

Original Article

Lysyl oxidase G473A promotes migration, invasion and metastasis of ovarian cancer cells through regulating p38/Akt signaling pathways

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Abstract: Objectives: Lysyl oxidase (LOX) always promotes cancer cell metastasis. This study aimed to investigate the influence of LOX G473A on ovarian cancer cells function and the related cell signaling pathways. Methods: Expression of LOX G473A in 3 ovarian cancer cell lines HO-8910 and A2780 as well as the siRNA-LOX G473A transfected SKOV3 cells were detected by western blotting analysis. Migration and invasion as well as mitosis ability of transfected cells were detected using in vitro transwell assay and flow cytometry, respectively. Cytokines related to cell migration, invasion and metastasis were detected to investigate the influence of siRNA-LOX G473A on their expression. Results: LOX G473A showed the highest expression level in SKOV3 cell line compared with the other two. siRNA-LOX G473A significantly reduced the expression of LOX G473A protein as well as cell migration, invasion and mitosis abilities. Moreover, cytokines associated with cell migration, invasion and metastasis were dysregulated by siRNA-LOX G473A. Conclusions: LOX G473A was a crucial factor modulating cell migration, invasion and metastasis of ovarian cancer cell lines. The facts of LOX G473A silence could reduce cell migration, invasion and metastasis abilities demonstrated that LOX G473A might be served as a potential therapeutic target for ovarian cancer cells.

Keywords: Lysyl oxidase G473A, ovarian cancer cells, invasion, AKT

Introduction

Ovarian cancer is one top leading cause of cancer related death and most ovarian cancers were diagnosed in advanced stages followed by low overall survival rate [1]. The pathogenesis of ovarian cancer is identified to be involved in genetic alterations including lysyl oxidase (LOX) 473 G>A (rs1800449) polymorphism, E-cadherin [2], ERCC1 (excision repair cross-complementing 1) [3] and BRCA1 [4].

LOX is an enzyme located in extracellular matrix and crucial for hypoxia-induced metastasis [5]. LOX catalyzes collagens and elastin cross-linking in the extracellular compartment [1, 6]. Reportedly, polymorphism of LOX 473 G>A has been evidenced to be associated with metastasis of various diseases, including ovarian cancer [1, 6], breast cancer [7], gastric cancer [8] as well as coronary artery disease [9]. These researches displayed that the polymorphism of

LOX G473A was significantly higher in patients with gastric cancer [8], breast cancer [7] and advanced ovarian cancer [1]. They demonstrated that LOX G473A polymorphism was a risk factor for these cancers.

It was reported that LOX G473A polymorphism affect ovarian cancer metastasis [1, 6]. Wang *et al* reported that overexpression of LOX suppressed the proliferation and invasion of ovarian cancer cells and LOX was a direct target of miR-29b [10]. Some reports showed that LOX was a tumor suppressor gene which could be inactivated by methylation [11]. However, there was no direct research focusing the effect of LOX G473A on cell function of ovarian cancer cells.

To investigate the effect of LOX G473A on cell function of ovarian cancer cells and verify the mechanisms related to the changes, we examined the expression of LOX G473A protein and

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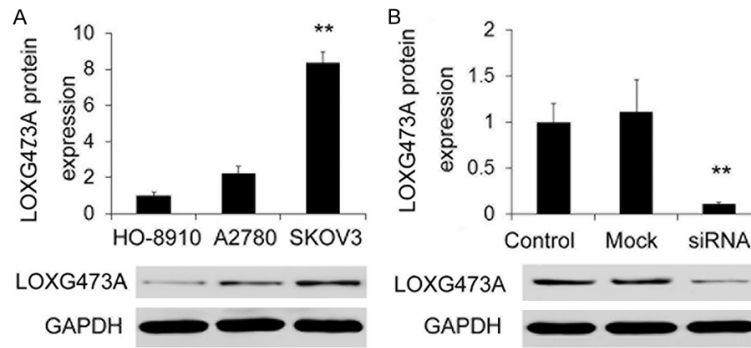


Figure 1. Expression of LOX G473A in three ovarian cancer cell lines and after LOX G473A silence. (A) Expression of LOX G473A in three ovarian cancer cell lines of HO-8910, A2780 and SKOV3 before LOX G473A silence; (B) Expression of LOX G473A in and SKOV3 before and after LOX G473A silence. All the determinations were performed using western blotting analysis. GAPDH was used as the internal reference gene for western blotting analysis. **indicates significant level at a *p* value of less than 0.01 comparing with the others (A) or control (B).

regulated the expression of LOX G473A. The migration and invasion of ovarian cancer cells were determined and metastasis-associated cytokines or signaling pathway were detected as well. This study would provide us with more information on the effect of LOX G473A on cell functions of ovarian cells.

Materials and methods

Cell line and culture conditions

Three human ovarian cancer cell lines HO-8910, A2780 and SKOV3 were obtained from Shanghai Institute of Cellular Biology of Chinese Academy of Sciences. Cells were cultured in DMEM or RPMI-1640 (Dulbecco's modified Eagle's medium, HyClone, USA) supplemented with 10% heat-inactivated fetal bovine serum (FBS; Gibco Laboratories, Grand Island, NY, USA) and penicillin-streptomycin. Cells were cultured at 37°C with 5% CO₂.

LOX G473A knockdown in ovarian cancer cell line

SiRNAs with sequence targeting LOX G473A were synthesized by GenePharma (Shanghai, China). SiRNA against LOX G473A were transfected into SKOV3 cells using Lipofectamine 2000 (Invitrogen, Carlsbad, CA, USA) following the manufactures' instruction. Cells plated into 24-well plate were transfected and cells transfected with siRNA-LOX G473A-NC was served as negative control. Cells were cultured at 37°C 5% CO₂ after transfection.

In vitro migration and invasion assay

Migration of transfected SKOV3 cells were detected using 24-well transwell chambers (Costar, Corning Incorporated, Corning, NY, USA) with polycarbonate membrane as described previously [12]. For cell migration assay, cells at a density of 50,000 were seeded into the upper chamber with DMEM medium without FBS. The lower chamber was filled with medium containing 10% FBS and incubated at 37°C 5% CO₂ for 24 h. For cell invasion assay, the 24-well transwell were coated with 80

µL Matrigel (BD Biosciences, Franklin Lakes, NJ, USA). Cells at a density of 100,000 were seeded into the upper chamber medium. The lower chamber was filled with medium containing 10% FBS and incubated at 37°C 5% CO₂ for 48 h. After incubation, cells on the upper surface filters were removed by cotton swab and filters were then fixed with paraformaldehyde for 10 min, followed with crystal violet staining. Stained cells were counted using a microscope and cells numbers at 5 randomly selected fields were averaged. All experiments were performed in triplicates and differences between groups were analyzed.

Cell cycle analysis

Cell cycle analysis for the transfected SKOV3 cells was performed using flow cytometry. Cells were harvested by trypsinization (Gibco Laboratories, Grand Island, NY, USA) and fixed using 70% ethanol for 24 h. DNA was stained with 50 µg/ml propidium iodide (PI, Biyuntian biological technology, Shanghai, China) and analyzed using a FACScalibur flow cytometer (BD Biosciences, Franklin Lakes, NJ, USA). All experiments were performed in triplicates.

Western blot analysis

Cultured cells in 6-well plates at a density of 2.0×10⁶ were harvested at 48 h post-transfection, washed in ice cold 1×PBS, and lysed in RIPA buffer (Thermo Scientific, Rockford, IL,

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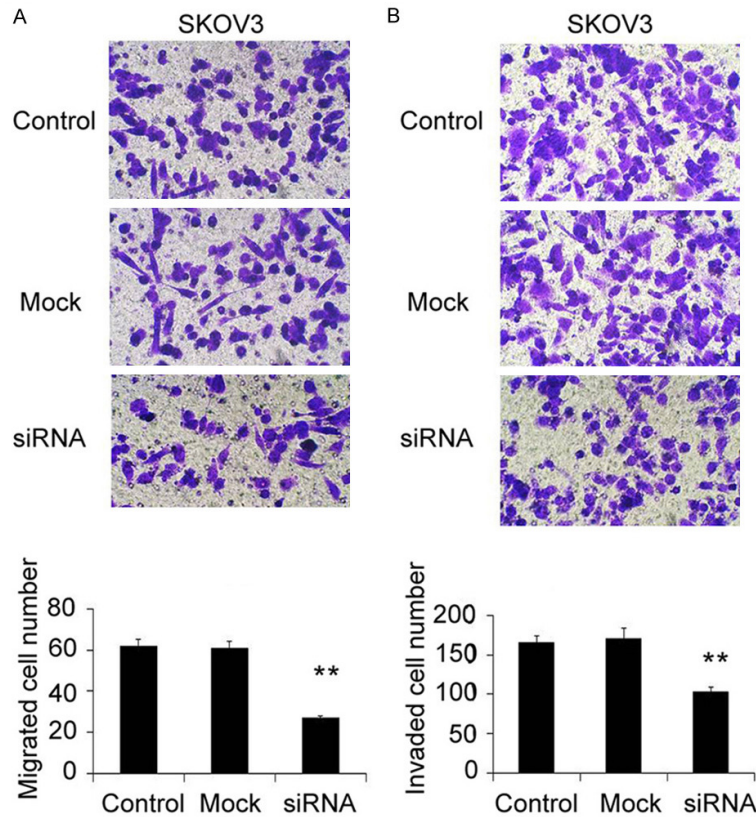


Figure 2. Effect of *LOX G473A* silence on cell migration and invasion. The ability of cell migration (A) and invasion (B) of transfected SKOV3 cells were detected using 24-well transwell chambers. Cell counting was realized using crystal violet staining and stained cells were counted using a microscope. **indicates significant level at a *p* value of less than 0.01 comparing with the control.

USA). Protein concentrations were then determined using a BCA protein assay kit (Thermo Scientific, Rockford, IL, USA). An equal amount of 35 μ g cell lysates were separated by 10% SDS-PAGE gels and were electrophoretically transferred to polyvinylidene difluoride (PVDF) membranes (Invitrogen Corp., Carlsbad, CA, USA). Then the PVDF membranes were blocked with 5% skimmed milk (BD Biosciences, Franklin Lakes, NJ, USA) and incubated with primary antibody against *LOX G473A* (dilution 1:1000), AKT (dilution 1:1000), phosphorylated (p)-AKT (dilution 1:1000), metastasis-associated protein (MTA) 1, E-cadherin (dilution 1:1000), RhoC (dilution 1:1000; Cell Signaling Technology, CST, Denvers, MA, USA), matrix metalloproteinase (MMP)9 (dilution 1:1000), and GAPDH (dilution 1:1500; Cell Signaling Technology, CST, Denvers, MA, USA) at 4°C overnight, and secondary antibodies for 1 h. The

polypeptide bands were detected using an enhanced chemiluminescence (ECL) detection system (Pierce, Rockford, IL, USA) and quantified with AlphaEase software (Alpha, USA).

Statistical analysis

Data were expressed as mean \pm standard deviation (SD) of 3 triplicates. Statistical analysis was performed using Student's *t* test or a one-way analysis of variance (ANOVA) test. *P*<0.05 was considered to be statistically significant.

Results

LOX G473A expresses the highest in SKOV3

The expressions of *LOX G473A* protein levels in the 3 ovarian cancer cell lines of HO-8910, A2780 and SKOV3 before and after siRNA-*LOX G473A* transfection were detected using western blotting analysis. The results showed that *LOX G473A* expressed the highest in

SKOV3 cell line compared with that in the other two cell lines (*P*<0.01, **Figure 1A**). Then we chose SKOV3 as the mediated cell in this study and successfully knocked down *LOX G473A* expression by 90% in SKOV3 cells using siRNA silencing methods (**Figure 1B**).

LOX G473A silence inhibits cell migration, invasion and mitosis

In order to detect the influence of *LOX G473A* on cell proliferation, we detected cell invasion, migration, and cell cycle of SKOV3 cells after siRNA-*LOX G473A* transfection. The results showed siRNA-*LOX G473A* transfected cells reduced migrated cells and invaded cells which determined that *LOX G473A* silence significantly inhibited cell ability of migration (*P*<0.01, **Figure 2A**) and invasion (*P*<0.01, **Figure 2B**). For cell cycle analysis, we confirmed that siRNA-*LOX G473A* inhibited cell proliferation by

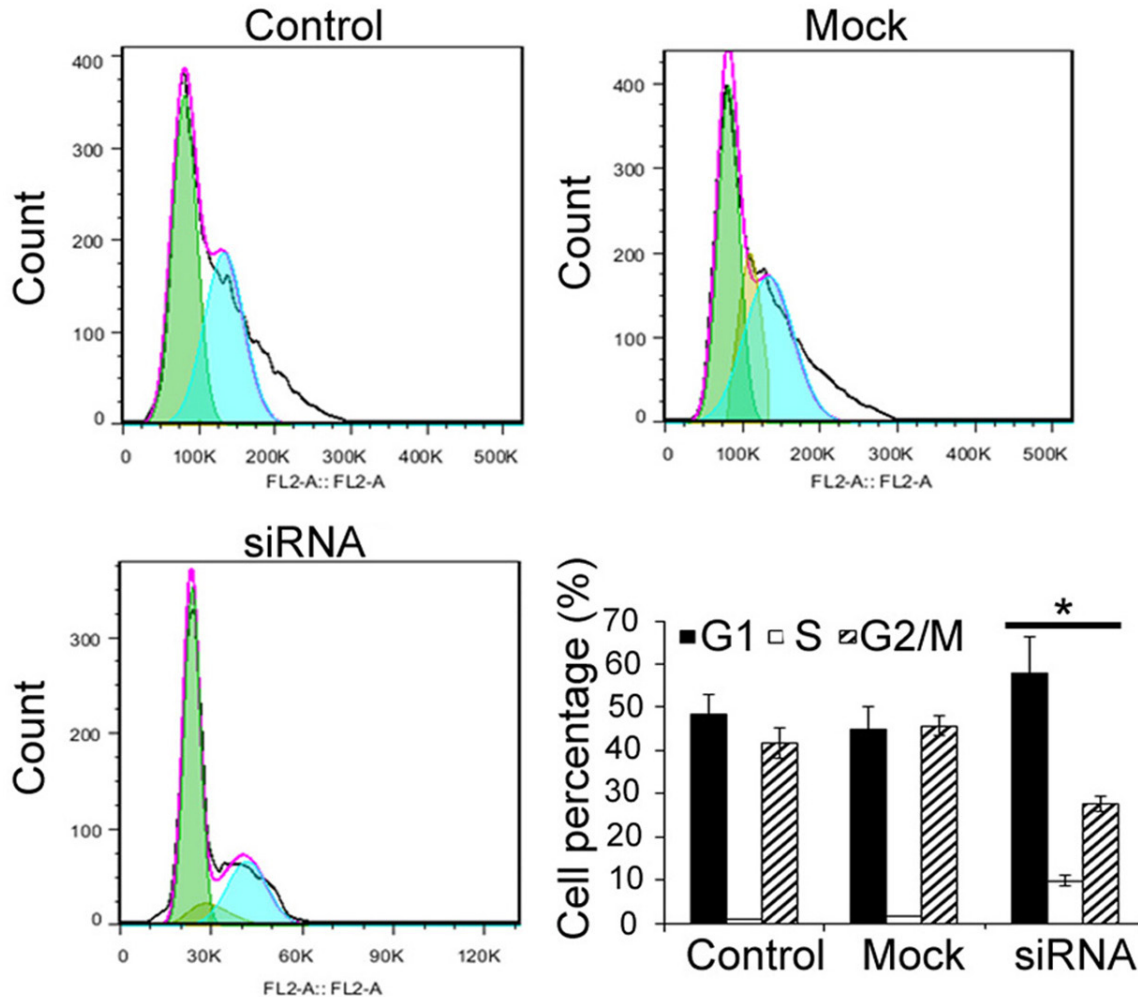


Figure 3. Effect of LOX G473A silence on cell mitosis. Cell cycle analysis was performed using flow cytometry. Fore flow cytometric analysis, DNA was stained with 50 $\mu\text{g}/\text{ml}$ propidium iodide. SiRNA-LOX G473A inhibited cell proliferation by increasing cell percentage in the G1 and S phases, and decreasing cell percentage in the G2/M phase. SiRNA-LOX G473A got SKOV3 cells arrest in the S phase and promoted cell apoptosis. *indicates significant level at a p value of less than 0.05 comparing with the control.

increasing cell percentage in the G1 and S phases, and decreasing cell percentage in the G2/M phase ($P < 0.01$, **Figure 3**). These showed that siRNA-LOX G473A got SKOV3 cells arrest in the S phase and promoted cell apoptosis. Taken together, the influence of siRNA-LOX G473A on SKOV3 cell function demonstrated that LOX G473A was positively correlated with cell growth and proliferation.

LOX G473A silence effects expression of cell cytokines related to cell invasion and metastasis

Given the above results of LOX G473A silence inhibited cell invasion and migration, we specu-

lated that LOX G473A silence might affect the expression of some cytokines related to cell migration, invasion, and metastasis via signaling pathway. To verified this assumption, we detected the expression of MTA1, E-cadherin, MMP9, RhoC, p-and P38, p-and AKT which had been reported to be associated with cell migration, invasion and metastasis using western blotting analysis [13-15]. Analysis showed the expression of MMP9, MTA1, and RhoC were depressed by siRNA-LOX G473A in SKOV3 cells ($P < 0.01$, **Figure 4A**). However, the expression of E-cadherin in SKOV3 cells was significantly upregulated by siRNA-LOX G473A ($P < 0.01$, **Figure 4A**). To investigate the effect of LOX G473A silence on p38/AKT sig-

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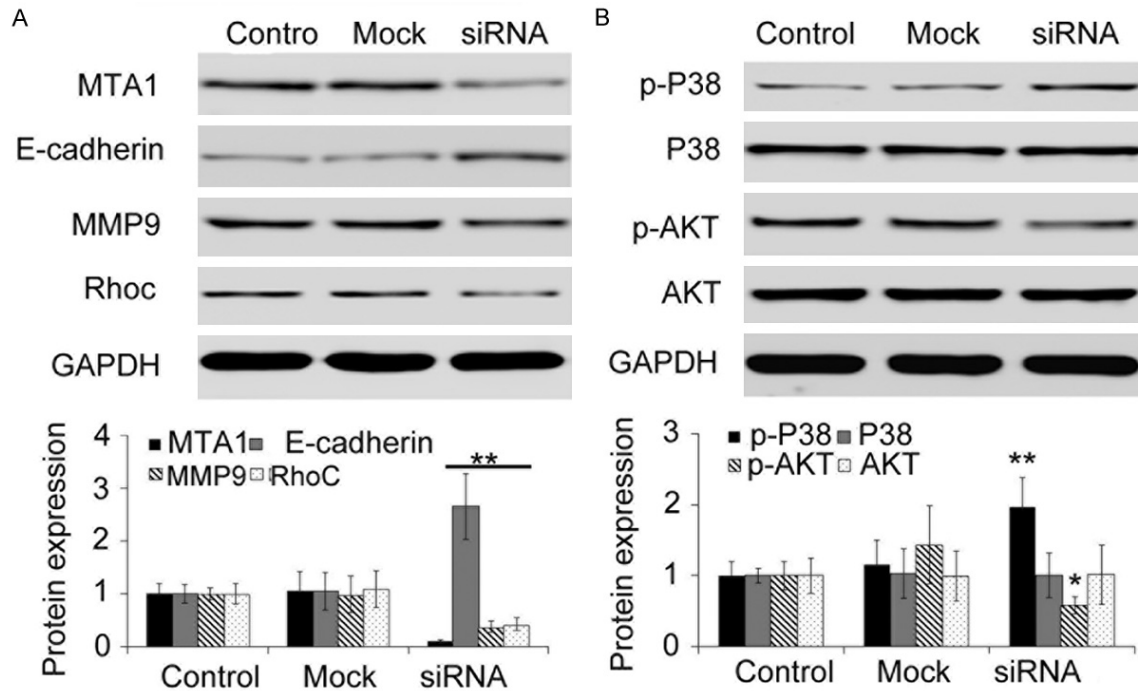


Figure 4. LOX G473A silence effects expression of cell cytokines related to cell invasion and metastasis. The expression of cytokines was performed using western blotting analysis. MTA1, E-cadherin, MMP9 and RhoC cytokines (A) and phosphorylated (p)-AKT, p-P38 and total AKT and P38 (B) were affected by siRNA-LOX G473A. **and * indicates significant level at a *p* value of less than 0.05 and 0.01 comparing with the control, respectively.

naling pathway, the expression of phosphorylated (p)-P38 and AKT, as well as the total protein of P38 and AKT were detected by western blotting analysis. Data showed that LOX G473A silence significantly induced and reduced the expression of p-P38 and p-AKT, respectively ($P < 0.01$ and $P < 0.05$, respectively, **Figure 4B**). However, there was no influence on the expression of total P38 protein and total AKT protein ($P > 0.05$, **Figure 4B**). These results showed LOX G473A silence mediated cell migration, invasion, and metastasis via P38/ATK and other MTA1, E-cadherin or RhoC-mediated signaling pathways.

Discussion

LOX G473A polymorphism is a new risk factor for cancers including ovarian cancer and LOX signaling affect the metastasis of ovarian cancer cells [1, 6]. This study was designed to investigate the expression of LOX G473A polymorphism in ovarian cancer cells and the effect of LOX G473A polymorphism on cell function of ovarian cancer cells. Results from the experiments showed ovarian LOX G473A

expressed the highest in ovarian cancer cell line SKOV3 than HO-8910 and A2780 cell lines. After being transfected with siRNA-LOX G473A plasmids, the expression of LOX G473A as well as cell migration, invasion and mitosis ability were inhibited, and metastasis-related cytokines including E-cadherin, MMP9 and P38/AKT signaling pathway were dysregulated. This demonstrated that LOX G473A was associated with cell growth, proliferation and metastasis.

As reported that LOX was a tumor suppressor and overexpression of it could suppress ovarian cancer cells proliferation and invasion [10, 11]. However, there is an opposite function of LOX in cancer cells acting as a promoter of cell metastasis [16], and polymorphism of LOX might associated with increased risk of cancers [7, 9, 17]. For example, patients with non-small cell lung cancer and cardiovascular diseases showed higher frequency of LOX 473 AA genotype and A allele, a novel polymorphism of LOX gene, compared with normal controls, showing LOX 473 G>A polymorphism is risk factor for cell metastasis and might be a prog-

nostic predictor for some diseases [9, 17]. However, Wang *et al* reported that overexpression of *LOX* suppressed the proliferation and invasion of ovarian cancer cells, demonstrating the tumor suppresser function of *LOX* gene [10]. Together to speak, these reports showed *LOX* gene has two opposing biofunctions in different cancers. In this study we demonstrated the expression of *LOX* 473GA polymorphism was highly expressed in ovarian cancer cell line SKOV3 and siRNA-*LOX* G473A successfully downregulated cell the expression of *LOX* G473A as well as reduced the ability of cell migration and invasion as well as arrested SKOV3 cells at S phase. These indicated that high frequency of *LOX* G473A polymorphism was associated metastasis ability of ovarian cancer cell line SKOV3, and *LOX* G473A was a metastasis promoter for ovarian cancer cells.

The cell metastasis, migration, invasion and cell cycle function were regulated by several signaling pathways and cytokines, such as RhoC-AKT signaling pathways [18, 19], E-cadherin [20], P38/AKT [21], as well as the MTA1 [22]. MTA1 gene promotes cell invasion, migration and metastasis of cancer cells directly or indirectly by promoting or suppressing expression of its targets [23-25]. E-cadherin, a tumor invasion suppressor gene, is one of the targets of MTA1 and was suppressed by MTA1 in malignant pleural mesothelioma [24, 26]. Xu *et al* revealed that MTA1 enhanced the invasion and migration of malignant pleural mesothelioma cells through suppressing E-cadherin expression. Moreover, Cagatay *et al* demonstrated that MTA1 silencing caused an increase in the epithelial marker of E-cadherin as well as a decrease in MMP9, a potential biomarker for cancer invasion and metastasis, in HCT-116 cells [23]. Further studies had shown that expression of *LOX* in human cancers suppressed cell migration and expression of MMP9 [27, 28]. In this study, we demonstrated that siRNA-mediated *LOX* G473A silence downregulated the expression of tumor promoter genes MTA1 and MMP9, and upregulated tumor invasion suppressor gene E-cadherin as well as suppressed cell migration and invasion. These demonstrated that *LOX* G473A was a tumor promoter in ovarian cancer cells, and downregulation of it might be a potential target for modulating cancer cell invasion, migration and even metastasis.

Additionally, depression of E-cadherin in cancer was reported to be correlated with RhoC upregulation, which promotes epidermal growth factor receptor (EGFR) stimulated migration and invasion [19, 29]. RhoC is a Ras superfamily and has been shown to promote cancer metastasis by promoting AKT activity, a crucial factor for cell apoptosis and proliferation [18, 30]. Accordingly, knockdown of RhoC suppressed AKT signaling and inhibited tumor invasion [30, 31]. Moreover, EGFR is a suppressor of cell apoptosis and inhibition of EGFR enhanced cell apoptosis of head and neck squamous cell carcinoma [32]. EGFR mediates AKT and MAPK pathways to modulate cell migration, invasion and growth, as the inhibition of EGFR inhibits cell migration invasion and growth via suppressing PI3K/Akt and MAPK signaling pathways [33, 34]. Moreover, activated p38 MAPK signaling pathway is assistance to cell apoptosis, due to the G2/M arrest Mechanically, RhoC promotes the EGFR-activated PI3K/Akt and MAPK signaling pathways as well as inhibits cell apoptosis [35, 36]. In this study, we revealed that the inhibition of *LOX* G473A gene inhibited growth and promoted apoptosis by get an S-phase arrest of SKOV3 cells through modulated the expression and activity of p38/AKT pathway.

Conclusion

In this study, we demonstrated that *LOX* G473A gene was a tumor promoter of ovarian cancer cells. The knock down of *LOX* G473A gene by siRNA silencing suggested *LOX* G473A gene was a crucial factor for ovarian cancer cell migration, invasion, and metastasis. Furthermore, we demonstrated that the cell growth inhibition by *LOX* G473A gene was related to p38/AKT signaling pathway and the cytokines associated with this pathway, including MTA1, E-cadherin, MMP9, and RhoC. These demonstrated that *LOX* G473A gene polymorphism might be regarded as a potential therapeutic target for ovarian cancer cells.

Disclosure of conflict of interest

None.

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References

- [1] Wang X, Cong JL, Qu LY, Jiang L, Wang Y. Association between lysyl oxidase G473A polymorphism and ovarian cancer in the Han Chinese population. *J Int Med Res* 2012; 40: 917-923.
- [2] Blehschmidt K, Sassen S, Schmalfeldt B, Schuster T, Höfler H, Becker KF. The E-cadherin repressor Snail is associated with lower overall survival of ovarian cancer patients. *Br J Cancer* 2008; 98: 489-495.
- [3] Lord RV, Brabender J, Gandara D, Alberola V, Camps C, Domine M, Cardenal F, Sánchez JM, Gumerlock PH, Tarón M, Sánchez JJ, Danenberg KD, Danenberg PV, Rosell R. Low ERCC1 expression correlates with prolonged survival after cisplatin plus gemcitabine chemotherapy in non-small cell lung cancer. *Clin Cancer Res* 2002; 8: 2286-2291.
- [4] Quinn JE, James CR, Stewart GE, Mulligan JM, White P, Chang GK, Mullan PB, Johnston PG, Wilson RH, Harkin DP. BRCA1 mRNA expression levels predict for overall survival in ovarian cancer after chemotherapy. *Clin Cancer Res* 2007; 13: 7413-7420.
- [5] Finger EC and Giaccia AJ. Hypoxia, inflammation, and the tumor microenvironment in metastatic disease. *Cancer Metastasis Rev* 2010; 29: 285-293.
- [6] Wu J, Cai C, Tong D, Hou H. Lysyl oxidase G473A polymorphism is associated with increased risk of ovarian cancer. *Genet Test Mol Biomarkers* 2012; 16: 915-919.
- [7] Ren J, Wu X, He W, Shao J, Cheng B, Huang T. Lysyl oxidase 473 G>A polymorphism and breast cancer susceptibility in Chinese Han population. *DNA Cell Biol* 2011; 30: 111-116.
- [8] Yoon JH, Park JK, Kang YH, Park YK, Nam SW, Lee JY, Park WS. Lysyl oxidase G473A polymorphism is closely associated with susceptibility to gastric cancer in a South Korean population. *Apmis* 2011; 119: 762-768.
- [9] Ma L, Song H, Zhang M, Zhang D. Lysyl oxidase G473A polymorphism is associated with increased risk of coronary artery diseases. *DNA Cell Biol* 2011; 30: 1033-1037.
- [10] Wang X, Wang Y, Wang GC, Liu PS. miR-29b regulates cell proliferation and invasion in human ovarian clear cell carcinoma by targeting Lysyl oxidase (LOX). *Arch Biol Sci* 2016; 68: 155-163.
- [11] Kaneda A, Wakazono K, Tsukamoto T, Watanabe N, Yagi Y, Tatematsu M, Kaminishi M, Sugimura T, Ushijima T. Lysyl oxidase is a tumor suppressor gene inactivated by methylation and loss of heterozygosity in human gastric cancers. *Cancer Res* 2004; 64: 6410-6415.
- [12] Mao L, Yang C, Wang J, Li W, Wen R, Chen J, Zheng J. SATB1 is overexpressed in metastatic prostate cancer and promotes prostate cancer cell growth and invasion. *J Transl Med* 2013; 11: 111.
- [13] Shen YJ, Zhu XX, Yang X, Jin B, Lu JJ, Ding B, Ding ZS, Chen SH. Cardamonin inhibits angiotensin II-induced vascular smooth muscle cell proliferation and migration by downregulating p38 MAPK, Akt, and ERK phosphorylation. *J Nat Med* 2014; 68: 623-629.
- [14] Mao M, Chen J, Li X, Wu Z. siRNA-TMEM98 inhibits the invasion and migration of lung cancer cells. *Int J Clin Exp Pathol* 2015; 8: 15661-9.
- [15] Ji Q, Zheng GY, Xia W, Chen JY, Meng XY, Zhang H, Rahman K, Xin HL. Inhibition of invasion and metastasis of human liver cancer HCC-LM3 cells by portulacacerebroside A. *Pharm Biol* 2015; 53: 773-80.
- [16] Erler JT and Giaccia AJ. Lysyl oxidase mediates hypoxic control of metastasis. *Cancer Res* 2006; 66: 10238-10241.
- [17] Shi W, Yang B, Li X, Sun S, Wang L, Jiao S. The effect of lysyl oxidase polymorphism on susceptibility and prognosis of nonsmall cell lung cancer. *Tumor Biol* 2012; 33: 2379-2383.
- [18] Liu Z, Zhu J, Cao H, Ren H, Fang X. miR-10b promotes cell invasion through RhoC-AKT signaling pathway by targeting HOXD10 in gastric cancer. *Int J Oncol* 2012; 40: 1553-60.
- [19] Tumor Z, Katebzadeh S, Guerra C, Bhushan L, Alkam T, Henson BS. RhoC mediates epidermal growth factor-stimulated migration and invasion in head and neck squamous cell carcinoma. *Neoplasia* 2015; 17: 141-151.
- [20] Canesin G, Cuevas EP, Santos V, López-Méndez C, Moreno-Bueno G, Huang Y, Csiszar K, Portillo F, Peinado H, Lyden D, Cano A. Lysyl oxidase-like 2 (LOXL2) and E47 EMT factor: novel partners in E-cadherin repression and early metastasis colonization. *Oncogene* 2015; 34: 951-964.
- [21] Kim WY, Jang JY, Jeon YK, Chung DH, Kim YG, Kim CW. Syntenin increases the invasiveness of small cell lung cancer cells by activating p38, AKT, focal adhesion kinase and SP1. *Exp Mol Med* 2014; 46: e90.
- [22] Zhang H, Yang D, Wang H, Wen S, Liu J, Luan Q, Huang Y, Wang B, Lin C, Qian H. Metastasis-associated gene 1 promotes invasion and migration potential of laryngeal squamous cell carcinoma cells. *Oncol Lett* 2014; 7: 399-404.
- [23] Tuncay Cagatay S, Cimen I, Savas B, Banerjee S. MTA-1 expression is associated with metastasis and epithelial to mesenchymal transition in colorectal cancer cells. *Tumor Biol* 2013; 34: 1189-1204.
- [24] Xu C, Hua F, Chen Y, Huang H, Ye W, Yu Y, Shen Z. MTA1 promotes metastasis of MPM via suppression of E-cadherin. *J Exp Clin Cancer Res* 2015; 34: 151.

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- [25] Pakala SB, Rayala SK, Wang RA, Ohshiro K, Mudvari P, Reddy SD, Zheng Y, Pires R, Casimiro S, Pillai MR, Costa L, Kumar R. MTA1 promotes STAT3 transcription and pulmonary metastasis in breast cancer. *Cancer Res* 2013; 73: 3761-3770.
- [26] Berx G, Cleton-Jansen AM, Nollet F, de Leeuw WJ, van de Vijver M, Cornelisse C, van Roy F. E-cadherin is a tumour/invasion suppressor gene mutated in human lobular breast cancers. *EMBO J* 1995; 14: 6107.
- [27] Xu X, Wang B and Xu Y. Expression of lysyl oxidase in human osteosarcoma and its clinical significance: a tumor suppressive role of LOX in human osteosarcoma cells. *Int J Oncol* 2013; 43: 1578-1586.
- [28] Barker HE, Cox TR and Erler JT. The rationale for targeting the LOX family in cancer. *Nat Rev Cancer* 2012; 12: 540-552.
- [29] Kawata H, Kamiakito T, Omoto Y, Miyazaki C, Hozumi Y, Tanaka A. RhoC upregulation is correlated with reduced E-cadherin in human breast cancer specimens after chemotherapy and in human breast cancer MCF-7 cells. *Horm Cancer* 2014; 5: 414-423.
- [30] Yu X, Li Z, Shen J, Wu WK, Liang J, Weng X, Qiu G. MicroRNA-10b promotes nucleus pulposus cell proliferation through RhoC-Akt pathway by targeting HOXD10 in intervertebral disc degeneration. *PLoS One* 2013; 8: e83080.
- [31] Sun HW, Tong SL, He J, Wang Q, Zou L, Ma SJ, Tan HY, Luo JF, Wu HX. RhoA and RhoC-siRNA inhibit the proliferation and invasiveness activity of human gastric carcinoma by Rho/PI3K/Akt pathway. *World J Gastroenterol* 2007; 13: 3517.
- [32] Stegeman H, Span PN, Cockx SC, Peters JP, Rijcken PF, van der Kogel AJ, Kaanders JH, Busink J. EGFR-inhibition enhances apoptosis in irradiated human head and neck xenograft tumors independent of effects on DNA repair. *Radiat Res* 2013; 180: 414-421.
- [33] Akhtar S, Yousif MH, Chandrasekhar B, Benter IF. Activation of EGFR/ERBB2 via pathways involving ERK1/2, P38 MAPK, AKT and FOXO enhances recovery of diabetic hearts from ischemia-reperfusion injury. *PLoS One* 2012; 7: e39066.
- [34] Chun J and Kim YS. Platycodin D inhibits migration, invasion, and growth of MDA-MB-231 human breast cancer cells via suppression of EGFR-mediated Akt and MAPK pathways. *Chem Biol Interact* 2013; 205: 212-221.
- [35] Weir NM, Selvendiran K, Kutala VK, Tong L, Vishwanath S, Rajaram M, Tridandapani S, Anant S, Kuppusamy P. Curcumin induces G2/M arrest and apoptosis in cisplatin-resistant human ovarian cancer cells by modulating Akt and p38 MAPK. *Cancer Biol Ther* 2007; 6: 178-184.
- [36] Zhang J, Tang J, Cao B, Zhang Z, Li J, Schimmer AD, He S, Mao X. The natural pesticide dihydrorotenone induces human plasma cell apoptosis by triggering endoplasmic reticulum stress and activating p38 signaling pathway. *PLoS One* 2013; 8: e69911.