

miR-133a inhibits cervical cancer growth by targeting EGFR

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Received May 7, 2015; Accepted June 11, 2015

DOI: 10.3892/or.2015.4101

Abstract. MicroRNAs (miRNAs) are small non-coding RNAs that play critical roles in cervical carcinogenesis and progression. microRNA-133a (miR-133a) has been reported to play a tumor-suppressor role in a range of cancers. However, the role and underlying molecular mechanism of miR-133a in cervical cancer have not been investigated. In the present study, we investigated the role of miR-133a in the tumorigenicity of cervical cancer cells *in vivo* and *in vitro*. The expression of miR-133a was investigated using real-time reverse transcription-polymerase chain reaction (qRT-PCR) in 30 cervical specimens and matched adjacent normal tissues and cervical cancer cell lines. We found that the expression level of miR-133a was significantly downregulated in cervical cancer tissues and cervical cancer cell lines, and the aberrant expression of miR-133a was correlated with lymph node metastasis, histological grade and FIGO stage. The role of miR-133a in tumorigenicity of cervical cancer cells was assessed by the restoration of miR-133a. We found that restoration of miR-133a inhibited cell proliferation, colony formation, migration and invasion, promoted cell apoptosis *in vitro* and suppressed tumorigenicity *in vivo*. The epidermal growth factor receptor (EGFR) was confirmed to be a direct target of miR-133a in cervical cancer cells using luciferase assay and western blotting. Restoration of miR-133a inhibited EGFR expression and activated the AKT and ERK signaling pathways. These results showed that miR-133a suppresses cervical cancer growth *in vitro* and *in vivo* through targeting

EGFR, suggesting that miR-133a can be a potential target for the treatment of cervical cancer.

Introduction

Cervical cancer is the third most common gynecologic cancer in women worldwide with more than 0.5 million new cases diagnosed annually (1). Although screening for cervical cancer is globally accessible, a large number of cases are still diagnosed with advanced disease, particularly in developing countries accounting for more than 85% of the cases and deaths (2). In China, more than 50,000 women succumb to this disease each year (3). Although previous studies have found that 99.7% of cases with cervical cancer can be attributed to persistent infection with high-risk human papillomaviruses (HPVs) (4), growing evidence shows that other factors are also involved in cervical cancer development (5). Therefore, there is an urgent need to identify such factors for the prevention and treatment of cervical cancer.

microRNAs (miRNAs) are small non-coding RNAs of ~21-25 nucleotides (nt) that typically suppress gene expression by binding to 3' untranslated regions (3'UTRs) of their target mRNAs for degradation (6,7). Since one miRNA targets many mRNAs, miRNAs have been found to play crucial roles in a vast range of biological processes, including cell proliferation, angiogenesis, cell cycle and cellular migration (8). Over the past decade, emerging evidence has demonstrated that alterations in miRNAs are involved in tumor development, progression and metastasis (9). Accumulating evidence indicates that miRNAs are abnormally expressed in various human cancers and they function as tumor promoters or suppressors depending on the nature of their targets (10). These findings may provide new insights into the molecular mechanisms underlying cervical carcinogenesis.

miR-133a is an important miRNA that was first experimentally characterized in mice (11), and reportedly plays a crucial role in myoblast proliferation and differentiation during embryonic muscle development through regulation of bone morphogenetic protein 2 (12). Several studies have reported downregulation of miR-133a in prostate (13), head and neck (14), breast (15), bladder (16), esophageal (17) and colorectal cancer (18). Accumulating evidence has shown that restoration of miR-133a expression has been reported to inhibit cancer cell proliferation, migration and invasion, and induce cancer cell apoptosis (13-18). These studies suggest

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Key words: cervical cancer, microRNAs, miR-133a, epidermal growth factor receptor, tumorigenicity

that miR-133a acts as a tumor suppressor in various human cancers. However, the clinical significance and the detailed role of miR-133a in cervical cancer has not yet been thoroughly validated.

Therefore, the aims of the present study were to investigate the expression pattern of miR-133a and its clinical significance in cervical cancer samples, and to evaluate the effects of miR-133a on cervical cancer growth *in vitro* and *in vivo*, as well as to determine its target gene and molecular mechanism in cervical cancer cells.

Materials and methods

Statement of ethics. The consent procedure and the protocol of the present study were approved by the Ethics Committee of Jilin University. The study was performed in compliance with the principles laid down in the Helsinki Declaration. Written consent was obtained from all patients prior to surgery.

Patients and samples. Cervical tissue samples and corresponding adjacent normal tissues were collected from 30 patients who underwent surgery at the Department of Pathology, China-Japan Union Hospital of Jilin University (Changchun, China) between August 2012 and October 2014. The pathological diagnosis of all 30 patients was cervical squamous cell carcinoma. The corresponding adjacent normal tissues from the same 30 patients with cervical cancer were obtained 3 cm beyond the boundary of the cervical cancer tissues. None of these patients received chemotherapy and radiotherapy, or had other treatment history or other inflammatory diseases before the surgery. The tissue specimens were immediately frozen in liquid nitrogen after surgical removal and stored at -80°C until use. Clinicopathological parameters including patient age, histological grade, tumor size, lymph node metastasis and International Federation of Gynecology and Obstetrics (FIGO) stage were collected and are listed in Table I.

Cell culture. HaCaT cells (an immortalized HPV-negative skin keratinocyte cell line) and five cervical cancer cell lines (MS751, C33A, HeLa, HeLa229 and SiHa) were purchased from the Type Culture Collection of the Chinese Academy of Sciences (Shanghai, China), and were maintained in Dulbecco's modified Eagle's medium (DMEM) (Invitrogen, San Diego, CA, USA) containing 10% fetal bovine serum (FBS) (HyClone Victoria, Australia), 100 IU/ml penicillin and 100 mg/ml streptomycin at 37°C in a humidified atmosphere containing 5% CO_2 .

Quantitative reverse-transcription polymerase chain reaction (qRT-PCR). Total RNA from the cells or tissues was isolated using TRIzol reagent (Invitrogen) following the manufacturer's instructions. Reverse transcription was carried out using the Takara PrimeScript™ First Strand cDNA Synthesis kit (Takara Bio, Inc., Dalian, Japan) according to the manufacturer's instructions. Then the miR-133a expression level was quantified as previously described (15) on an ABI Applied Biosystems 7500 Real-Time PCR system (Applied Biosystems, White Plains, NY, USA). The U6 small RNA was used as an internal control for miR-133a. The comparative $2^{-\Delta\Delta\text{Ct}}$ method was used for relative quantification and statistical analysis.

Table I. Association between miR-133a expression and clinicopathological features of the human cervical cancer cases.

| Feature | n | miR-133a expression level | P-value |
|-----------------------|----|---------------------------|---------|
| Age, years | | | 0.689 |
| <60 | 14 | 0.53±0.05 | |
| ≥60 | 16 | 0.51±0.07 | |
| FIGO stage | | | <0.01 |
| Ib-IIa | 20 | 0.62±0.09 | |
| IIB-IIIa | 10 | 0.32±0.04 | |
| Histological grade | | | <0.05 |
| Well/moderate | 24 | 0.58±0.12 | |
| Poor | 6 | 0.28±0.05 | |
| Tumor size (cm) | | | 0.875 |
| <5 | 17 | 0.53±0.10 | |
| ≥5 | 13 | 0.51±0.08 | |
| Lymph node metastasis | | | <0.01 |
| No | 22 | 0.64±0.11 | |
| Yes | 8 | 0.20±0.04 | |

miRNA transfection. Human miR-133a mimic and corresponding negative control miRNA (miR-Ctrl) which did not target any human genes were purchased from Shanghai GenePharma (Shanghai, China), and were transiently transfected into HeLa cells in 6-well plates using Oligofectamine™ transfection reagent (Invitrogen) according to the manufacturer's instructions at a concentration of 100 nM. Transfection efficiencies were determined by qRT-PCR 48 h post-transfection.

Cell proliferation assay. The capacity for cellular proliferation was measured with the 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) assay. Briefly, 24 h after transfection, 1×10^4 cells were incubated into 96-well microtiter plates and cultured for 24, 48, 72 and 96 h, respectively. Then, the cells were incubated with 20 μl of MTT (5 mg/ml; Sigma-Aldrich, St. Louis, MO, USA) for 4 h at 37°C . Then 200 μl of dimethylsulfide (DMSO; Sigma) was added to solubilize the crystals for 20 min at room temperature. Cell viability was assessed by the absorbance at 490 nm using a microplate reader (Bio-Rad, Gaithersburg, MD, USA). All experiments were performed three times.

Cell cycle and cell apoptosis assay. Cell cycle and cell apoptosis assays were performed using flow cytometry. First, HeLa cells were transfected with either miR-133a or miR-Ctrl and cultured for 48 h. For cell cycle analysis, the transfected cells were fixed in 70% ethanol for 2 h at 4°C . After washing with phosphate-buffered saline (PBS), the cells were treated with RNase A (50 $\mu\text{g}/\text{ml}$) and stained with propidium iodide (PI; 25 $\mu\text{g}/\text{ml}$) (both from Sigma) for 30 min at 37°C in the dark, and then analyzed by flow cytometry (BD Biosciences, Mansfield, MA, USA). Distribution of cell cycle phases was determined using ModFIT software (BD Biosciences).

For cell apoptosis, the transfected cells were collected and stained with FITC-Annexin V and PI using the FITC/Annexin V apoptosis detection kit (BD Biosciences, Franklin Lakes, NJ, USA), according to the manufacturer's protocol and were then analyzed by fluorescence-activated cell sorting (FACS) and flow cytometric analysis (BD Biosciences). Experiments were performed in triplicate.

Colony formation assay. Approximately 1,000 transfected cells were placed in a fresh 6-well plate for another 12 h and maintained in DMEM containing 10% FBS for 14 days. Colonies were fixed with methanol and stained with 0.1% crystal violet in 20% methanol for 15 min. Cells were counted under a light microscope (Olympus, Tokyo, Japan). The colony formation was calculated by adjusting the percentage of miR-Ctrl cells to 100%. Experiments were performed in triplicate.

Migration and invasion assays. *In vitro* cell migration and invasion assays were performed using Transwell chambers. For the migration assays, 2×10^4 transfected cells suspended in serum-free DMEM were added into the upper chamber of 8- μ m Transwells (BD Biosciences, Franklin Lakes, NJ, USA). For the invasion assays, 2×10^4 transfected cells suspended in serum-free DMEM were added into the upper chamber of 8- μ m Transwells pre-coated with Matrigel (BD Biosciences). In both assays, medium containing 10% FBS was added into the lower chamber serving as the chemoattractant. After a 24-h incubation, the cells that did not migrate or invade through the pores were carefully removed using cotton. Filters were fixed with 70% ethanol for 30 min and stained with 0.2% crystal violet staining for 10 min. The invaded or migrated cells were photographed and counted in five randomly selected fields/chamber under an inverted microscope (Olympus). All experiments were performed in triplicate.

Tumor growth in vivo. Twenty female BALB/c mice, 4-5 weeks old were purchased from the Experimental Animal Center of Changchun Biological Institute (Changchun, China) and kept under specific pathogen-free (SPF) conditions. Animal experiments were performed in strict accordance with the Guide for the Care and Use of Laboratory Animals of the US National Institutes of Health. Animal protocols were approved by the Institutional Animal Care and Use Committee of Jilin University (Changchun, China).

Ten mice in each group were subcutaneously (s.c.) injected into the flanks with 2×10^6 HeLa cells stably expressing miR-133a or miR-NC, respectively. Mice were monitored for tumor growth and weight every week and sacrificed at 4 weeks after injection. Tumor volume was measured using a vernier caliper every week, and tumor volume was calculated according to the formula: Volume (mm^3) = $1/2 \times \text{width}^2 \times \text{length}$. On day 28, the mice were sacrificed, and tumor tissues were resected and weighed. Total RNAs of the tumor tissues were extracted to measure the miR-133a level by qRT-PCR.

miRNA target prediction. Prediction of miR-133a target genes was performed using two publicly available algorithms: TargetScan (release 6.2; <http://www.targetscan.org/>) and miRanda (release 16.0; <http://www.microrna.org/>).

Vector construction and luciferase reporter assay. The miR-133a binding sites from the 3'UTR EGFR (wild-type) or mutant 3'UTR (mutant-type) were cloned into the downstream *Renilla* luciferase gene in the pGL3/Luciferase vector (Ambion, Austin, TX, USA). For the reporter assay, 100 nM miR-133a mimic or control miRNA was co-transfected with 0.1 μ g of the pGL3-3'UTR wild-type or mutant plasmid DNAs into HeLa cells in 96-well plates using Lipofectamine 2000 (Life Technologies) according to the manufacturer's instructions. At 48 h after transfection, luciferase activity was detected using the Dual-Luciferase Reporter Assay system (Promega, Madison, USA). *Renilla* luciferase was used for normalization.

Western blot analysis. Cells were harvested and lysed in ice-cold RIPA buffer (Beyotime, Jiangsu, China) according to the manufacturer's instructions. Concentrations of total cellular protein were quantified using a BCA assay kit (Pierce, Rockford, IL, USA) according to the manufacturer's instructions. Twenty micrograms of protein were separated by SDS-PAGE, and then transferred onto PVDF membranes (Millipore, Bedford, MA, USA). After being blocked with 5% non-fat milk for 1.5 h at room temperature, the membranes were incubated with the following primary antibodies overnight at 4°C: mouse monoclonal anti-human β -actin (1:3,000; Cell Signaling Technology, New England Biolabs); mouse monoclonal anti-human epidermal growth factor receptor (EGFR) (1:1,000; Santa Cruz Biotechnology, Santa Cruz, CA, USA), mouse monoclonal anti-human phosphorylated (p)-ERK1/2 (1:1,000); mouse monoclonal anti-human ERK1/2 (1:1,000); mouse monoclonal anti-human AKT (2:1,000) and mouse monoclonal anti-human p-AKT (1:1,000) (all from Cell Signaling Technology). The membranes were washed with PBS and incubated with horseradish peroxidase (HRP)-conjugated goat anti-mouse IgG (1:5,000; Santa Cruz Biotechnology) for 2 h at room temperature. The proteins were detected using chemiluminescent (ECL) detection system (Millipore) and the results of the western blot analyses were analyzed using the ImageJ program.

Statistical analysis. Data from at least three independent experiments are expressed as mean \pm standard deviation (SD). The differences between two groups were analyzed using the two-sided Student's t-test. The statistical analyses of cases in groups were performed using the Chi-square test. All data were analyzed using GraphPad Prism version 5.01 (GraphPad Software, San Diego, CA, USA). $P < 0.05$ was used to indicate a statistically significant difference.

Results

Expression of miR-133a is markedly downregulated in cervical cancer specimens and cell lines. The expression of miR-133a was detected in 30 pairs of human cervical cancer and adjacent normal tissues by real-time quantitative RT-PCR (qRT-PCR). As shown in Fig. 1A, miR-133a was markedly downregulated in cervical cancer samples when compared with that in the adjacent normal tissues ($P < 0.01$). In addition, the association between miR-133a expression and the clinicopathological parameters of the patients, including age, FIGO stage, histological grade, lymph node metastasis and

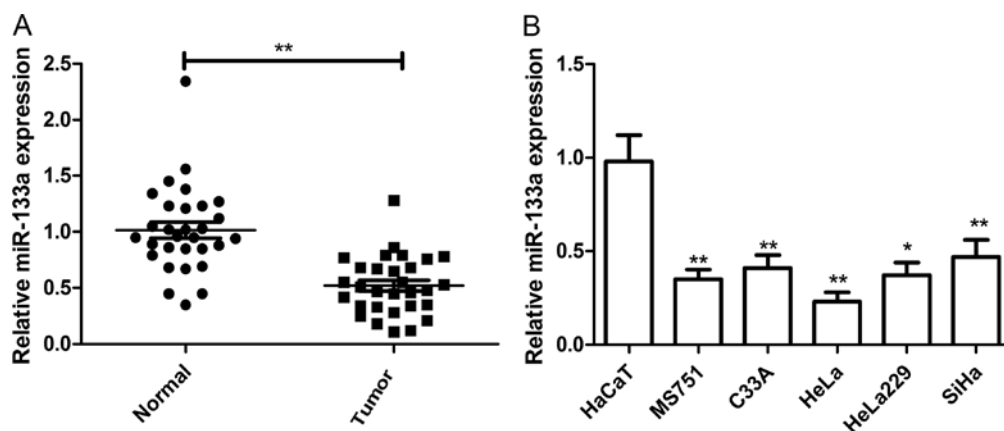


Figure 1. miR-133a is significantly downregulated in cervical cancer tissues and cell lines. (A) Real-time quantitative RT-PCR (qRT-PCR) analysis of miR-133a expression in cervical cancer tissues (tumor) and matched adjacent normal tissues (normal). U6 was used as a loading control. ** $P < 0.01$ vs. normal cervical epithelium samples. (B) qRT-PCR analysis of miR-133a expression in human cervical cancer cell lines (MS751, C33A, HeLa, HeLa229 and SiHa) and normal cervical cells (HaCaT). * $P < 0.05$, ** $P < 0.01$ vs. HaCaT cells.

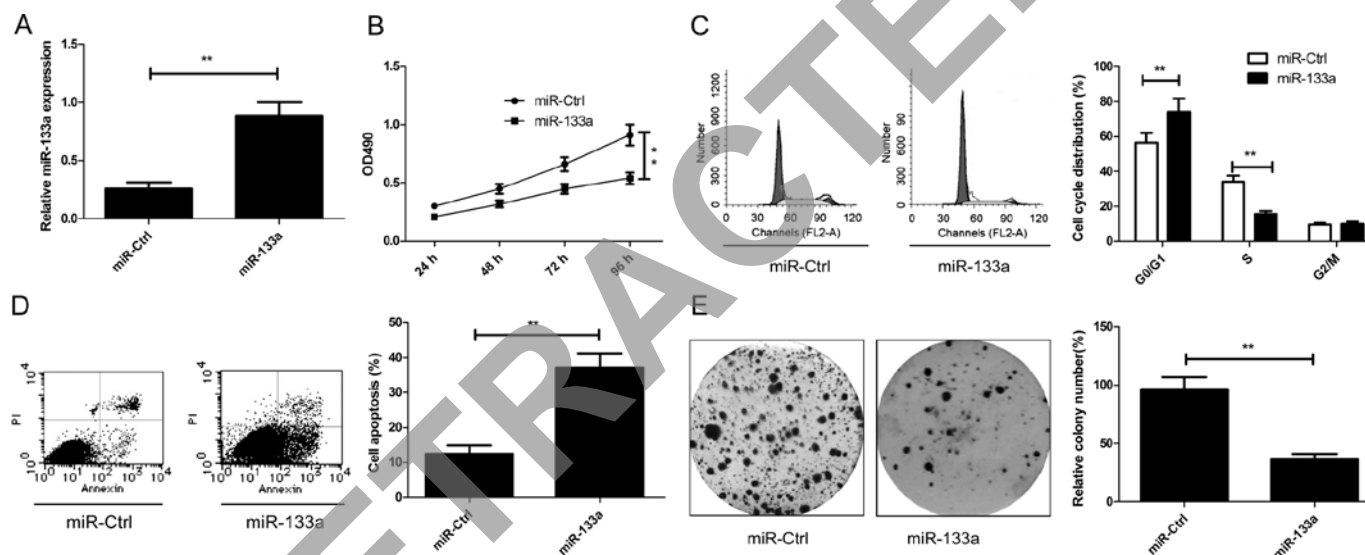


Figure 2. Overexpression of miR-133a retards cell proliferation and colony formation and promotes cell apoptosis and cell cycle at the G0/G1 stage in cervical cancer cells. (A) The relative expression levels of miR-133a in HeLa cells were determined by qRT-PCR after transfection with miR-133a or miR-Ctrl. (B) Determination of HeLa cell proliferation with an MTT assay after transfection with miR-133a or miR-Ctrl. (C) Determination of HeLa cell cycle distribution by PI staining after transfection with miR-133a or miR-Ctrl. (D) Determination of HeLa cell apoptosis with the FITC/Annexin V apoptosis detection kit after transfection with miR-133a or miR-Ctrl. (E) Determination of the capacity for colony formation of HeLa cells using a colony formation assay after transfection with miR-133a or miR-Ctrl. ** $P < 0.01$ vs. miR-Ctrl.

tumor size was assessed (Table I). It was found that the aberrant expression of miR-133a was correlated with lymph node metastasis ($P < 0.01$), histological grade ($P < 0.01$) and FIGO stage ($P < 0.01$), which are all indicators of poor prognosis. No significant association was found between the expression of miR-133a and age and tumor size in cervical cancer. These data suggest that miR-133a plays a critical role in cervical cancer metastasis and progression.

In addition to cervical cancer tissues, endogenous expression of miR-133a was detected in a panel of cervical cancer cell lines (MS751, C33A, HeLa, HeLa229 and SiHa) and normal cervical cells (HaCaT). It was found that miR-133a was also significantly decreased in four cervical cancer cell lines compared with that in the HaCaT cells (Fig. 1B), and that the lowest level was observed in HeLa cells (Fig. 1B).

Given the above results, it was decided to use the HeLa cells for subsequent experiments.

Overexpression of miR-133a inhibits cell proliferation and colony formation, and induces the cell cycle and apoptosis of cervical cancer cells. To explore the relevant effect of miR-133a on cervical cancer cell growth, miR-133a and miR-Ctrl were transfected into cervical cancer HeLa cells. We found that the intracellular level of miR-133a was higher in the HeLa cells transfected with the miR-133a mimic compared with the level in the cells transfected with miR-Ctrl (Fig. 2A). Then, cell proliferation of the HeLa cells was assessed using MTT assays after transfection of miR-133a or miR-Ctrl. As shown in Fig. 2B, restoration of the expression of miR-133a significantly inhibited cell proliferation in the HeLa cells ($P < 0.05$). As

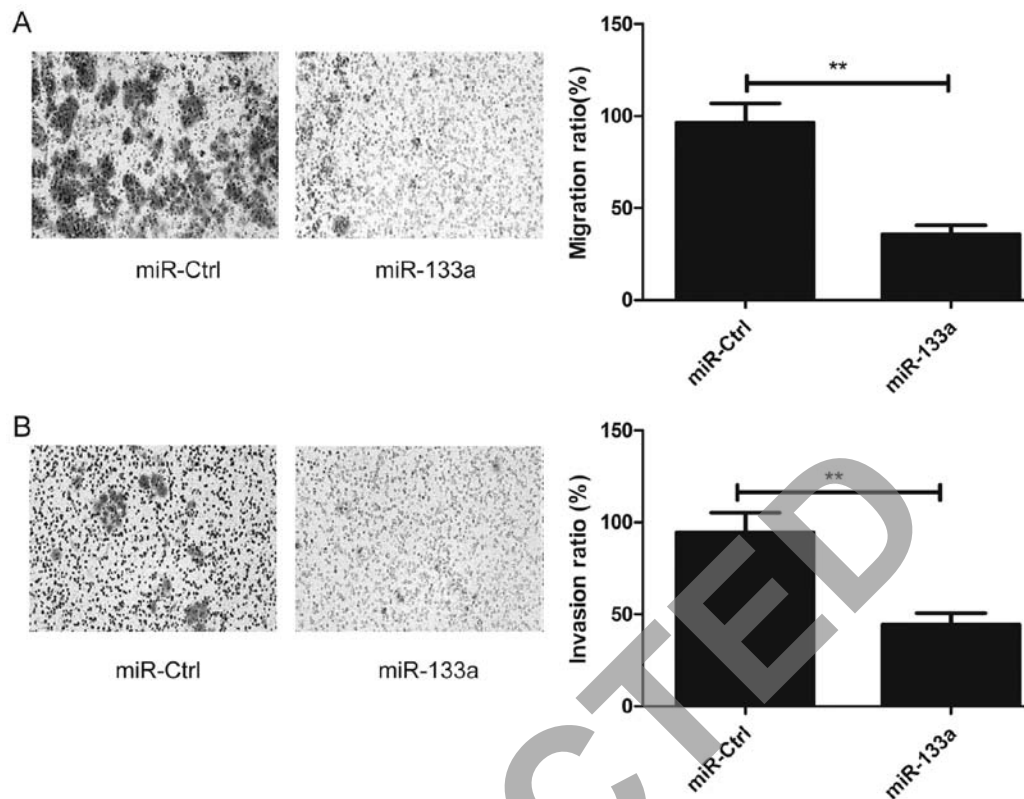


Figure 3. Overexpression of miR-133a inhibits cell migration and invasion of cervical cells. (A) Transwell migration assays of HeLa cells transfected with the miR-133a mimic or miR-Ctrl. (B) Transwell invasion assays of HeLa cells transfected with the miR-133a mimic or miR-Ctrl. **P<0.001 vs. miR-Ctrl.

proliferation is directly associated with cell cycle distribution, the effect of miR-133a on cell cycle progression was evaluated in HeLa cells. We found that the percentage of S phase cells was decreased, while the percentage of G0/G1 phase cells was increased in the HeLa cells of the miR-133a mimic transfection group when compared to the miR-Ctrl transfection group (P<0.05, Fig. 2C). To reveal the biological role of miR-133a in cervical cancer cell apoptosis, cell apoptosis assay was performed in the HeLa cells 48 h after transfection with the miR-133a mimic or miR-Ctrl. We found that overexpression of miR-133a increased cell apoptosis relative to the miR-Ctrl group (P<0.05, Fig. 2D). In addition, colony formation ability was investigated to assess the role of miR-133a in cervical cancer cell growth. As shown in Fig. 2E, restored expression of miR-133a significantly decreased the colony formation in the HeLa cells compared with that in the miR-Ctrl group. Taken together, these results suggested that miR-133a efficiently inhibits cell proliferation and colony formation and induces cell cycle distribution at the G0/G1 stage and apoptosis of cervical cancer cells.

Overexpression of miR-133a inhibits the migration and invasion of cervical cancer cells. Since miR-133a downregulation was observed to be associated with lymph node metastasis in patients with cervical cancer, we performed migration and invasion assays in cervical cancer cells using a Transwell chamber after transfection with the miR-133a mimic or miR-Ctrl. Consistent with the clinical data, overexpression of miR-133a reduced migration and invasion capacities of the HeLa cells (P<0.05; Fig. 3A and B).

miR-133a suppresses tumor growth in vivo. Based on the observed decreases in migratory, invasive and proliferative behavior in the HeLa cells transfected with miR-133a, we next investigated the role of miR-133a *in vivo*. We subcutaneously inoculated nude mice with equal numbers (2×10^6 cells/mouse) of HeLa cells with the stable expression of miR-133a or miR-Ctrl. Tumor incidence was assessed every week until week 4. Tumors appeared in all of the mice. The results showed that overexpression of miR-133a significantly suppressed the growth of cervical cancer xenografts in nude mice (Fig. 4A), and decreased tumor volume (Fig. 4B) and tumor weight (Fig. 4C). Furthermore, we also determined the miR-133a expression in the tumor tissue by western blotting. miR-133a expression was significantly increased in the HeLa-miR-133a group when compared to the HeLa-miR-Ctrl group (P<0.01, Fig. 4D). These data indicated that miR-133a suppressed tumor growth of cervical growth *in vivo*.

EGFR is a direct target of miR-133a. To understand how miR-133a facilitates cervical cancer growth and metastasis, we used two algorithms (Targetscan and miRanda) to help identify miR-133a targets in human cervical cancers. EGFR was selected from several putative miR-133a target genes, since IGF-1R has been shown to be involved in tumorigenesis and metastasis (19,20). As shown in Fig. 5A, miR-133a contains two predicted binding sites in the 3'UTR of EGFR mRNA. Luciferase assay further revealed that HeLa cells transfected with miR-133a repressed wild-type EGFR-3'UTR reporter activity by ~51% compared with the cells cotransfected with the miR-Ctrl (P<0.01), while miR-133a had no inhibitory

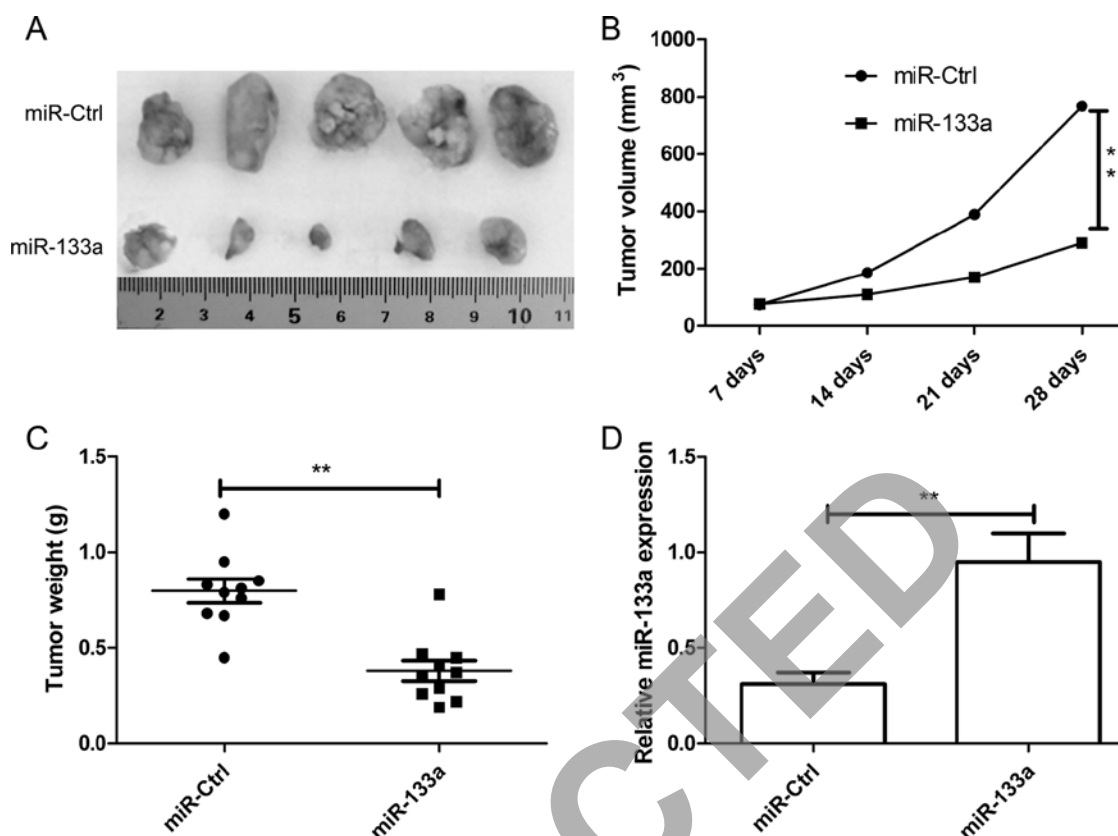


Figure 4. Inhibition of the growth of the HeLa xenografts in nude mice by the miR-133a mimic. (A) Image of tumor specimens of the xenograft model at day 28 after inoculation is shown. (B) Growth curves of tumor volume in xenografts of nude mice. (C) Tumor weight. (D) Determination of the miR-133a expression level in the tumor tissue by qRT-PCR. ** $P < 0.01$ vs. the miR-Ctrl group.

effect on the mutant EGFR-3'UTR reporter activity (Fig. 5B), indicating the direct regulation of miR-133a in the 3'UTR of EGFR mRNA.

To determine whether miR-133a affects the regulation of endogenous EGFR, we transiently reintroduced the miR-133a mimic into HeLa cells. We found that ectopic expression of miR-133a markedly reduced EGFR protein expression in the HeLa cells (Fig. 5C), suggesting that EGFR is a *bona fide* target of miR-133a.

Ectopic expression of miR-133a regulates the AKT and ERK signaling pathways. The EGF receptor (EGFR), which is a member of the ErbB receptor family, plays crucial roles in cell proliferation, differentiation and development (21) since EGFR activation initiates several signal transduction cascades, including the MAPK and PI3K/AKT pathways, leading to DNA synthesis and cell proliferation (22). To determine whether miR-133a suppresses downstream signaling of EGFR in the cervical cancer cells, AKT, p-AKT, ERK1/2 and p-ERK1/2 protein expression was analyzed in HeLa cells by western blotting after transfection with the miR-133a mimic or miR-Ctrl. Our results showed that the expression of p-AKT and p-ERK1/2 was decreased in cells transfected with the miR-133a mimic (Fig. 6), while total AKT and ERK1/2 were not significantly changed in each group (Fig. 6). These results suggested that overexpression of miR-133a suppressed cervical cancer cell growth partly through regulation of the AKT and ERK signaling pathways.

Discussion

Growing evidence demonstrates that the aberrant expression of miRNAs contributes to tumorigenesis and tumor development by inhibiting the expression of their target genes and may potentially serve as biomarkers for prediction and prognosis in various types of cancer, and as therapeutic targets for the treatment of various cancers including cervical cancer (23,24). Therefore, there is a need to identify specific miRNAs and their targets involved in tumorigenesis for the diagnosis and therapy of patients with malignancies. In the present study, we found that the expression of miR-133a was significantly decreased in cervical cancer tissue samples and cell lines, and its expression level was significantly associated with poor prognostic clinicopathological parameters including lymph node metastasis, histological grade and FIGO stage. We also found that overexpression of miR-133a significantly inhibited cervical cell proliferation, migration and invasion, and induced cell apoptosis and the cell cycle at the G0/G1 stage *in vitro*, as well as reduced tumor growth of the xenograft nude mouse model. These findings suggest that miR-133a is not only a useful biomarker of poor prognosis, but is also a therapeutic target for patients with cervical cancer.

miR-133a, an important member of the miR-133 family, has been reported to be weakly expressed in several types of cancers and plays a critical role in cancer initiation and development. Dong *et al* (18) reported that miR-133a is frequently downregulated in colorectal cancer tissues and cancer cell

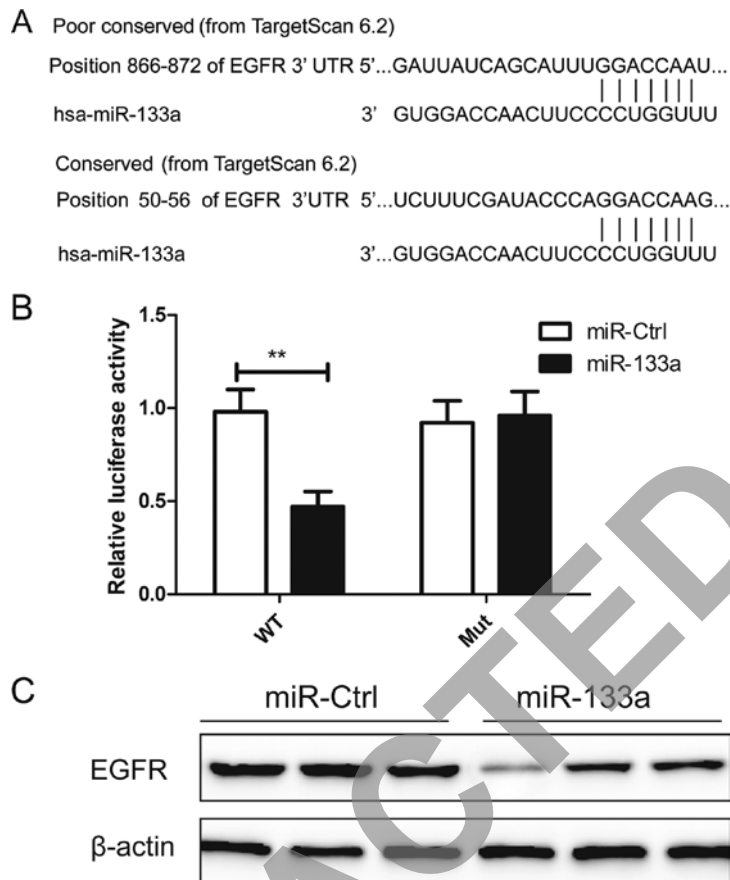


Figure 5. miR-133a targets the EGFR gene in cervical cancer cells. (A) The predicted miR-133a binding sites in 3'UTR of EGFR by Targetscan and miRanda. (B) Relative luciferase activity was analyzed upon co-transfection with wild-type (WT) or mutant-type (mt) reporter plasmids and miR-133a or miR-Ctrl in HeLa cells. (C) Western blotting of EGFR protein expression in the HeLa cells after transfection with the miR-133a mimic or miR-Ctrl. β -actin was used as an internal control.

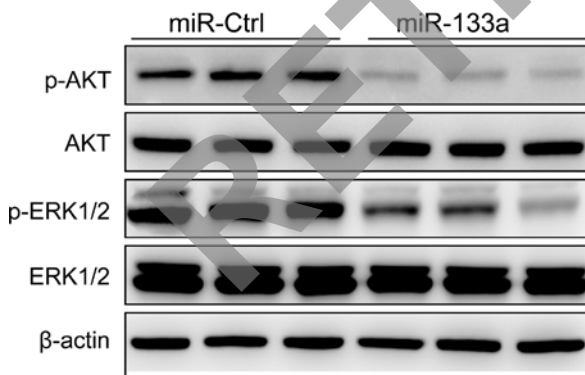


Figure 6. Overexpression of miR-133a inhibits the activation of AKT and ERK signaling pathways in cervical cancer cells. AKT, p-AKT, ERK1/2 and p-ERK1/2 protein expression was determined in HeLa cells by western blotting after transfection with the miR-133a mimic or miR-Ctrl. β -actin was used as an internal control.

lines, and that restoration of miR-133a inhibited colorectal cancer *in vitro* and *in vivo*, at least in part, by reducing ring finger and FYVE-like domain containing E3-ubiquitin protein ligase (RFFL) translation and by activating the p53/p21 pathway. Ji *et al* (25) reported that overexpression of miR-133a expression in osteosarcoma cells significantly reduced cell proliferation, promoted cell apoptosis *in vitro*, as well as suppressed tumorigenicity *in vivo* by targeting

Bcl-xL and Mcl-1. Cui *et al* (15) showed that overexpression of miR-133a in breast cancer cells and breast cancer tissues was significantly downregulated, and that miR-133a functions as a tumor suppressor in breast cancer, regulating the cell cycle and proliferation in tumorigenesis by targeting EGFR through the downstream signal molecule Akt. Moriya *et al* (26) showed that restoration of miR-133a expression in lung squamous carcinoma cells resulted in significant inhibition of cell proliferation by targeting ARPC5 and GSTP1. However, whether miR-133a functions in the development and progression of cervical cancer by involvement in other pathological processes remains unknown. In the present study, we shed light on the functionality and mechanism of the involvement of miR-133a in cervical cancer processes, and showed that miR-133a acts as a tumor suppressor in cervical cancer and blocks tumor growth *in vitro* and *in vivo* by targeting EGFR through inhibition of the activation of the AKT and ERK signaling pathways.

It is well known that miRNAs usually exert their biological functions by inhibiting the expression of target mRNAs by binding to the 3'UTRs of target mRNAs (27). In the present study, we used two bioinformatic algorithms to predict gene targets for miR-133a. We found that the epidermal growth factor receptor (EGFR/ErbB-1/HER1) contains two highly conserved miR-133a binding sites on the 3'UTR (Fig. 5A). The luciferase assay further confirmed that the EGFR gene is a direct target of miR-133a, which is consistent with a previous

study that miR-133a inhibits EGFR expression by directly targeting its 3'UTR in lung (28), prostate (29) and breast cancer (15). EGFR, a cell-surface receptor for members of the epidermal growth factor (EGF), is a member of the ErbB family of receptors, and plays a key role in stimulation of intrinsic intracellular protein tyrosine kinase activity (21). It has been reported to be overexpressed in a variety of tumors, including cervical cancer (30), and overexpression of EGFR has been found to be involved in tumor progression, resistance to chemotherapy and radiation therapy and poor prognosis, suggesting it acts as an oncogene (21,31). Notable, it has been shown that abnormal expression of EGFR affects two major downstream signaling pathways; the MAP kinase pathway and the AKT pathway (22,32), which are two key molecular mechanisms of tumorigenesis and development. Thus, in the present study, we also ascertained whether miR-133a affects activation of the AKT and ERK pathways. Our results showed that overexpression of miR-133a inhibited p-AKT and p-ERK1/2 protein expression (Fig. 6). These findings suggest that miR-133a suppresses cervical cancer cell growth by targeting EGFR through the AKT and ERK signaling pathways.

In summary, the results presented in the present study, first demonstrated that miR-133a is downregulated in cervical cancer tissues and cell lines, and its expression level is significantly associated with lymph node metastasis, histological grade and FIGO stage. Our results also showed that miR-133a functions as a tumor suppressor and has a significant suppressive effect on the tumor growth of cervical cancer *in vitro* and *in vivo*. In addition, EGFR was identified as a crucial target gene of miR-133a. Overexpression of miR-133a inhibited EGFR expression and activation of the AKT and ERK signaling pathways. These results suggest that miR-133a may be a promising drug target for cervical cancer therapy.

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