

# Small interfering RNA-induced silencing of galectin-3 inhibits the malignant phenotypes of osteosarcoma *in vitro*

PENGFEEI LEI\*, HONGBO HE\*, YIHE HU and ZHAN LIAO

Department of Orthopedics, Xiangya Hospital of Central South University, Changsha, Hunan 410008, P.R. China

Received October 8, 2014; Accepted June 25, 2015

DOI: 10.3892/mmr.2015.4165

**Abstract.** Osteosarcoma (OS) is the most common malignant tumor of bone. It has recently been demonstrated that galectin-3, a multifunctional  $\beta$ -galactoside-binding, is significantly upregulated in OS tissues, and is correlated with its progression and metastasis. However, the detailed role of galectin-3 in the regulation of cellular biological processes in OS cells has remained to be elucidated. The present study reported that the mRNA and protein levels of galectin-3 were significantly increased in OS tissues compared to those in their matched normal adjacent tissues. Furthermore, galectin-3 was upregulated in three OS cell lines, Saos-2, MG63 and U2OS, when compared with that in the human osteoblast cell line hFOB1.19. Knockdown of galectin-3 by galectin-3-specific small interfering RNA markedly inhibited OS-cell proliferation and induced cell apoptosis. Furthermore, silencing of galectin-3 expression significantly inhibited OS cell migration and invasion, accompanied with a marked decrease in the protein expression of matrix metalloproteinase 2 and -9. Mechanistic investigation suggested that the mitogen-activated protein kinase kinase/extracellular signal-regulated protein kinase signaling pathway may be involved in the galectin-3-mediated OS cell invasion. In conclusion, the present study was the first to report that silencing of galectin-3 inhibited the malignant phenotypes of osteosarcoma *in vitro*. Therefore, galectin-3 may serve as a potential therapeutic target for OS.

## Introduction

Osteosarcoma (OS) is the most common mesenchymal sarcoma with high morbidity, mainly arising from the metaphysis of the long bones of adolescents and young adults (1). Despite tumor

excision combined with chemotherapy and radiotherapy, the five-year survival rate of patients with recurrent or metastatic OS has remained as low as ~30% (1). As aberrant upregulation of oncogenes is closely associated with the progression of OS, the identification of novel oncogenes is crucial for developing effective therapeutic targets for OS (2).

Galectin-3, a member of the galectin family, is an endogenous  $\beta$ -galactoside-binding lectin. It has been well established that galectin-3 has a role in the regulation of cell recognition, adhesion, chemoattraction, proliferation, apoptosis, cell cycle, differentiation, immunomodulation and angiogenesis (3,4). Accumulating evidence has demonstrated that galectin-3 participates in cancer aggressiveness and is closely associated with tumor cell transformation, migration, invasion and metastasis (5-7). Recently, galectin-3 was found to be associated with the progression of OS; Zhou *et al* (8) reported that the serum levels of galectin-3 were markedly elevated in patients with OS when compared with those in healthy controls, and that increased serum levels of galectin-3 were significantly associated with the stage of OS. Furthermore, galectin-3 was upregulated in OS tissues compared to that in non-malignant tissues, and its expression in OS tissues was correlated with the OS stage and metastasis (8). These findings suggested that galectin-3 may act as an oncogene in OS. However, the exact role of galectin-3 in the regulation of OS cells has remained to be determined.

The present study aimed to explore the role of galectin-3 in the regulation of OS cell proliferation, apoptosis, migration and invasion. In addition, the underlying molecular mechanism was investigated.

## Materials and methods

**Agents.** RPMI 1640 medium, fetal bovine serum (FBS), Lipofectamine 2000, TRIzol reagent, First Strand cDNA Synthesis kit (cat. no. K1612), DyNAmo ColorFlash SYBR Green qPCR assay kit (cat. no. F-416L) and gentian violet were purchased from Invitrogen Life Technologies (Carlsbad, CA, USA). MTT was purchased from Biosharp (Hefei, Anhui, China). Monoclonal mouse anti-human galectin-3 (cat. no. ab2785; 1:200; incubation, 3 h at room temperature), monoclonal mouse anti-human matrix metalloproteinase (MMP)2 (cat. no. ab86607; 1:200; incubation, 3 h at room temperature), monoclonal mouse anti-human MMP9 (cat. no. ab119906; 1:50; incubation, 3 h at room temperature),

---

*Correspondence to:* Dr Zhan Liao, Department of Orthopedics, Xiangya Hospital of Central South University, 87 Xiangya Road, Changsha, Hunan 410008, P.R. China  
E-mail: csuliao@163.com

\*Contributed equally

**Key words:** osteosarcoma, galectin-3, proliferation, migration, apoptosis, invasion

polyclonal rabbit anti-human phosphorylated extracellular signal-regulated kinase (p-ERK; cat. no. ab131438; 1:200; incubation, 3 h at room temperature), monoclonal mouse anti-human ERK (cat. no. ab119933; 1:100; incubation, 3 h at room temperature) and monoclonal mouse anti-GAPDH (cat. no. ab8245; 1:50; incubation, 3 h at room temperature) antibodies, as well as rabbit anti-mouse immunoglobulin G (IgG; cat. no. ab46540; incubation, 40 min at room temperature) and mouse anti-rabbit IgG (cat. no. ab99700; incubation, 40 min at room temperature) secondary antibody were purchased from Abcam (Cambridge, UK). The washing steps between all antibody treatments were as follows: Three washes with Dulbecco's phosphate buffered saline (DPBS), each for 5 min. A SuperSignal West Pico Chemiluminescent Substrate kit (cat. no. 34080) was purchased from Pierce (Rockford, IL, USA). Annexin V-fluorescein isothiocyanate (FITC) Apoptosis Detection kit (cat. no. 556547) was purchased from BD Biosciences (Franklin Lakes, NJ, USA). A Transwell chamber was obtained from Corning, Inc. (Corning, NY, USA).

*Tissue specimens.* The present study was approved by the Ethics Committee of Central South University (Changsha, China). Written informed consent was obtained from each patient. Fifteen primary OS samples and their normal matched adjacent tissues were collected at the Department of Orthopedics, Xiangya Hospital of Central South University (Changsha, China). Tissues were immediately snap-frozen in liquid nitrogen after surgical removal.

*Cell culture.* The human OS cell line Saos-2, MG63 and U2OS, and the human osteoblast cell line hFOB1.19 were obtained from the Cell Bank of Central South University (Changsha, China). Cells were cultured in RPMI 1640 medium supplemented with 10% FBS at 37°C in a humidified incubator containing 5% CO<sub>2</sub>.

*Reverse transcription quantitative-polymerase chain reaction (RT-qPCR) analysis.* Total RNA was extracted from tissues or cells using TRIzol reagent in accordance with the manufacturer's instructions. Total RNA was reverse-transcribed into cDNA by using a First Strand cDNA Synthesis kit, in accordance with the manufacturer's instructions. Expression of mRNA was examined using the SYBR green qPCR assay kit, in accordance with the manufacturer's instructions. The specific primer pairs (Shanghai Shenggong Co., Ltd., Shanghai, China) were as follows: Galectin-3 sense, 5'-GTGAAGCCCAATGCAAACAGA-3' and anti-sense, 5'-AGCGTGGGTAAAGTGGAAGG-3'; GAPDH (internal reference) sense, 5'-CTGGGCTACACTGAGCACC-3' and anti-sense, 5'-AAGTGGTCGTTGAGGGCAATG-3'. The PCR was conducted using using an ABI 7500 thermocycler (Invitrogen Life Technologies) with the following cycling conditions: 95°C for 10 min, 40 cycles of denaturation at 95°C for 15 sec, and an annealing/elongation step at 60°C for 1 min. The experiments were independently repeated three times. The PCR products were separated by SDS-PAGE, and analyzed using SDS Relative Quantification Software 2.2.2 (Applied Biosystems Life Technologies, Carlsbad, CA, USA). The same baseline and cycle threshold (CT) were set for each target. The relative mRNA expression was analyzed using the 2<sup>-ΔΔCt</sup> method (9).

*Transfection.* Lipofectamine 2000 was used to perform transfection according to the manufacturer's instructions. Briefly, cells were cultured to 70% confluence and re-suspended in serum-free medium. Small interfering RNA (siRNA) specific for galectin-3 (Nlunbio, Changsha, China) and Lipofectamine 2000 were diluted, mixed and incubated for 20 min at room temperature, followed by addition to the cell suspension. After incubation at 37°C for 6 h, the medium was replaced with normal serum-containing medium. Cells were then cultured for 24 h prior to being subjected to the following assays. The MG63 cells transfected with galectin-3 siRNA were treated with 10 mM curcumin for 3 h.

*Western blot analysis.* Tissues or cells were solubilized in cold radioimmunoprecipitation assay lysis buffer (Sigma-Aldrich, St. Louis, MO, USA). Proteins were separated by 12% SDS-PAGE (Nlunbio) and transferred onto a polyvinylidene difluoride (PVDF) membrane. The PVDF membrane (Invitrogen Life Technologies) was then incubated with Tris-buffered saline containing Tween 20 (Sigma-Aldrich) containing 5% skimmed milk at room temperature for 3 h and then incubated with mouse anti-galectin-3, MMP2, MMP9, p-ERK, ERK and GAPDH primary antibodies, respectively, at room temperature for 3 h. After incubation with the rabbit anti-mouse secondary antibodies at room temperature for 40 min, ECL detection was performed using an ECL kit and an ECL detection apparatus with an X-ray exposure cartridge (MitoScience, Eugene, OR, USA) and film (Kodak, Tokyo, Japan). Relative protein expression was analyzed using Image-Pro plus software 6.0 (Media Cybernetics, Rockville, MD, USA), and expressed as the density ratio vs. GAPDH.

*Cell proliferation assay.* The MTT assay was used to assess cell proliferation. The cells in each group were cultured in 96-well plates at a density of 1x10<sup>5</sup> cells/well, at 37°C for 0, 24, 48 and 72 h. A total of 100 μl fresh serum-free medium supplemented with 0.5 g/l MTT was subsequently added to each well, and incubated at 37°C for 4 h. The medium was then removed by aspiration, and 50 μl dimethylsulfoxide (Sigma-Aldrich) was added to each well. After incubation at 37°C for a further 10 min, the absorbance at 570 nm of each sample was measured using a PHERAstar FS microplate reader (Invitrogen Life Technologies).

*Wound healing assay.* A wound healing assay was performed to evaluate the cell migratory capacity. In brief, cells were cultured to full confluence. Wounds of ~1 mm width were created with a pipette tip (Gilson, Inc., Middleton, WI, USA), and cells were washed and incubated in serum-free medium. After incubation for 24 h in serum-free medium, cells were incubated in medium containing 10% fetal bovine serum. Cultures at 0 and 48 h were observed under a CX22 microscope (Olympus, Tokyo, Japan).

*Cell invasion assay.* The invasive ability of OS cells was determined in 24-well plates. Transwell chambers containing a layer of Matrigel. A cell suspension (density, 1x10<sup>6</sup>) was added in the upper chamber, and RPMI 1640 containing 10% FBS was added into the lower chamber. After incubation for 24 h, non-invading cells as well as the Matrigel on the interior of

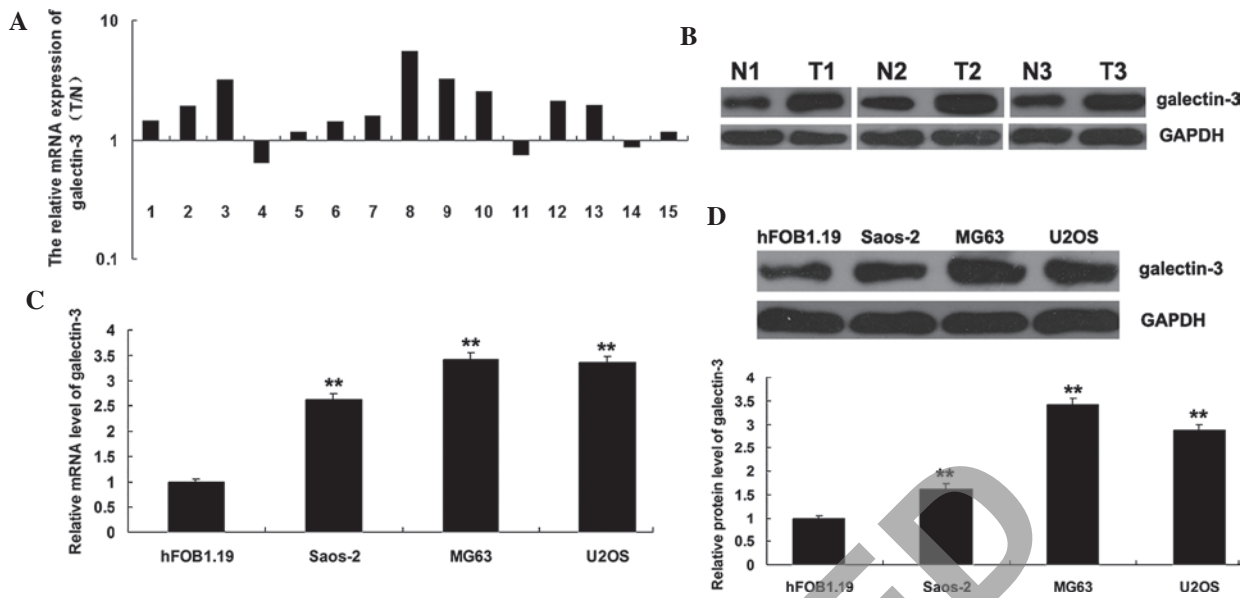


Figure 1. (A) mRNA levels of galectin-3 were determined by performing RT-qPCR in OS tissues and their matched normal adjacent tissues. (B) Protein expression of galectin-3 was determined by western blot analysis of OS tissues and their matched normal adjacent tissues. Blots are representative of three experiments with similar results. (C) Relative mRNA expression of galectin-3 was determined in the human OS cell lines Saos-2, MG63 and U2OS, and the human osteoblast cell line hFOB1.19 by RT-qPCR. \*\*P<0.01 vs. hFOB1.19. (D) The relative protein expression of galectin-3 was determined in the human OS cell lines Saos-2, MG63, and U2OS, and the human osteoblast cell line hFOB1.19 by western blot analysis. \*\*P<0.01 vs. hFOB1.19. Values are expressed as the mean  $\pm$  standard deviation. RT-qPCR, reverse transcription quantitative polymerase chain reaction; OS, osteosarcoma; T, tumor tissue; N, normal tissue.

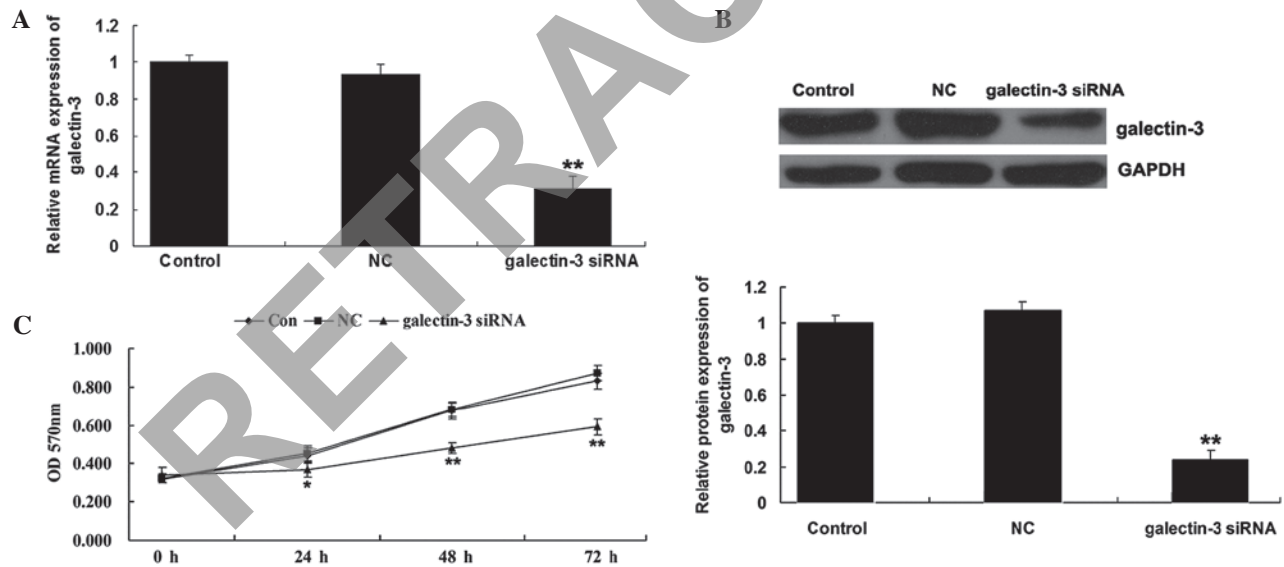


Figure 2. (A) The mRNA expression of galectin-3 in MG63 cells transfected with galectin-3 siRNA was examined by reverse transcription quantitative polymerase chain reaction. (B) The protein expression of galectin-3 in MG63 cells transfected with galectin-3 siRNA was examined by western blot analysis. (C) MTT cell proliferation assay was performed on MG63 cells transfected with galectin-3 siRNA. Values are expressed as the mean  $\pm$  standard deviation. \*P<0.05; \*\*P<0.01 vs. Control. siRNA, small interfering RNA; OD, optical density; NC, cells transfected with non-specific siRNA; Con, untreated control group.

the inserts was removed using a cotton-tipped swab. Invasive cells on the lower surface of the membrane were stained with gentian violet, rinsed with water and air-dried. Five fields were randomly selected and the cell number was counted under a CX22 microscope.

**Apoptosis analysis.** The levels of cell apoptosis were determined using an Annexin V-FITC Apoptosis Detection kit (BD Biosciences) according to the manufacturer's instructions, and analyzed using a C6 flow cytometer (BD Biosciences). A

total of 24 h post-transfection, the cells were harvested and washed twice with cold PBS. Subsequently,  $1 \times 10^6$  cells were resuspended in 200  $\mu$ l binding buffer supplemented with 10  $\mu$ l Annexin-V-FITC and 5  $\mu$ l propidium iodide-PE, and incubated in the dark for 30 min. Finally, 300  $\mu$ l binding buffer was added, and the cells were analyzed by flow cytometry.

**Statistical analysis.** Values are expressed as the mean  $\pm$  standard deviation. One-way analysis of variance was used to statistically analyze data. SPSS 17 software (SPSS, Inc.,

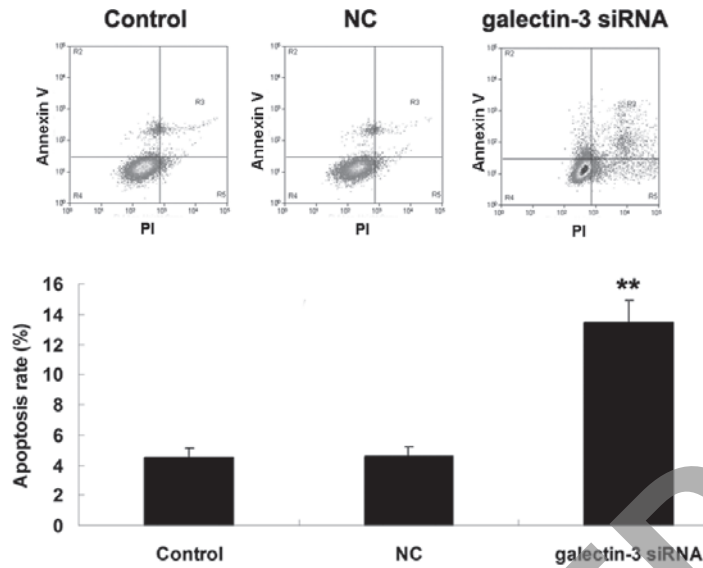


Figure 3. Cell apoptosis assay was performed on MG63 cells transfected with galectin-3 siRNA. The sum of the first quadrant (R3, late apoptosis) and the fourth quadrant (R5, early apoptosis) were used to calculate the apoptotic rates. Values are expressed as the mean  $\pm$  standard deviation. \*\* $P < 0.01$  vs. Control. NC, cells transfected with non-specific siRNA; siRNA, small interfering RNA.

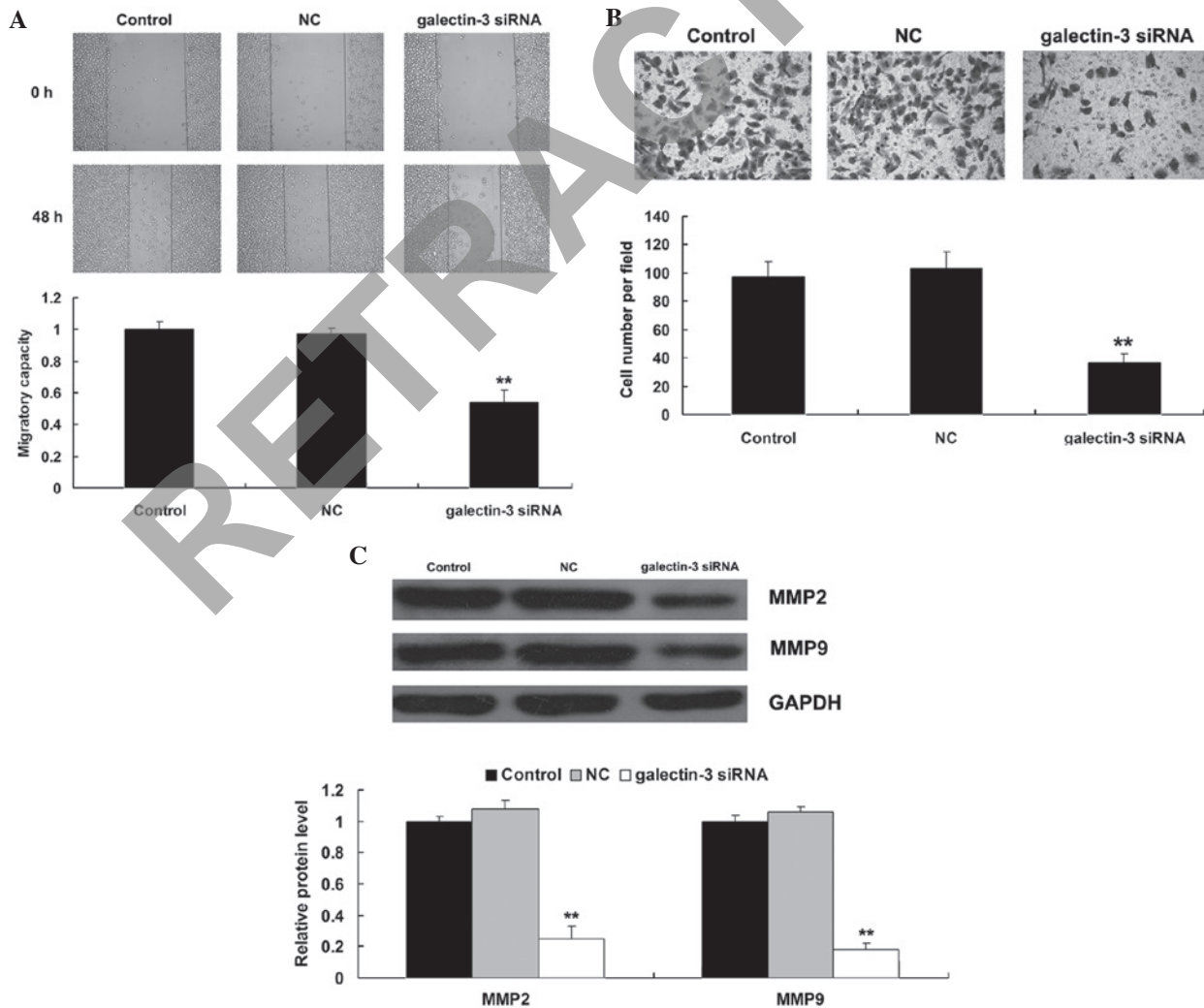


Figure 4. (A) Cell migration assay was performed on MG63 cells with or without transfection with galectin-3-specific siRNA. (B) Cell invasion assay was performed on MG63 cells with or without transfection with galectin-3-specific siRNA. (C) Western blot analysis was performed to determine the protein expression of MMP2 and MMP9 in MG63 cells transfected with galectin-3 siRNA. GAPDH used as an internal reference. Values are expressed as the mean  $\pm$  standard deviation. \*\* $P < 0.01$  vs. Control. Magnification,  $\times 200$ . MMP, matrix metalloproteinase; siRNA, small interfering RNA; NC, cells transfected with non-specific siRNA.

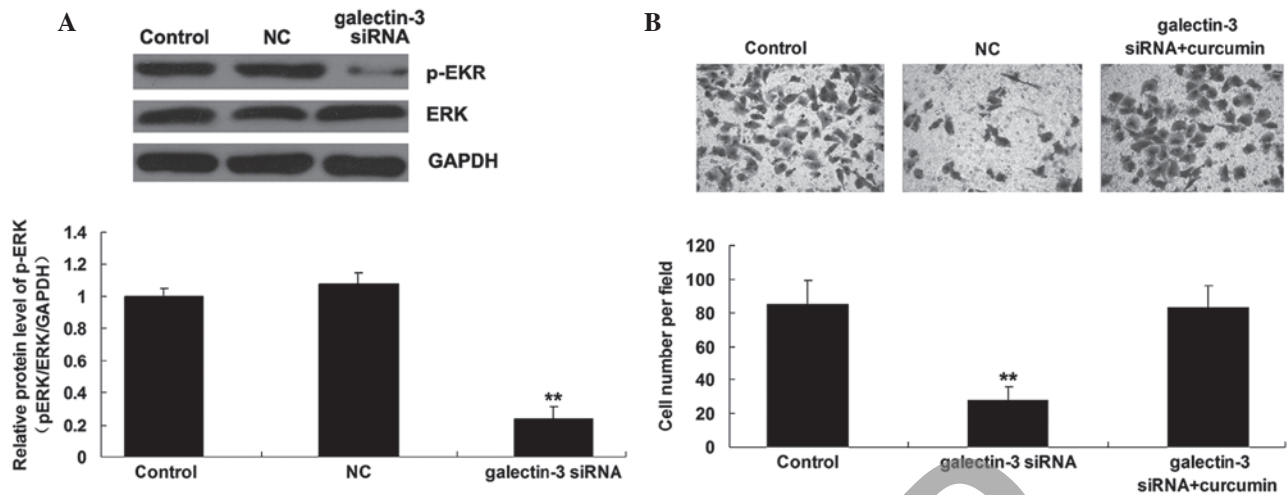


Figure 5. (A) Western blot analysis was performed to determine the protein expression of EKR and p-EKR in MG63 cells transfected with galectin-3 siRNA. GAPDH used as an internal reference. (B) Transwell assay was performed to examine the invasive capacity of MG63 cells transfected with galectin-3 siRNA, with or without pre-treatment of curcumin. Values are expressed as the mean  $\pm$  standard deviation. \*\* $P < 0.01$  vs. Control. Magnification,  $\times 200$ . p-ERK, phosphorylated extracellular signal-regulated kinase; siRNA, small interfering RNA; NC, cells transfected with non-specific siRNA.

Chicago, IL, USA) was used for statistical analyses.  $P < 0.05$  was considered to indicate a statistically significant difference between values.

## Results

*Galectin-3 is overexpressed in OS tissues and cell lines.* To explore the role of galectin-3 in OS, the mRNA and protein expression of galectin-3 in OS tissues as well as their matched normal adjacent tissues was determined by RT-qPCR and western blot analyses. As shown in Fig. 1A and B, the mRNA and protein expression levels of galectin-3 were frequently upregulated in OS tissues when compared with those in normal adjacent tissues. Furthermore, the mRNA and protein expression of galectin-3 were assessed in the three OS cell lines Saos-2, MG63 and U2OS, as well as in the human osteoblast cell line hFOB1.19. As shown in Fig. 1C and D, the mRNA and protein expression of galectin-3 in OS cells was higher than that in hFOB1.19 cells ( $P < 0.01$ ). Furthermore, MG63 cells showed the highest expression of galectin-3 amongst all cell lines tested. Accordingly, this cell line was used in the subsequent experiments of the present study.

*Galectin-3 knockdown inhibits OS cell proliferation.* To investigate the role of galectin-3 in the regulation of OS-cell proliferation, MG63 cells were transfected with galectin-3 siRNA. To confirm knockdown of galectin, the mRNA and protein expression of galectin-3 in MG63 cells was then assessed. As shown in Fig. 2A and B, transfection with galectin-3 siRNA significantly inhibited the mRNA and protein expression of galectin-3 in MG63 cells ( $P < 0.01$ ). Subsequently, an MTT assay was performed to determine the effect of galectin-3 silencing on cell proliferation. As shown in Fig. 2C, after transfection with galectin-3 siRNA, the cell proliferation was significantly downregulated compared to that in the control group ( $P < 0.01$ ), suggesting that siRNA-induced knockdown of galectin-3 inhibited OS-cell proliferation.

*Knockdown of galectin-3 enhances apoptosis of MG63 cells.* The effect of siRNA-induced downregulation of galectin-3 on MG63-cell apoptosis was assessed. As shown in Fig. 3, the apoptotic rate of MG63 cells was markedly upregulated after transfection with galectin-3-specific siRNA ( $P < 0.01$ ), suggesting that siRNA-induced galectin-3 downregulation promoted OS-cell apoptosis.

*Knockdown of galectin-3 suppresses migration and invasion of MG63 cells.* The present study then investigated the effect of siRNA-induced downregulation of galectin-3 on the migration and invasion of MG63 cells. As shown in Fig. 4A and B, the cell migration and invasion were significantly decreased in MG63 cells transfected with galectin-3 siRNA compared to those in the control group ( $P < 0.01$ ), suggesting that galectin-3 has a promoting role in the regulation of OS-cell migration and invasion. As MMP2 and MMP9 are two crucial regulators involved in tumor cell migration and invasion (10), the present study then examined the protein levels of MMP2 and MMP9 in MG63 cells with or without galectin-3 knockdown. As shown in Fig. 4C, siRNA-induced galectin-3 knockdown led to a marked decrease in MMP2 and MMP9 expression in MG63 cells ( $P < 0.01$ ).

*The mitogen-activated protein kinase kinase (MEK)/ERK signaling pathway is involved in the galectin-3-mediated invasiveness of OS cells.* The present study further investigated the activity of MEK/ERK pathway-associated signaling in MG63 cells with or without transfection with galectin-3 siRNA. As shown in Fig. 5A, downregulation of galectin-3 markedly inhibited the activity of MEK/ERK signaling ( $P < 0.01$ ), suggesting that the MEK/ERK signaling pathway may act as a downstream effector of the malignant properties of MG63 cells. As the MEK/ERK signaling pathway has been demonstrated to be involved in the regulation of OS-cell invasion (11,12), the present study used curcumin, an agonist of MEK, to upregulate the activity of the MEK/ERK signaling pathway. As shown in Fig. 5B, the suppressive effect

of galectin-3 knockdown on MG63 cell invasion was markedly reversed by treatment with curcumin ( $P < 0.01$ ), suggesting that the MEK/ERK signaling pathway is involved in the galectin-3-mediated OS cell invasion.

## Discussion

As most OS have been shown to display a marked alternation of their gene expression profile compared with that of normal osteoblasts, understanding of the de-regulation of these oncogenes or tumor suppressors may aid in the development of effective therapeutic strategies for OS (13). The present study reported that galectin-3 was significantly upregulated in OS tissues and cells. In addition, the present study suggested that galectin-3 acts as an oncogene in OS cells and that the MEK/ERK signaling pathway is involved in galectin-3-mediated OS-cell invasion.

Galectin-3, a versatile 29-35 kDa protein, is the only chimera galectin found in vertebrates. Galectin-3 has been found to participate in several biological processes, including cell adhesion (3), cell activation and chemoattraction (3), growth and differentiation (14), and apoptosis and cell cycle progression (15). Accumulating evidence has suggested that galectin-3 has a role in multiple types of cancer (16), including gastric carcinoma (17), parathyroid cancer (18), multiple myeloma (19), ovarian cancer (19) and OS (8). Furthermore, galectin-3 has emerged as a useful biomarker in the diagnosis and/or prognosis of certain malignancies (20). However, the detailed role of galectin-3 in the regulation of cellular biological processes of OS cells has remained to be fully elucidated. The present study showed that the expression of galectin-3 was significantly increased in OS tissues when compared with that in normal adjacent tissues. In addition, galectin-3 was also upregulated in three OS cell lines compared to a human osteoblast cell line. These results were consistent with those of a previous study, which reported that the serum levels as well as the tissue expression levels of galectin-3 were increased in patients with OS compared to those in healthy controls (8). These findings suggested that galectin-3 is involved in the development and progression of OS.

To further determine whether galectin-3 is relevant to OS progression, galectin-3-specific siRNA was used to knockdown the expression of galectin-3 in OS cells. It was found that silencing of galectin-3 expression significantly suppressed OS-cell proliferation and promoted OS-cell apoptosis. Similar findings have been reported in other studies; Zheng *et al* (21) demonstrated that downregulation of galectin-3 inhibited the proliferation of hepatocellular carcinoma cells. Furthermore, Huang *et al* (22) found that inhibition of galectin-3 expression by siRNA suppressed cell proliferation and induced cell apoptosis of pituitary tumor cells. In addition, galectin-3 was found to be involved in the regulation of cell cycle progression; Wang *et al* (23) showed that galectin-3 was involved in the regulation of prostate cancer cell growth and apoptosis by modulating the expression of p21, an important regulator in cell cycle progression. Furthermore, galectin-3 may be involved in the regulation of cyclin-D, which regulates the G1-to-S phase transition, in non-small cell lung cancer cells (24). Accordingly, it is hypothesized that the inhibition of

cell proliferation caused by galectin-3 knockdown observed in the present study may due to cell cycle arrest.

It has been well established that galectin-3 participates in the regulation of tumor-cell migration and invasion. For instance, Zhang *et al* (25) reported that silencing of galectin-3 inhibited migration and invasion of human tongue cancer cells via inhibition of  $\beta$ -catenin. However, to the best of our knowledge, the effect of galectin-3 on OS-cell migration and invasion has never been studied. The present study showed that siRNA-induced galectin-3 inhibition markedly inhibited OS-cell migration and invasion; furthermore, MMP2 and MMP9 were also downregulated after silencing of galectin-3 in OS cells. In addition, several studies have shown that MEK/ERK signaling is involved in galectin-3-mediated cell invasion. Song *et al* (26) reported that inhibition of galectin-3 downregulated the activity of Ras, as well as its downstream ERK signaling. Curcumin is an agonist of MEK, which can further activate ERK. Curcumin was used in the present study to determine whether galectin-3 exerted its effects on OS cell invasion via MEK signaling. However, it remains unclear whether curcumin exhibits anti-carcinogenic properties. The results demonstrated that pre-treatment with curcumin effectively reversed the suppressive effect of galectin-3 knockdown on OS-cell invasion, suggesting that MEK/ERK signaling participates in galectin-3-mediated OS-cell invasion.

In conclusion, the present study showed that the expression of galectin-3 was significantly increased in OS tissues and cell lines. siRNA-induced inhibition of galectin-3 significantly inhibited proliferation, migration and invasion, and induced apoptosis of OS cells. In addition, MEK/ERK signaling was found to be involved in the galectin-mediated OS-cell invasion. These results suggested that galectin-3 may be a promising target for the treatment of OS.

## References

1. Thompson LD: Osteosarcoma. *Ear Nose Throat J* 92: 288-290, 2013.
2. Yang J and Zhang W: New molecular insights into osteosarcoma targeted therapy. *Curr Opin Oncol* 25: 398-406, 2013.
3. Fortuna-Costa A, Gomes AM, Kozlowski EO, Stelling MP and Pavão MS: Extracellular galectin-3 in tumor progression and metastasis. *Front Oncol* 4: 138, 2014.
4. Viguier M, Advedissian T, Delacour D, Poirier F and Deshayes F: Galectins in epithelial functions. *Tissue Barriers* 2: e29103, 2014.
5. Laderach DJ, Gentilini L, Jaworski FM and Compagno D: Galectins as new prognostic markers and potential therapeutic targets for advanced prostate cancers. *Prostate Cancer* 2013: 519436, 2013.
6. Eisa NH, Ebrahim MA, Ragab M, Eissa LA and El-Gayar AM: Galectin-3 and matrix metalloproteinase-9: Perspective in management of hepatocellular carcinoma. *J Oncol Pharm Pract*, 2014 (Epub ahead of print).
7. von Klot CA, Kramer MW, Peters I, Hennenlotter J, Abbas M, Scherer R, Herrmann TR, Stenzl A, Kuczyk MA, Serth J and Merseburger AS: Galectin-1 and Galectin-3 mRNA expression in renal cell carcinoma. *BMC Clin Pathol* 14: 15, 2014.
8. Zhou X, Jing J, Peng J, Mao W, Zheng Y, Wang D, Wang X, Liu Z and Zhang X: Expression and clinical significance of galectin-3 in osteosarcoma. *Gene* 546: 403-407, 2014.
9. Hou F, Wang L, Wang H, Gu J, Li M, Zhang J, Ling X, Gao X, and Luo C: Elevated gene expression of S100A12 is correlated with the predominant clinical inflammatory factors in patients with bacterial pneumonia. *Mol Med Rep* 11: 4345-4352, 2015.
10. Gao J, Ding F, Liu Q and Yao Y: Knockdown of MACC1 expression suppressed hepatocellular carcinoma cell migration and invasion and inhibited expression of MMP2 and MMP9. *Mol Cell Biochem* 376: 21-32, 2013.

11. Miao JH, Wang SQ, Zhang MH, Yu FB, Zhang L, Yu ZX and Kuang Y: Knockdown of galectin-1 suppresses the growth and invasion of osteosarcoma cells through inhibition of the MAPK/ERK pathway. *Oncol Rep* 32: 1497-1504, 2014.
12. Tsubaki M, Satou T, Itoh T, Imano M, Ogaki M, Yanae M and Nishida S: Reduction of metastasis, cell invasion and adhesion in mouse osteosarcoma by YM529/ONO-5920-induced blockade of the Ras/MEK/ERK and Ras/PI3K/Akt pathway. *Toxicol Appl Pharmacol* 259: 402-410, 2012.
13. Diao CY, Guo HB, Ouyang YR, Zhang HC, Liu LH, Bu J, Wang ZH and Xiao T: Screening for metastatic osteosarcoma biomarkers with a DNA microarray. *Asian Pac J Cancer Prev* 15: 1817-1822, 2014.
14. Gao P, Simpson JL, Zhang J and Gibson PG: Galectin-3: Its role in asthma and potential as an anti-inflammatory target. *Respir Res* 14: 136, 2013.
15. Sundblad V, Croci DO and Rabinovich GA: Regulated expression of galectin-3, a multifunctional glycan-binding protein, in haematopoietic and non-haematopoietic tissues. *Histol Histopathol* 26: 247-265, 2011.
16. Funasaka T, Raz A and Nangia-Makker P: Galectin-3 in angiogenesis and metastasis. *Glycobiology* 24: 886-891, 2014.
17. Leal MF, Calcagno DQ, Chung J, de Freitas VM, Demachki S, Assumpção PP, Chammas R, Burbano RR and Smith MC: Deregulated expression of annexin-A2 and galectin-3 is associated with metastasis in gastric cancer patients. *Clin Exp Med*, 2014 (Epub ahead of print).
18. Truran PP, Johnson SJ, Bliss RD, Lennard TW and Aspinall SR: Parafibromin, galectin-3, PGP9.5, Ki67 and cyclin D1: Using an immunohistochemical panel to aid in the diagnosis of parathyroid cancer. *World J Surg* 38: 2845-2854, 2014.
19. Mirandola L, Nguyen DD, Rahman RL, Grizzi F, Yuefei Y, Figueroa JA, Jenkins MR, Cobos E and Chiriva-Internati M: Anti-Galectin-3 therapy: A new chance for multiple myeloma and ovarian cancer? *Int Rev Immunol* 33: 417-427, 2014.
20. van den Brûle F, Califice S and Castronovo V: Expression of galectins in cancer: A critical review. *Glycoconj J* 19: 537-542, 2004.
21. Zheng D, Hu Z, He F, Gao C, Xu L, Zou H, Wu Z, Jiang X and Wang J: Downregulation of galectin-3 causes a decrease in uPAR levels and inhibits the proliferation, migration and invasion of hepatocellular carcinoma cells. *Oncol Rep* 32: 411-418, 2014.
22. Huang CX, Zhao JN, Zou WH, Li JJ, Wang PC, Liu CH and Wang YB: Reduction of galectin-3 expression reduces pituitary tumor cell progression. *Genet Mol Res* 13: 6892-6898, 2014.
23. Wang Y, Balan V, Kho D, Hogan V, Nangia-Makker P and Raz A: Galectin-3 regulates p21 stability in human prostate cancer cells. *Oncogene* 32: 5058-5065, 2013.
24. Kosacka M, Piesiak P, Kowal A, Golecki M and Jankowska R: Galectin-3 and cyclin D1 expression in non-small cell lung cancer. *J Exp Clin Cancer Res* 30: 101, 2011.
25. Zhang D, Chen ZG, Liu SH, Dong ZQ, Dalin M, Bao SS, Hu YW and Wei FC: Galectin-3 gene silencing inhibits migration and invasion of human tongue cancer cells in vitro via downregulating  $\beta$ -catenin. *Acta Pharmacol Sin* 34: 176-184, 2013.
26. Song S, Ji B, Ramachandran V, Wang H, Hafley M, Logsdon C and Bresalier RS: Overexpressed galectin-3 in pancreatic cancer induces cell proliferation and invasion by binding Ras and activating Ras signaling. *PLoS One* 7: e42699, 2012.

RETRACTED