downregulation of miRNA-490-3p promotes apoptosis and inhibits proliferation in GC cells. To determine the regulatory effect of miRNA-490-3p on GC cell proliferation, CCK-8 and colony formation assays were performed. CCK-8 assays demonstrated that miRNA-490-3p overexpression inhibited the proliferative ability of GC cells compared with the negative control, whilst miRNA-490-3p knockdown induced the

opposite effect (Fig. 2A). Similar results were obtained in the colony formation assays whereby miRNA-490-3p overexpression inhibited colony formation in GC cells compared with the negative control, whilst miRNA-490-3p knockdown induced the opposite effect (Fig. 2B and C). In addition, miRNA-490-3p overexpression induced GC cell apoptosis (Fig. 2D).

miRNA-490-3p negatively regulates AKT1 expression. Following miRNA-490-3p overexpression, luciferase activity indicated that miRNA-490-3p suppressed WT AKT1 expression compared with MUT AKT1, in both GC cell lines (Fig. 3A and B). Overexpression of miRNA-490-3p significantly decreased the mRNA expression level of AKT1, conversely miRNA-490-3p knockdown significantly increased the mRNA expression level of AKT1 in both SNU-1 and N87 cells (Fig. 3C and D). Western blot analysis revealed that AKT1 protein expression was negatively regulated by miRNA-490-3p (Fig. 3E).

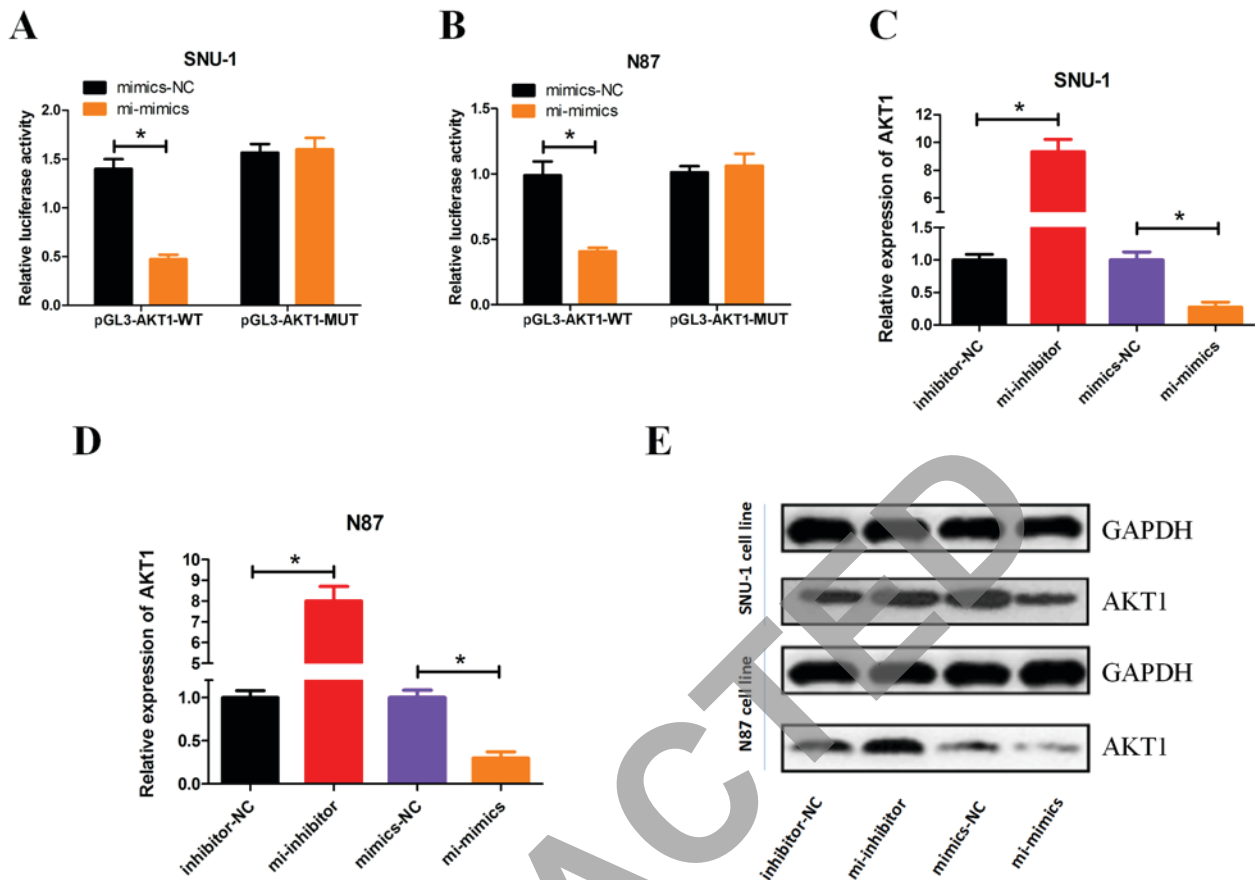


Figure 3. miRNA-490-3p directly targets AKT1 expression. Following miRNA-490-3p overexpression luciferase activity was measured in (A) SNU-1 and (B) N87 cells. The mRNA expression level of AKT1 was determined by reverse transcription-quantitative polymerase chain reaction in (C) SNU-1 and (D) N87 cells following transient transfection with miRNA-490-3p mimic, inhibitor and negative control. (E) The protein expression level of AKT1 was determined by western blot analysis. *P<0.05. AKT1, protein kinase B; AKT1-WT, AKT1 wild type; AKT1-MUT, AKT1 mutant-type; GC, gastric cancer; SNU-1 and N87, GC cell lines; inhibitor-NC and mimics-NC, GC cell line (SNU-1 or N87) transfected with miRNA-NC inhibitor; mi-inhibitor, GC cell line (SNU-1 or N87) transfected with miRNA-490-3p inhibitor; mi-mimics, GC cell line (SNU-1 or N87) transfected with miRNA-490-3p mimic.

AKT1 overexpression partially suppresses miRNA-490-3p-induced apoptosis. To determine the regulatory effect of miRNA-490-3p on AKT1 expression, cell proliferation rescue experiments were performed. CCK-8 assays demonstrated that the decreased proliferation of GC cells induced by miRNA-490-3p overexpression was partially suppressed by AKT1 overexpression (Fig. 4A and B). Similarly, the increased rate of GC cell apoptosis induced by miRNA-490-3p overexpression was suppressed by AKT1 overexpression (Fig. 4C and D), suggesting that miRNA-490-3p negatively regulates AKT1 expression.

Discussion

miRNAs are small non-coding, single-stranded RNAs 18-25 nucleotides in length that can negatively regulate post-transcriptional gene expression (6). A number of studies have demonstrated that differentially expressed miRNAs in tumors can be associated with tumor development and chemotherapy sensitivity (18). It is therefore important to identify tumor-specific miRNAs as potential therapeutic targets in cancer. miRNA-490-3p is considered to be a potential tumor suppressor involved in cell proliferation, migration and invasion in a number of different tumors (8). In colorectal

cancer, miRNA-490-3p is significantly downregulated and miRNA-490-3p knockdown promotes colorectal cancer cell migration and invasion capabilities by targeting transforming growth factor receptor 1 (19). Chen *et al* (20) revealed that miRNA-490-3p is also downregulated in human ovarian epithelial tissues. miRNA-490-3p targets cyclin dependent kinase 1 expression and inhibits ovarian epithelial carcinoma tumorigenesis and progression (21). Similarly, miRNA-490-3p regulates cell proliferation and apoptosis in osteosarcoma (22). The exact role of miRNA-490-3p in GC remains largely unknown.

In the present study, the cellular function of miRNA-490-3p in GC and its underlying mechanism were investigated. The data presented in this study demonstrated that miRNA-490-3p was downregulated in GC cell lines as well as GC tissue samples from patients, indicating a potential role of this miRNA in GC. Furthermore, miRNA-490-3p knockdown promoted proliferation and inhibited apoptosis of GC cells *in vitro*.

To determine the molecular mechanism of miRNA-490-3p in GC development, bioinformatics analysis was used to identify target genes of miRNA-490-3p. AKT1 was identified as a potential downstream target gene of miRNA-490-3p, which was further verified by dual-luciferase reporter gene assay. The AKT pathway is a signal transduction pathway

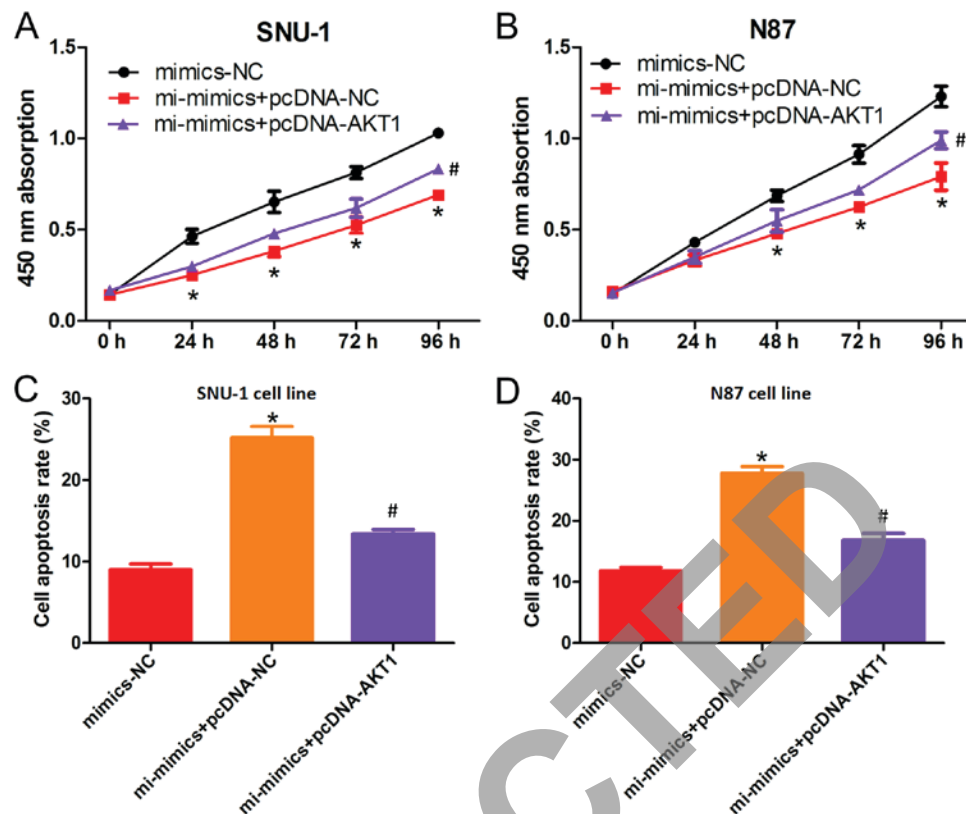


Figure 4. AKT1 overexpression partially reverses miRNA-490-3p-induced apoptosis. The effect of AKT1 on (A) SNU-1 and (B) N87 cell growth was analyzed by cell counting kit-8 assay following miRNA-490-3p overexpression. The effect of AKT1 on the rate of apoptosis in (C) SNU-1 and (D) N87, following overexpression of miRNA-490-3p. * $P < 0.05$ vs. mimics-NC, # $P < 0.05$ vs. mimics-NC+pcDNA-NC. AKT1, protein kinase B; GC, gastric cancer; SNU-1 and N87, GC cell lines; NC, negative control; mimics-NC, GC cell line (SNU-1 or N87) transfected with miRNA-NC inhibitor; mi-mimics + pcDNA-NC, co-transfection with miRNA-490-3p mimic and negative control in GC cell lines; mi-mimics + pcDNA-AKT1, co-transfection with miRNA-490-3p mimic and AKT1 in GC cell lines.

that regulates several cellular processes by enhancing or suppressing the activity of target proteins (14,15). In GC, the AKT pathway is known to be involved in a number of processes, including cellular proliferation, differentiation, apoptosis and migration (23,24). In the current study, miRNA-490-3p negatively regulated AKT1 mRNA and protein levels. In addition, rescue experiments demonstrated that decreased proliferation and increased apoptosis of GC cells induced by miRNA-490-3p overexpression were partially suppressed by AKT1 overexpression. These results indicated that miRNA-490-3p may regulate GC development via AKT1.

In conclusion, miRNA-490-3p knockdown promoted proliferation and inhibited apoptosis of GC cells via direct targeting of AKT1. Although the current study provided some understanding of miRNA-490-3p in GC, the mechanism involved in regulating miRNA-490-3p activity was not addressed in this study and further investigation may be required.

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Availability of data and materials

All datasets used and/or analyzed during the present study are available from the corresponding author on reasonable request.

Authors' contributions

HY and YX designed and performed the experiments. HY, JS and SJ collected the data. HY and JS analyzed the data. HY and YX prepared the manuscript. All authors read and approved the final manuscript.

Ethics approval and consent to participate

The present study was approved by the Medical Ethics Committee at Yantai Yuhuangding Hospital (Yantai, China). Written informed consent was obtained from all participants and/or guardians.

Patient consent for publication

Patients or their guardians have provided written informed consents for publication.

Competing interests

The authors declare that they have no competing interests.

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