

# MicroRNA-29a plays a suppressive role in non-small cell lung cancer cells via targeting LASP1

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**Abstract:** MicroRNA (miR)-29a has been implicated in non-small cell lung cancer (NSCLC), but the mechanism remains largely unclear. LASP1, a cAMP- and cGMP-dependent signaling protein, was recently found to promote proliferation and aggressiveness in NSCLC. However, the regulatory mechanism of LASP1 expression in NSCLC, as well as the relationship between LASP1 and miR-29a, has never been previously studied. In this study, we found that miR-29a was remarkably downregulated and low expression of miR-29a was associated with the malignant progression of NSCLC. Moreover, the expression of LASP1 was markedly increased in NSCLC tissues and cell lines. Bioinformatics analysis and luciferase reporter assay data further identified LASP1 as a target gene of miR-29a, and the expression of LASP1 was negatively mediated by miR-29a at the post-transcriptional level in NSCLC cells. Overexpression of miR-29a reduced the proliferation, migration, and invasion of NSCLC cells, just as the effects of LASP1 knock-down. Moreover, overexpression of LASP1 attenuated the suppressive effect of miR-29a on the malignant phenotypes of NSCLC cells. In addition, upregulation of miR-29a decreased the growth of A549 cells in nude mice and protected the animals from tumor-induced death. Therefore, we demonstrate that miR-29a plays a suppressive role in NSCLC via targeting LASP1, suggesting that the miR-29a/LASP1 axis may become a promising therapeutic target for NSCLC.

**Keywords:** non-small cell lung cancer, microRNA-29a, LIM and SH3 protein 1, proliferation, migration, invasion

## Introduction

Lung cancer is the most common malignant tumor worldwide.<sup>1,2</sup> Non-small cell lung cancer (NSCLC), including squamous cell carcinoma, adenocarcinoma, and large cell carcinoma, accounts for ~85% of lung cancers.<sup>1,2</sup> Despite improvements in surgery combined with radiotherapy and/or chemotherapy, the prognosis for NSCLC patients is still unsatisfactory, mainly due to its metastasis and recurrence.<sup>3,4</sup> In the recent decade, many cancer-related genes have been found to be dysfunctioned in NSCLC, which may contribute to its progression.<sup>5,6</sup> Therefore, revealing the regulatory roles and the underlying mechanisms of these oncogenes and tumor suppressors is beneficial for developing more effective diagnostic and/or therapeutic strategies for NSCLC treatment.

MicroRNAs (miRs) are a kind of non-coding RNAs with a length of 18–25 nucleotides functioning as key regulators of gene expression at the post-transcriptional level through directly binding to the 3'-untranslational region (UTR) of their target messenger RNAs (mRNAs), causing either translation inhibition or mRNA degradation.<sup>7,8</sup> Through mediation of their target genes, miRs participate in the regulation of various biological processes, such as cell proliferation, survival, apoptosis, differentiation, cell cycle progression, and angiogenesis. Moreover, miRs are also involved in tumorigenesis.

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Deregulations of miRs have been found in a variety of human cancers, including NSCLC, and contribute to the malignant progression and poor prognosis of cancer patients.

miR-29a has been found to be involved in many physiological and pathological processes. For instance, miR-29a regulates the chondrogenic differentiation of mesenchymal stem cells and cartilage formation.<sup>9</sup> Besides, it is also a key regulator of collagen expression in systemic sclerosis.<sup>10</sup> Moreover, miR-29a plays a promoting or suppressive role in some common human malignancies, such as breast cancer,<sup>11</sup> gastric cancer,<sup>12</sup> oral squamous cell carcinoma,<sup>13</sup> and glioma.<sup>14</sup> Recently, the expression of miR-29a was reported to be significantly reduced in more invasive lung cancer cell lines, and overexpression of miR-29a resulted in a significant reduction in the invasion and proliferation of lung cancer cells.<sup>15</sup> Tan et al<sup>16</sup> reported that miR-29a could promote the expression of WIF-1 through directly targeting DNMT3A and DNMT3B, which further suppressed the oncogenic Wnt/ $\beta$ -catenin signaling pathway in NSCLC cells. However, whether other target genes of miR-29a exist in NSCLC still remains to be studied.

Therefore, the objective of our study was to explore the regulatory roles of miR-29a in NSCLC *in vitro* and *in vivo* and to reveal the potential targets of miR-29a involved in this process.

## Patients and methods

### Clinical tissue samples

NSCLC tissues (n=78) and matched adjacent non-tumor tissues (n=78) were collected at Xiangya Hospital, Central

South University from April 2013 to January 2014, the histomorphology of which were confirmed by the Department of Pathology. Tissues were immediately snap-frozen in liquid nitrogen and stored at  $-80^{\circ}\text{C}$  before use. The study was approved by the ethics committee of Central South University, Changsha, People's Republic of China. Written informed consents were obtained from all studied patients. The clinical information of NSCLC patients is summarized in Table 1.

### Cell culture

Normal human lung epithelial cell line BEAS-2B and NSCLC cell lines, including A549, SK-MES-1, H460, and SPC-A1, were purchased from Cell Bank of Chinese Academic Institute, Shanghai, People's Republic of China. All cell lines were cultured in Dulbecco's Modified Eagle's Medium (DMEM; Thermo Fisher Scientific, Waltham, MA, USA) supplemented with 10% fetal bovine serum (FBS; Thermo Fisher Scientific) in a  $37^{\circ}\text{C}$  humidified incubator with 5%  $\text{CO}_2$ .

### Real-time quantitative polymerase chain reaction (PCR) assay

Total RNA was extracted using TRIzol Reagent (Thermo Fisher Scientific) according to the manufacturer's instruction. The relative expression level of miR-29a was determined by quantitative real-time reverse transcription (RT) PCR using mirVana™ Real-Time RT-PCR MicroRNA Detection Kit (Thermo Fisher Scientific), in accordance with the manufacturer's instructions. U6 was used as an internal reference.

**Table 1** Association between miR-29a expression and clinicopathological characteristics of patients with NSCLC

Variables	Patients (n)	Low miR-29a (n=41)	High miR-29a (n=37)	P-value
Age (years)				0.927
<55	27	14	13	
$\geq 55$	51	27	24	
Gender				0.262
Male	52	25	27	
Female	26	16	10	
Tumor size				0.723
$\leq 4$ cm	49	25	24	
$> 4$ cm	29	16	13	
Differentiation				0.011
Well-moderate	57	25	32	
Poor	21	16	5	
Lymph node metastasis				0.015
No	48	20	28	
Yes	30	21	9	
Distant metastasis				0.146
No	62	30	32	
Yes	16	11	5	
Clinical stage				0.003
I-II	39	14	25	
III-IV	39	27	12	

**Abbreviations:** miR, microRNA; NSCLC, non-small cell lung cancer.

For mRNA expression detection, real-time RT-PCR was conducted using standard SYBR Green RT-PCR Kit (Thermo Fisher Scientific), according to the manufacturer's instruction. GAPDH was used as an internal reference. The specific primer pairs are shown as follows: miR-29a forward: 5'-ACACTCCAGCTGGGACTGATTTCTTTTGGT-3', reverse: 5'-CTCAACTGGTGTCTGGAGTCGGCAATTCAGTTGAGTCA GGTGT-3'; U6 forward: 5'-CTCGCTTCGGCAGCACACA-3', reverse: 5'-AACGCTTCACGAATTTGCGT-3'; LASP1 forward: 5'-TGCGGCAAGATCGTGTATCC-3', reverse: 5'-GCAGTAGGGCTTCTTCTCGTAG-3'; and GAPDH forward: 5'-GGAGCGAGATCCCTCCAAAAT-3', reverse: 5'-GGCTGTTGTCATACTTCTCATGG-3'. The  $2^{-\Delta\Delta C_t}$  method was used to determine the relative expression of miR or mRNA.

## Western blot

Cells were lysed in cold radioimmunoprecipitation assay buffer, and the protein was separated with 12% sodium dodecyl sulfate polyacrylamide gel electrophoresis, which was then transferred to the polyvinylidene difluoride membrane (Thermo Fisher Scientific). After that, the membrane was incubated in phosphate-buffered saline (PBS) with 5% non-fat dried milk (Yili, Beijing, People's Republic of China) for overnight at 4°C. Then, the membrane was incubated with primary antibodies (Abcam, Cambridge, MA, USA) for 3 h and with secondary antibody (Abcam) for 1 h. The immune complexes was detected using ECL Western Blotting Kit (Thermo Fisher Scientific). The relative protein expression was analyzed using Image-Pro Plus software 6.0 (Media Cybernetics, Rockville, MD, USA), and GAPDH was used as the internal reference.

## Cell transfection

Cell transfection was conducted using Lipofectamine 2000 (Thermo Fisher Scientific), according to the manufacture's instruction. All of the plasmids and vectors used in this study were designed and purchased from Guangzhou RiboBio Co., Ltd. (Guangzhou, People's Republic of China). In brief, serum-free medium was used to dilute scramble miR mimic (miR-negative control [NC]), miR-29a mimic, blank pcDNA3.1 vector, pcDNA3.1-LASP1 expression plasmid, non-specific small interfering RNA (siRNA), and LASP1-specific siRNA, which was then added with the diluted Lipofectamine 2000 and incubated at room temperature for 20 min. After that, they were added into the cell suspension. After incubating for 6 h, the medium was replaced by DMEM with 10% FBS. After transfection for 48 h, the following assays were performed.

## Dual-luciferase reporter assay

For determining the target relationship between miR-29a and LASP1, we generated the wild-type (WT) and mutant-type (MT) 3'-UTR of LASP1, which was then inserted into the multiple cloning site of the psiCHECK™-2 luciferase reporter vector. A549 cells were transfected with WT-LASP1-3'-UTR or MT-LASP1-3'-UTR vector, plus miR-NC or miR-29a mimics. At 48 h after transfection, the Renilla luciferase activity and firefly luciferase activity were determined using the dual-luciferase reporter assay system. Renilla luciferase activity was normalized to firefly luciferase activity.

## MTT assay

A549 cells in each group were suspended in 100  $\mu$ L of DMEM containing 0.5 g/L MTT, seeded in 96-well plates, and incubated at 37°C for 4 h. After that, the MTT medium was removed and 50  $\mu$ L of dimethyl sulfoxide was added and then incubated at 37°C for 10 min. The optical density at 570 nm was measured using the ELx800 Absorbance Microplate Reader (BioTek, Winooski, VT, USA). The experiments were repeated three times.

## Wound healing assay

Wound healing assay was conducted to examine the cell migratory capacity. In brief, we created a wound of 1 mm width when culturing A549 cells using a plastic scribe. Then, the cells were washed once with PBS. The serum-free DMEM was added. After incubated for 24 h, the serum-free DMEM was replaced by the DMEM with 10% FBS. At 48 h after wounding, the cells were observed under a microscope.

## Transwell assay

Transwell assay was conducted using the 24-well transwell chambers with a layer of matrigel (EMD Millipore, Bedford, MA, USA). A549 cell suspension was added in the upper chamber, and DMEM containing 10% FBS was added into the lower chamber. After incubation for 24 h, non-invading cells in the interior of the inserts were removed using a cotton-tipped swab. Cells on the lower surface of the membrane were stained with gentian violet and then rinsed with water and dried in air. Five fields were randomly selected, and cell number was counted under the microscope.

## Stable transfection and tumor growth analysis

The study was approved by the ethics committee of Central South University, Changsha, People's Republic of China. All

experiments were performed in accordance with the Guide for the Care and Use of Laboratory Animals.

Male BALB/C-nu/nu nude mice (10 weeks) were maintained at the animal center of our hospital. The pYr-LVX-miR-29a lentiviral plasmid was obtained from Amspring (Changsha, People's Republic of China). A549 cells were then stably transfected with pYr-LVX-miR-29a lentiviral plasmid. Blank pLVX-IRES-ZsGreen1 vector was used as control. To determine the effect of miR-29a on the tumorigenesis of lung cancer cells in vivo, nude mice (n=6) were injected subcutaneously in the dorsal flank with  $5 \times 10^6$  A549 cells stably transfected with miR-29a-overexpressing plasmid. Besides, nude mice (n=6) in the control group were injected with A549 cells stably transfected with the blank vector. Nude mice were sacrificed, if not died, on day 60 after tumor implantation. Tumor volume was calculated using the following formula:

$$V (\text{mm}^3) = 0.5 \times a \times b^2$$

where  $a$  is the maximum length in diameter and  $b$  the maximum transverse diameter. Tumor weight was also recorded when the mice died.

## Statistical analysis

Data were expressed as mean  $\pm$  standard deviation. SPSS 19.0 software (IBM Corporation, Armonk, NY, USA) was used to conduct statistical analysis. Comparison of qualitative data was analyzed by the chi-square test. Comparison of quantitative data was analyzed by the unpaired  $t$ -test. Correlation was determined by Pearson correlation analysis.  $P < 0.05$  was considered as statistically significant.

## Results

### Expression of miR-29a and LASP1 in NSCLC

In our study, we first conducted real-time RT-PCR to determine the miR-29a levels in a total of 78 cases of human NSCLC tissues and their matched adjacent non-tumor tissues. As indicated in Figure 1A, miR-29a was significantly downregulated in NSCLC tissues, when compared with that in their matched adjacent non-tumor tissues. The median of the expression of miR-29a was used as the cutoff value. If the expression of miR-29a was greater than the median, it was defined as high expression; otherwise, it was defined as low expression. Further investigation revealed that low expression of miR-29a was associated with poor differentiation, lymph node metastasis, and advanced clinical stage in

NSCLC, without any association with gender, age, tumor size, and distant metastasis (Table 1).

We further found that the expression of LASP1 was markedly increased in NSCLC tissues compared to their matched adjacent non-tumor tissues (Figure 1B). After that, we examined the expression of miR-29a and LASP1 in several common human NSCLC cell lines, including A549, SK-MES-1, H460, and SPC-A1. Normal human lung epithelial BEAS-2B cells were used as the control group. The miR-29a levels were also downregulated in NSCLC cell lines compared to BEAS-2B cells (Figure 1C). Moreover, the mRNA and protein levels of LASP1 were also upregulated in NSCLC cells compared to BEAS-2B cells (Figure 1D and E). Therefore, our findings indicated that miR-29a was downregulated while LASP1 was upregulated in NSCLC.

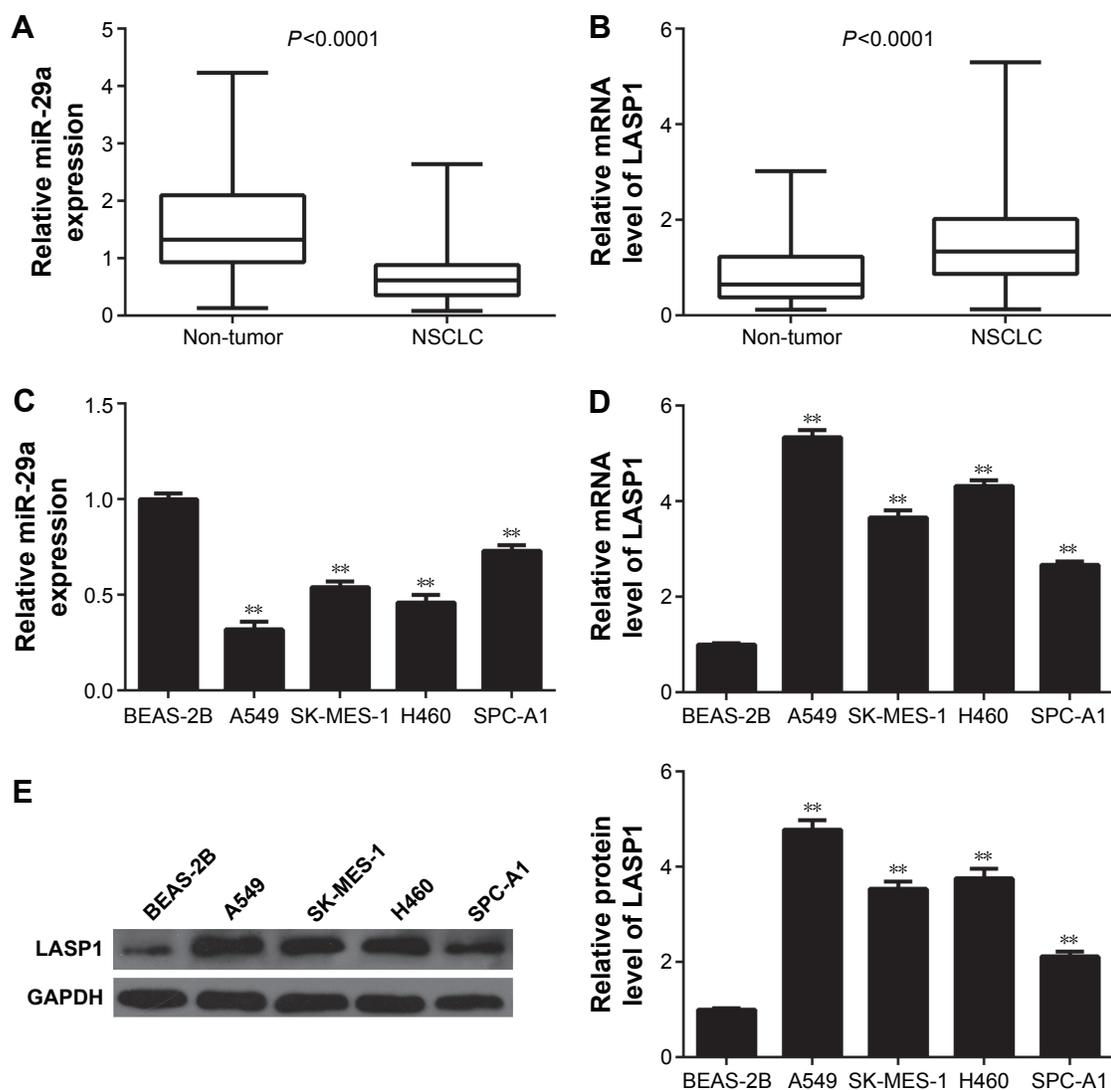
### LASP1 is a direct target of miR-29a in NSCLC cells

Bioinformatical analysis showed that LASP1 was a direct target of miR-29a (Figure 2A). The WT-LASP1-3'-UTR (Figure 2B) or MT-LASP1-3'-UTR (Figure 2C) luciferase reporter vector was generated. Therefore, we further performed luciferase reporter assay to confirm their relationship in NSCLC A549 cells. As shown in Figure 2D, the luciferase activity was significantly downregulated only in NSCLC A549 cells co-transfected with miR-29a mimics and WT-LASP1-3'-UTR vector, which was eliminated when co-transfection with miR-29a mimic and MT-LASP1-3'-UTR vector (Figure 2D), indicating that miR-29a could directly bind to the 3'-UTR of LASP1 mRNA in NSCLC cells.

Accordingly, we further examined the role of miR-29a in the regulation of the LASP1 expression in NSCLC cells. After transfection with miR-29a mimics, the miR-29a levels were remarkably increased (Figure 2E). We then examined the protein and mRNA expression of LASP1 using Western blot and real-time quantitative PCR assay. We found that the protein level of LASP1 was markedly reduced in miR-29a-overexpressing A549 cells compared to the control group (Figure 2F). However, the mRNA expression of LASP1 was not affected after overexpression of miR-29a (Figure 2G). Therefore, miR-29a can inhibit the expression of its target LASP1 at the post-transcriptional level.

### miR-29a suppresses migration and invasion of A549 cells via targeting LASP1

We further investigated the regulatory effects of miR-29a on the proliferation, migration, and invasion of NSCLC cells. We found that overexpression of miR-29a markedly



**Figure 1** miR-29a is downregulated, while LASP1 is upregulated in NSCLC.

**Notes:** Real-time RT-PCR was conducted to examine the expression levels of miR-29a (A) and LASP1 (B) in 78 cases of NSCLC samples and their matched adjacent non-tumor tissues (adjacent). (C) Real-time RT-PCR was conducted to examine the expression levels of miR-29a in human NSCLC cell lines and normal human lung epithelial BEAS-2B cells. (D) Real-time RT-PCR and (E) Western blot were conducted to examine the mRNA and western expression levels of LASP1 in human NSCLC cell lines and normal human lung epithelial BEAS-2B cells. For (C–E), \*\* $p < 0.01$  vs BEAS-2B.

**Abbreviations:** miR, microRNA; mRNA, messenger RNA; NSCLC, non-small cell lung cancer; RT-PCR, reverse transcription polymerase chain reaction.

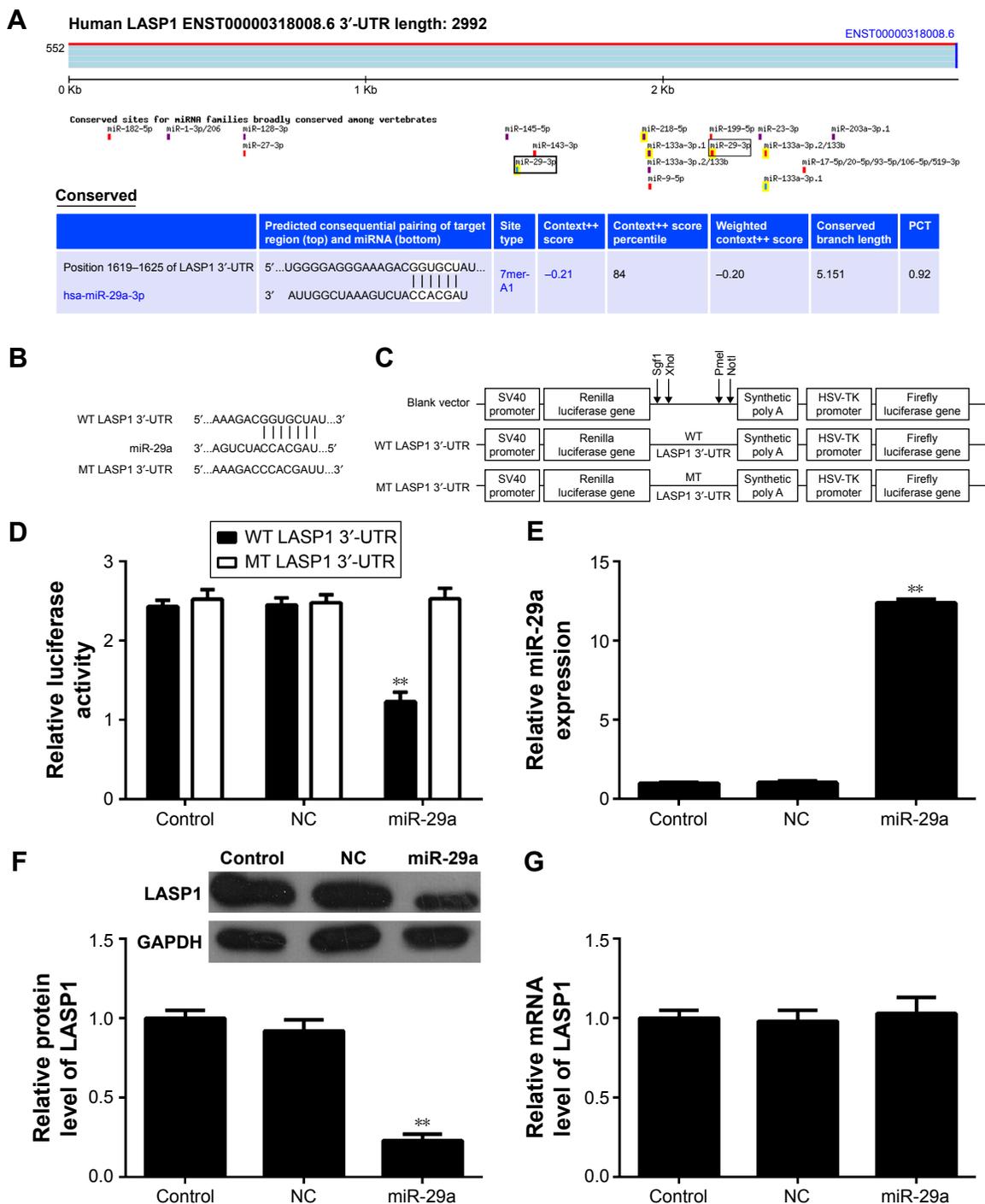
reduced the proliferation, migration, and invasion of A549 cells (Figure 3A–C). A549 cells were then transfected with LASP1 siRNA, and the LASP1 protein levels were significantly decreased (Figure 4A). Similar findings showed that knockdown of LASP1 also decreased A549 cell proliferation, migration, and invasion (Figure 4B–D).

To further investigate whether LASP1 acts as the downstream effector in the miR-29a-mediated malignant phenotypes of A549 cells, miR-29a-overexpressing A549 cells were transfected with LASP1 expression plasmid. After transfection, the protein expression of LASP1 was significantly upregulated (Figure 5A). Further investigation revealed that overexpression of LASP1 reversed the

inhibitory effect of miR-29a on the proliferation, migration, and invasion of A549 cells (Figure 5B–D). Accordingly, our data indicate that miR-29a inhibits NSCLC cell proliferation, migration, and invasion, partly at least, via inhibition of LASP1 expression.

### miR-29a inhibits the growth of NSCLC cells in nude mice

Finally, we studied the function of miR-29a in the growth of NSCLC xenograft in vivo. We cloned the miR-29a to pLVX-IRES-ZsGreen1 vector to construct the pYr-LVX-miR-29a lentiviral plasmid. A549 cells were then stably transfected with the pYr-LVX-miR-29a lentiviral plasmid.



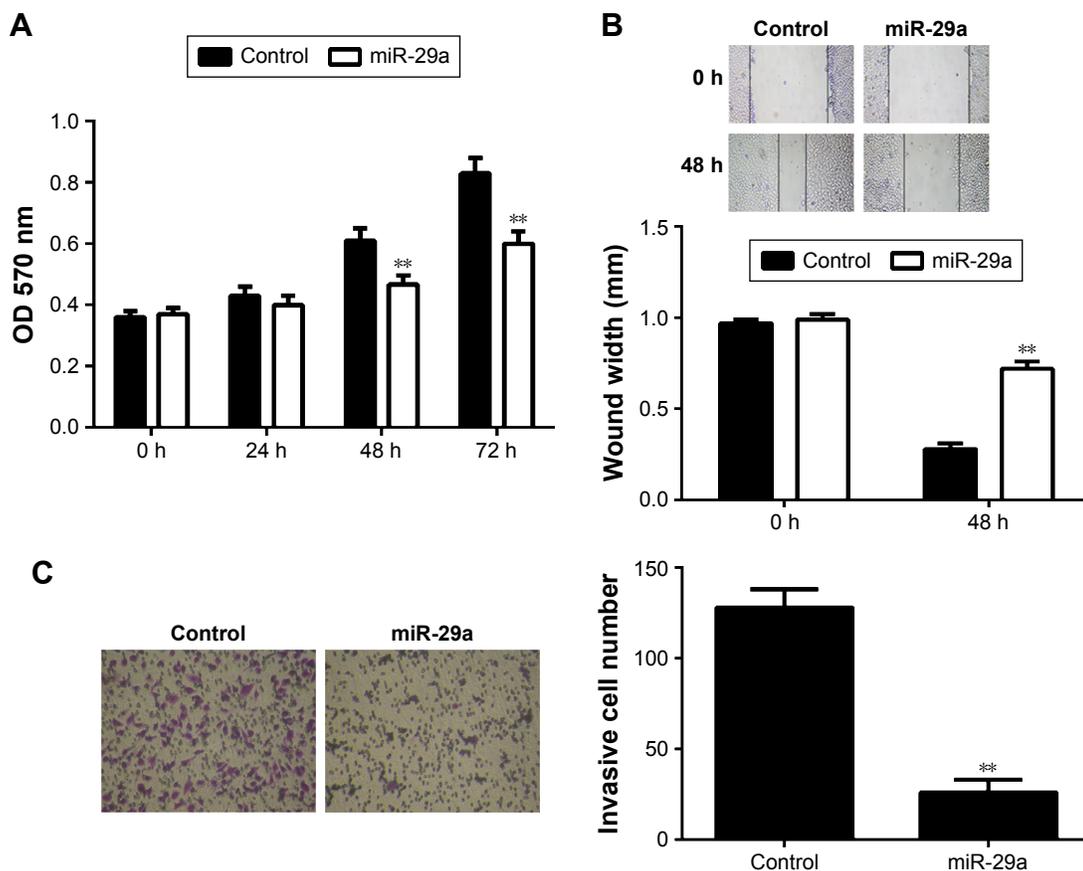
**Figure 2** LASP1 is a direct target of miR-29a in NSCLC cells.

**Notes:** (A) TargetScan data showed that LASP1 was a direct target of miR-29a. (B and C) A549 cells were co-transfected with psiCHECK™-2-LASP1-3'-UTR, psiCHECK™-2-LASP1-mut 3'-UTR vector plus miR-29a mimics, or scramble miR mimics as NC. (D) Dual-luciferase reporter assay system was used to determine the luciferase activities 48 h after co-transfection. Renilla luciferase activity was normalized to firefly luciferase activity. \*\* $P < 0.01$  vs control. (E) Real-time RT-PCR was conducted to examine the expression levels of miR-29a in A549 cells transfected with miR-29a mimics or scramble miR (NC). (F) Western blot and (G) real-time RT-PCR were conducted to examine the protein and mRNA levels of LASP1 in A549 cells transfected with miR-29a mimics and scramble miR (NC), respectively. For (E–G), \*\* $P < 0.01$  vs control.

**Abbreviations:** miR, microRNA; NSCLC, non-small cell lung cancer; UTR, untranslated region; NC, negative control; RT-PCR, reverse transcription polymerase chain reaction; WT, wild type; MT, mutant type; mRNA, messenger RNA; HSV-TK, Herpes simplex virus-thymidine kinase; PCT, probability of preferentially conserved targeting; SV40, simian virus 40.

The miR-29a levels were significantly increased after transfection (Figure 6A). Nude mice were then subcutaneously implanted with these A549 cells. After implantation, we found that miR-29a overexpression in A549 cells protected

animals from tumor-induced death (Figure 6B). On day 90 after implantation, all mice were sacrificed, if had not died. We obtained the tumor xenograft (Figure 6C). Moreover, the weight and volume of the tumor xenograft were significantly



**Figure 3** Overexpression of miR-29a reduces the proliferation, migration, and invasion of A549 cells.

**Notes:** (A) MTT assay, (B; 40× magnification) wound healing assay, and (C; 200× magnification) transwell assay were conducted to determine the cell proliferation, migration, and invasion in A549 cells transfected with miR-29a mimic or scramble miR as control. \*\* $P < 0.01$  vs control.

**Abbreviations:** h, hours; miR, microRNA; OD, optical density.

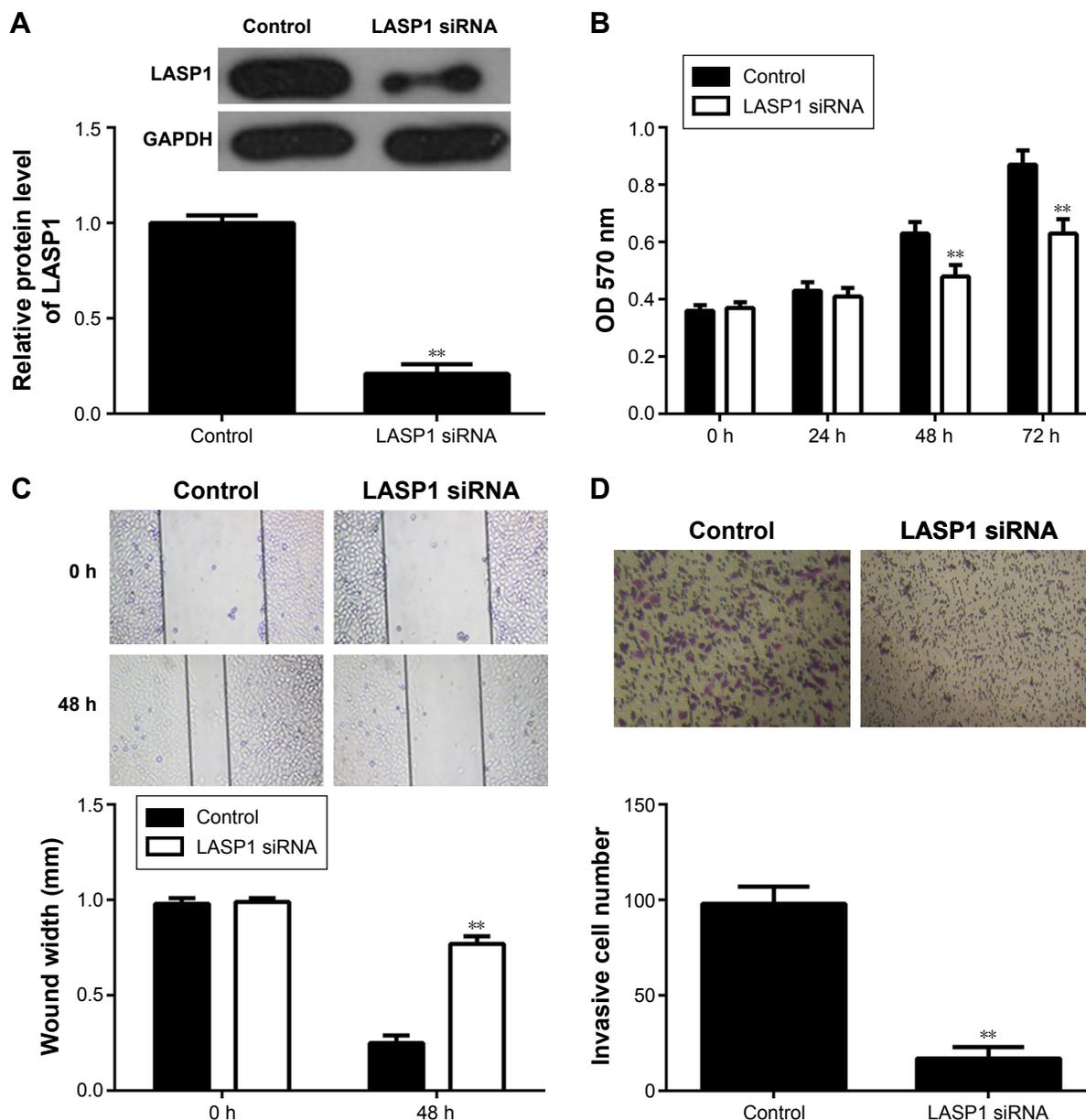
higher in the miR-29a-overexpressing group when compared to the control group (Figure 6D and E). We also performed Western blot to analyze the expression of the markers for proliferation and invasion in xenografted tumor tissues. We found that overexpression of miR-29a significantly inhibited the expression of LASP1, Ki67, and MMP2 (Figure 6F). Therefore, miR-29a has a suppressive effect on the growth of NSCLC cells in vivo.

## Discussion

Deregulations of miR-29a have been observed in many human cancers, including NSCLC,<sup>11,12,16</sup> but the regulatory mechanism of miR-29a in NSCLC remains obscure. In the present study, we showed that miR-29a was remarkably downregulated, and reduced miR-29a levels were significantly associated with the malignant progression, including tumor grade, tumor–node–metastasis (TNM) stage, and lymph node metastasis. Moreover, LASP1 was significantly upregulated in NSCLC tissues and cell lines. LASP1 was further found to be a target gene of miR-29a, and the LASP1 protein levels were decreased by miR-29a overexpression in

NSCLC A549 cells. Overexpression of miR-29a significantly inhibited the proliferation, migration, and invasion of A549 cells, and knockdown of LASP1 also decreased these phenotypes of A549 cells. Moreover, overexpression of LASP1 attenuated the inhibitory effects of miR-29a on the malignant phenotypes of NSCLC cells. In addition, in vivo study further showed that overexpression of miR-29a inhibited the growth of A549 cells in nude mice and protected animals from tumor-induced death.

Many miRs have been demonstrated to participate in NSCLC development and progression.<sup>17,18</sup> For instance, miR-200c was downregulated in NSCLC tissues and cell lines and could inhibit the invasive and chemoresistant phenotypes of NSCLC cells.<sup>19</sup> miR-145 is downregulated in NSCLC and inhibits NSCLC cell proliferation by targeting c-Myc.<sup>20</sup> miR-34a inhibits the proliferation and promotes the apoptosis of NSCLC cells by targeting TGFbetaR2.<sup>21</sup> Recently, miR-29a was reported to play a role in NSCLC.<sup>16</sup> However, the expression and clinical significance of miR-29a in NSCLC remain largely unclear. Here, we found that miR-29a was significantly downregulated in NSCLC tissues



**Figure 4** Knockdown of miR-29a promotes the proliferation, migration, and invasion of A549 cells.

**Notes:** (A) Western blot assay was conducted to examine the protein expression of LASP1 in A549 cells transfected with LASP1-specific siRNA or non-specific siRNA as control. (B) MTT assay, (C: 40× magnification) wound healing assay, and (D: 200× magnification) transwell assay were conducted to determine cell proliferation, migration, and invasion. \*\* $P < 0.01$  vs control.

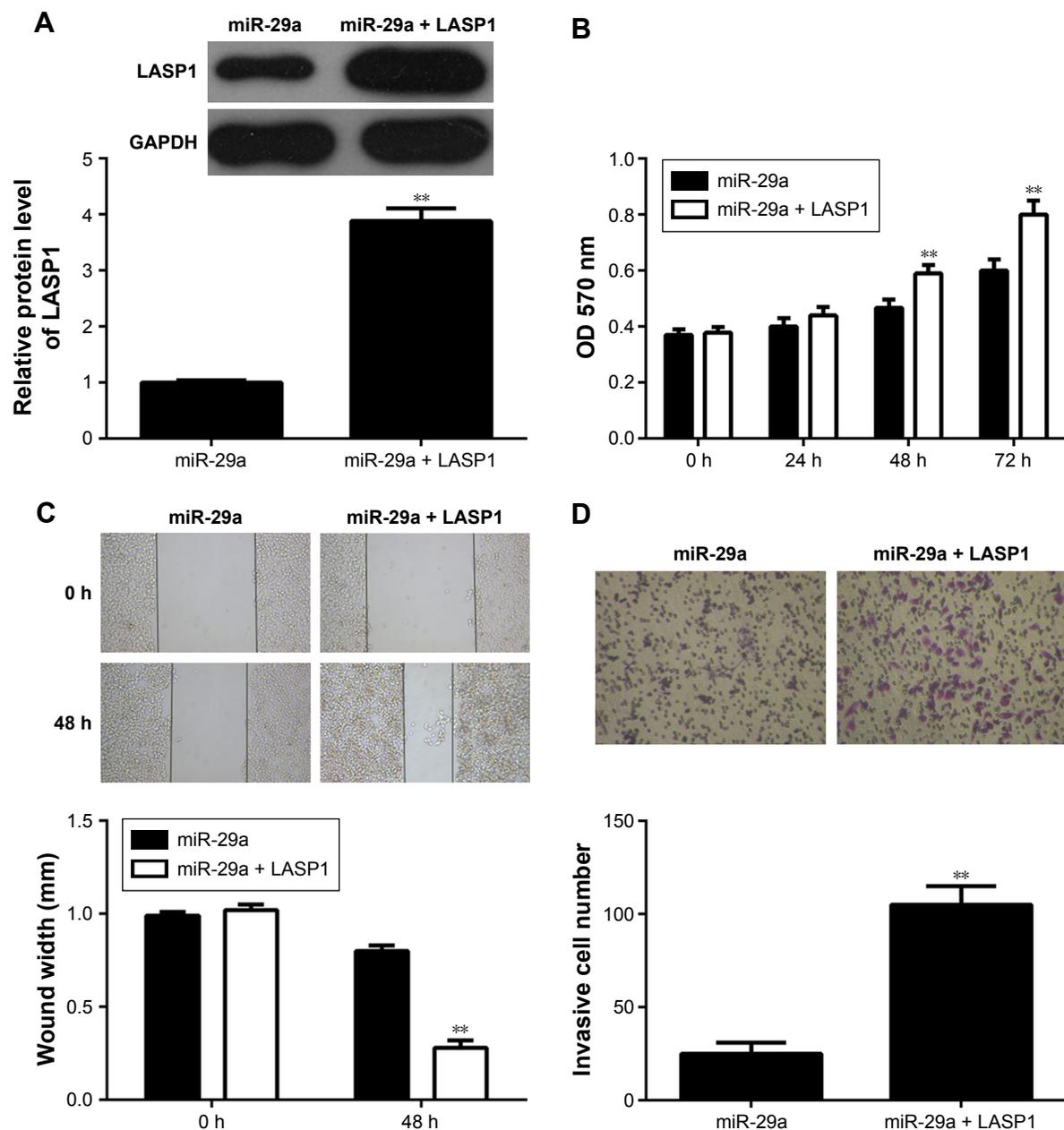
**Abbreviations:** h, hours; miR, microRNA; OD, optical density; siRNA, small interfering RNA.

and cell lines. Moreover, we found that the reduced expression of miR-29a was significantly associated with poor differentiation, advanced TNM stage, and lymph node metastasis in NSCLC. Accordingly, we suggest that downregulation of miR-29a promotes the malignant progression of NSCLC.

Recently, Muniyappa et al<sup>15</sup> used miR expression profiling of human NSCLC cell lines to indicate that the miR-29a levels were reduced in more invasive cell lines and showed that miR-29a could reduce the invasion and proliferation of NSCLC cells. Besides, overexpression of miR-29a was found to inhibit the expression of  $\beta$ -catenin through upregulation of WIF-1

by inhibiting the methylation of its promoter and suppress NSCLC cell proliferation while inducing their apoptosis.<sup>16</sup> However, the underlying mechanism of miR-29a in regulating the malignant phenotypes of NSCLC cells remains unknown. Here, we showed that miR-29a played a suppressive role in regulating the proliferation, migration, and invasion of NSCLC A549 cells, consistent with the previous study.<sup>15</sup>

LASP1, a member of LIM proteins and a member of the nebulin family of actin-binding proteins, is characterized by an LIM motif and a domain of Src homology region 3.<sup>22</sup> It is a cAMP- and cGMP-dependent signaling protein and binds to



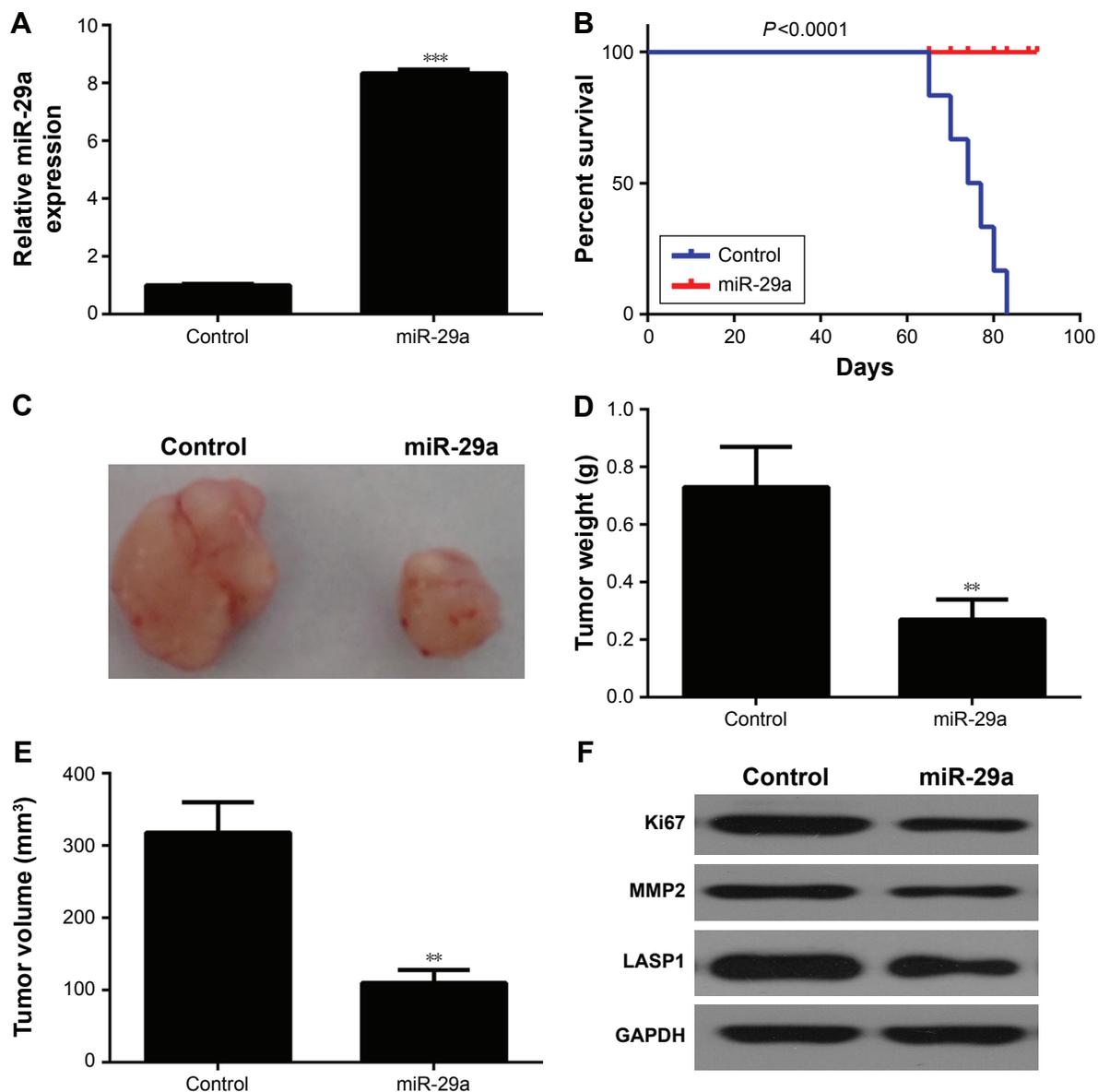
**Figure 5** miR-29a inhibits NSCLC cell migration and invasion via targeting LASP1.

**Notes:** (A) Western blot assay was conducted to examine the protein expression of LASP1 in A549 cells transfected with miR-29a mimic or co-transfected with miR-29a mimic and LASP1 expression plasmid. (B) MTT assay, (C; 40× magnification) wound healing assay, and (D; 200× magnification) transwell assay were conducted to determine the cell proliferation, migration, and invasion. \*\* $P < 0.01$  vs miR-29a.

**Abbreviations:** h, hours; miR, microRNA; NSCLC, non-small cell lung cancer; OD, optical density.

the actin cytoskeleton at extensions of the cell membrane.<sup>22</sup> Recently, deregulations of LASP1 have been implicated in some cancers, such as breast cancer, colorectal cancer, prostate cancer, and so forth.<sup>23–26</sup> For instance, it promotes tumor proliferation and metastasis and is an independent unfavorable prognostic factor in gastric cancer.<sup>26</sup> miR-1 inhibits the malignant phenotypes of esophageal squamous cell carcinoma cells by targeting LASP1.<sup>27</sup> However, the exact role of LASP1 in NSCLC has never been studied.

In the present study, we found that the expression of LASP1 was significantly increased in NSCLC tissues and cell lines, when compared to adjacent non-tumor tissues and normal lung epithelial cell line, respectively. Moreover, LASP1 was identified as a target of miR-29a by using bioinformatical analysis and luciferase reporter assay. Therefore, we speculated that LASP1 might act as a downstream effector in the miR-29a-mediated malignant phenotypes of NSCLC cells. To clarify this speculation, the expression of LASP1 was



**Figure 6** miR-29a inhibits the growth of NSCLC cells in nude mice.

**Notes:** (A) A549 cells were stably transfected with pYr-LVX-miR-29a lentiviral plasmid or pYr-LVX-scramble miR lentiviral plasmid as control. Real-time RT-PCR was conducted to examine the expression levels of miR-29a. (B) Nude mice were then subcutaneously implanted with these A549 cells. miR-29a overexpression in A549 cells effectively protected nude mice from tumor-induced death. (C) At 90 days after implantation, all mice that had not died were sacrificed. The tumor xenograft was obtained. (D) The weight and (E) volume of the tumor xenograft were examined. (F) Western blot assay was conducted to examine the protein expression of LASP1, Ki67, and MMP2 in xenografted tumor tissues. \*\* $P < 0.01$  and \*\*\* $P < 0.001$  vs control.

**Abbreviations:** miR, microRNA; NSCLC, non-small cell lung cancer; RT-PCR, reverse transcription polymerase chain reaction.

inhibited in A549 cells by transfection with LASP1-specific siRNA, and further investigation showed that knockdown of LASP1 reduced the proliferation, migration, and invasion of A549 cells. Moreover, we found that overexpression of LASP1 attenuated the suppressive effect of miR-29a on A549 cell proliferation, migration, and invasion. These findings confirm that miR-29a inhibits the proliferation, migration, and invasion of NSCLC cells, partly at least, via suppressing the protein expression of LASP1.

According to our findings, we highlight the clinical significance of the miR-29a/LASP1 axis in NSCLC and suggest that miR-29a and LASP1 may become promising therapeutic candidates and targets for NSCLC treatment.

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## Disclosure

The authors report no conflicts of interest in this work.

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