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ORIGINAL RESEARCH

RETRACTED ARTICLE: Implications of the Receptor Tyrosine Kinase Axl in Gastric Cancer Progression

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Background: Gastric cancer (GC) is an aggressive malignancy with high lethality. Systematic chemotherapy is the main therapeutic strategy for advanced GC patients. The overexpression of Axl is associated with poor prognosis and regulates tumor growth and metastasis in many types of cancer. However, the role of Axl in GC progression remains elusive.

Materials and Methods: Western blot and quantitative real-time PCR assay (RT-PCR) assays were used to detect the expression of Gas6, Axl, ZEB1 and epithelial-mesenchymal transition (EMT)-related markers in GC cells. Cell proliferation was determined by EdU cell proliferation assay and CCK-8 assay. Transwell invasion assay was performed to explore the effect of Axl and ZEB1 on cell invasion. Tumor xenografts and lung metastasis models were conducted to examine the effect of Axl on the growth and lung metastasis of GC cells.

Results: In our study, we found that high levels of Gas6 and Axl expression were associated with reduced overall survival (OS) of GC patients and the expression of Gas6 and Axl was upregulated in GC cell lines. Ectopic expression of Axl induced EMT and promoted GC cell invasion and proliferation. The knockdown of Axl inhibited EMT and suppressed the proliferation and invasion of GC cell. In vivo study showed that inhibition of Axl impaired tumor growth and lung metastasis of GC cells. Mechanistic investigations revealed that Axl promoted EMT, invasion, and proliferation via upregulating ZEB1 expression in GC cells.

Conclusion: Our results demonstrated that the Gas6/Axl/ZEB1 signaling pathway regulated EMT, invasion, and proliferation in GC cells and might represent a potential therapeutic target for GC treatment.

Keywords: gastric cancer, Gas6/Axl signaling pathway, ZEB1, EMT, invasion, proliferation

Introduction

Gastric cancer (GC), an aggressive tumor with high incidence and high fatality, is one of leading causes of cancer death all over the world.[1,2] Combination of chemotherapy, surgery, and radiation was the current therapeutic strategy for patients with GC.[3] Chemotherapeutic agents, including 5-Fu, platinum, and docetaxel, are commonly used in clinic[3] and they can induce tumor cell apoptosis though DNA damage or can inhibit tumor cell proliferation via cell cycle arrest. Seriously, despite initial response, the clinical benefits of GC patients remained limited and dissatisfactory because of tumor recurrence and metastasis.[4,5] Thus, we should further investigate the molecular mechanisms of GC invasion and proliferation and it is urgent to develop more effective therapeutic targets.

Axl is a member of the TYRO3, AXL, and MERTK (TAM) family of receptor tyrosine kinases (RTKs) and it can be activated by its ligand Gas6,[6] which is closely

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implicated in tumor progression.[7–9] The Gas6/Axl signaling pathway has been reported to regulate cell proliferation, migration, invasion, and chemoresistance in many malignancies, such as breast cancer,[10,11] prostate cancer,[12] and hepatocellular carcinoma.[13] High expression of Axl is observed in many types of solid and hematological tumors,[14–16] which was closely associated with poor prognosis, distant metastasis, and local recurrence in cancer patients.[17–19] More remarkably, the knockdown of Axl and pharmacological inhibition of Axl pathway were confirmed to suppress tumor growth, mobility and increase the sensitivity to chemotherapeutic agents in tumor cells.[10,20-22] In addition, the Gas6/Axl singling contributed to GC cell survival and invasion though the activation of Akt pathway.[23] However, the effect and mechanisms of Axl pathway on GC invasion and proliferation have not been clearly elucidated.

Many studies have reported the role of Axl pathway in the invasion and proliferation of several kinds of cancer cells, whereas the effect of Axl on GC progression has been poorly investigated. In our study, we aimed at exploring the role of Axl in GC growth and metastasis. We found that the Gas6/Axl/ZEB1 axis was upregulated in GC cell lines and negatively correlated with OS in GC patients. Axl-mediated EMT, invasion and proliferation were enhanced by upregulating ZEB1. Our findings indicated a role of Gas6/Axl/ZEB1 pathway in GC progression.

Materials and Methods

Ethics Statement

All experimental plans and procedures using animals have been performed in accordance with a protocol reviewed and approved by the Animal Ethics Committee of Peking University Shenzhen Hospital and animal studies were performed according to the NIH Guide for the Care and Use of Laboratory Animals. Tumor-bearing mice were anaesthetized with 0.5% pentobarbital sodium (approximately 200 μL/mouse) before the collection of tumor and lung tissues.

Cells and Cell Culture

Human GC cell lines BGC-823, MGC-803, SGC-7901, and AGS, and human normal gastric epithelial GES-1 cells were purchased from Cell Bank of Type Culture Collection of Chinese Academy of Sciences (Shanghai, China). All the cells were cultured in DMEM (Invitrogen, Carlsbad, CA, USA) containing 10% FBS (Hyclone, South Logan, UT, USA) and 1% penicillin-streptomycin (Hyclone, South Logan, UT, USA) and maintained at 37°C in a humidified atmosphere with 5% CO_2.

Western Blot Assay

Total cell protein of four GC cells and GES-1 cells were harvested and performed with RIPA lysis buffer (Beyotime Biotechnology, Shanghai, China) containing protease inhibitor cocktails (Roche, Basel, Switzerland). The protein concentrations were determined by a BCA Protein Assay Kit (Beyotime Biotechnology, Shanghai, China). Proteins were electrophoretically separated by 10% SDS-polyacrylamide gels and detected with Western blot analysis. Antibodies against Gas6, Axl, p-Axl (Y702), E-cadherin, vimentin, ZEB1 and GAPDH were obtained from Cell Signaling Technology (Danvers, MA, USA). The bands were visualized with an enhanced chemiluminescence (ECL, Bio-Rad, Hercules, CA, USA) system.

Cell Transient Transfection

GC cells were transfected with Axl siRNA, ZEB1 siRNA (Santa Cruz Biotechnology, Santa Cruz, CA, USA) or pCMV3-Axl plasmid (GenePharm, Shanghai, China) by using Lipofectamine™ 3000 Transfection Reagent (Invitrogen, Carlsbad, CA, USA) according to the manufacturer's protocol. Scrambled sequence serves as a control siRNA (siNC) and pCMV3 Vector was used as a control plasmid. After a 6-h transfection, medium was refreshed. Cells were further cultured for 24 h and then performed as indicated.

Cell Stable Transfection

Axl short hairpin RNA (shRNA) was used to downregulate Axl expression in BGC-823 cells. Axl shRNA lentiviral particles (shAxl) were obtained from Santa Cruz Biotechnology. Scrambled sequence was used as a control shRNA (shCTL) (Santa Cruz Biotechnology, Santa Cruz, CA, USA). In brief, cells were incubated with viruses according to the protocol of shRNA lentiviral particle transduction. Then, cells were selected with Puromycin dihydrochloride (Santa Cruz Biotechnology, Santa Cruz, CA, USA). The knockdown efficiency in polyclonal cell populations was determined with RT-PCR and Western blot assays.

Cell Proliferation Assay

The proliferation of GC cells was measured by EdU cell proliferation assay (Beyotime Biotechnology, Shanghai, China) and CCK-8 assay (Beyotime Biotechnology, Shanghai, China). For EdU cell proliferation assay, 4×10^3 cells were seeded in 96-well plates and cultured overnight. At

48 h after transfections, cells were incubated with EdU for 2 h and then performed with EdU cell proliferation assay according to the manufacturer's protocol. The images were photographed with an invert fluorescence microscope. For CCK-8 assay, the absorbance at 450 nm was examined with a microplate reader at different times (0, 24, 48, 72, 96 h).

Transwell Invasion Assay

The effect of Axl on GC cell invasion was examined by Transwell invasion assay (Corning, NY, USA). In brief, the upper filters were pre-coated with 30 μL diluted Matrigel (Corning, NY, USA). Then, GC cells after the indicated transfections were trypsinized, resuspended in serum-free DMEM, and added into the upper filters. The low chambers were filled with 600 μL DMEM containing 10% FBS. After incubation for 24 h, cells in the upper filters were fixed with 4% paraformaldehyde (Sigma, St. Louis, MO, USA) and stained with 0.1% crystal violet (Sigma, St. Louis, MO, USA). Then cells on the inner side of the upper filters were removed with cotton swabs and invaded cells on the bottom side of the filters were observed and counted.

Quantitative Real-Time PCR (RT-PCR) Assay

Four GC cells and GES-1 cells were harvested and total RNA was extracted with RNAeasy™ Animal RNA Isolation Kit with Spin Column (Beyotime Biotechnology, Shanghai, China). The Transcriptor First Strand cDNA Synthesis Kit (Roche, Basel, Switzerland) was used for reverse transcription. cDNA was mixed with 2× SYBR Green PCR Mastermix (Solarbio, Beijing, China) and then amplified and quantified by LightCycler 480 real-time PCR system (Roche, Basel, Switzerland). The level of mRNA expression was normalized to *ACTB* and $2^{-\Delta\Delta C}$ method was used to evaluate relative gene expression.

Tumor Xenograft Study

BGC-823 cells transfected with shCTL (BGC-823-shCTL) or shAxl (BGC-823-shAxl) were used for the establishment of tumor xenograft models. In brief, cells (5×10^6 cells in 200 μL diluted Matrigel/mouse) were subcutaneously inoculated into the flank of male (aged 6 to 8 weeks) Balb/c Nude mice (Beijing Vital River Lab Animal Technology). Tumor growth was measured with caliper every other day after cell implantation for 7 days. Tumor sizes were calculated with the following formula: $\pi/6 \times a \times b^2$, where a refers the long diameter and b is the short diameter perpendicular to a. Tumor tissues were harvest at 32 day after inoculation and tumor weight was analyzed.

Establishment of Lung Metastasis Models

BGC-823-shCTL and BGC-823-shAxl cell were suspended in serum-free DMEM and intravenously injected into male (aged 6 to 8 weeks) Balb/c Nude mice (Beijing Vital River Lab Animal Technology). After inoculation for 28 days, mice were anesthetized with 50 mg/kg pentobarbital sodium by intraperitoneal injection and lung tissues were collected. Then, lungs tissues were fixed with 4% paraformaldehyde and followed by hematoxylin-eosin (H&E) staining according to standard procedures.

Statistical Analysis

All the in vitro experiments were performed at least three independent times. Statistical analyses were analyzed with GraphPad Prism 7.0 software. Data are shown as mean ± SEM. Statistical analysis was performed with unpair two-tailed *t* test (two groups) or one-way ANOVA followed by Tukey's test (three or more groups). $P < 0.05$ was considered statistically significant.

Results

Axl Is Upregulated in GC Cell Lines and Overexpressed Gas6 or Axl Predicts Poor Overall Survival in GC Patients

Given that Axl overexpression was observed in many types of cancer and predicted poor prognosis,[8] we first detected the expression of Gas6, Axl, and p-Axl in human normal gastric epithelial GES-1 cells and GC cell lines. Western blot assay showed that the expression of Gas6, Axl, and p-Axl was upregulated in four selected GC cell lines, including MGC-803, BGC-823, AGS, and SGC-7901 cells (Figure 1A). RT-PCR assay revealed that the levels of Gas6 and Axl mRNA expression were increased by 1.5- to 2.2-fold in GC cell lines when compared with GSE-1 cells (Figure 1B). Then, we further examined the correlation between the expression of Axl and overall survival (OS) in GC patients by using Kaplan-Meier plotter database. As expected, we found that high level of Axl was associated with reduced OS in GC patients (Figure 1C. 202685_s_at, HR = 2.2, $P < 0.001$; 202686_s_at, HR = 1.42, $P < 0.001$). Since Gas6 is a ligand of the Axl receptor and binds to Axl to activate the Axl pathway, we also determined the correlation between Gas6 level and OS in GC patients. There was a significantly negative correlation between Gas6 expression level and OS

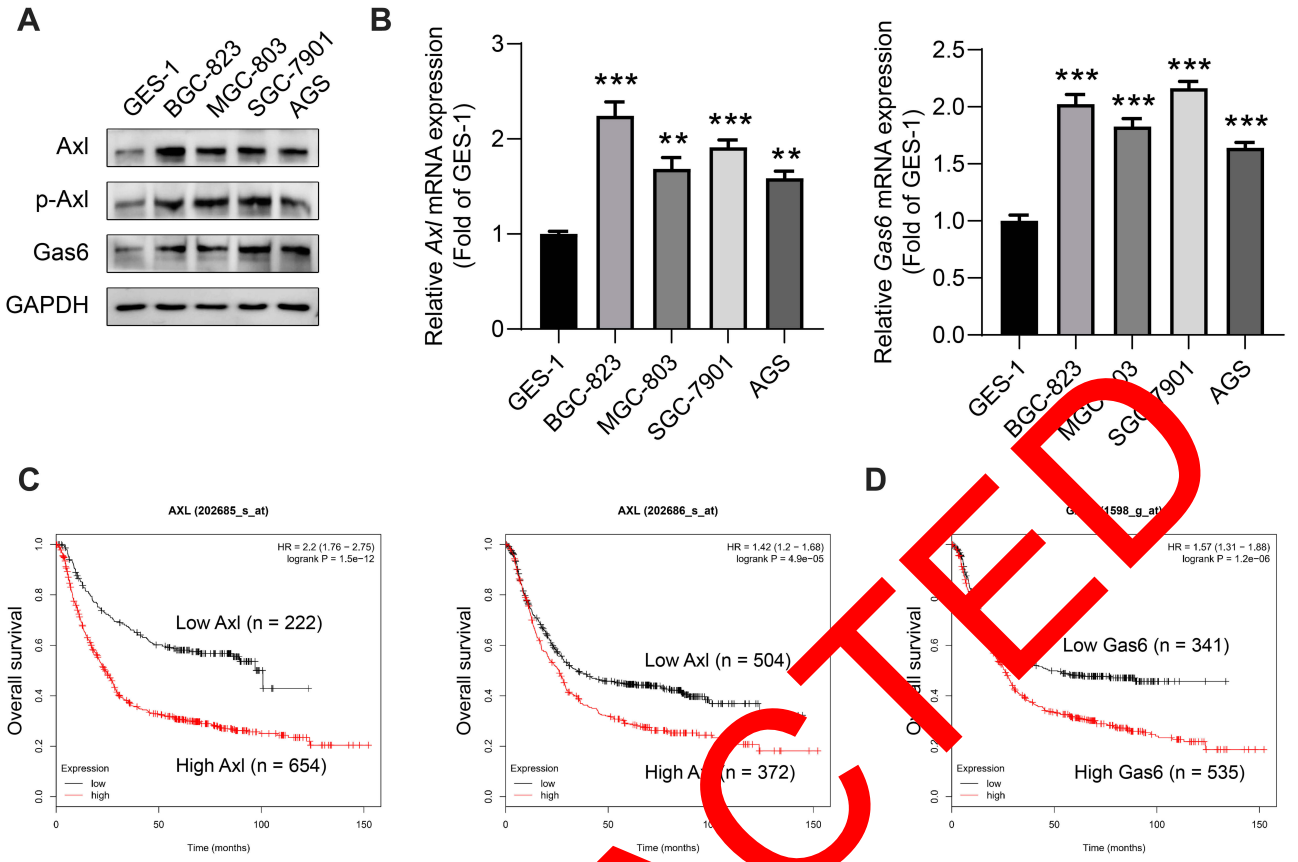

Figure 1 The Gas6/Axl axis is upregulated in GC cells and negatively correlated with overall survival in GC patients. (**A** and **B**) The expression level of Axl and Gas6 in human normal gastric epithelial GES-1 cells and four GC cells are determined by (**A**) Western blot assay and (**B**) RT-PCR assay. (**C** and **D**) Kaplan-Meier analysis of the correlations between (**C**) Axl or (**D**) Gas6 expression levels and OS in GC patients. $^{**}P < 0.01$ and $^{***}P < 0.001$ compared with GES-1 cells.

in GC patients (Figure 1D. 1598_g_at, HR = 1.57, P = 1.2e−06, 0.001). Together, these data suggest that the Gas6/Axl pathway is upregulated in GC cell lines and high level of Gas6 or Axl predicts reduced OS in GC patients.

Ectopic Expression of Axl Induces EMT and Promotes the Invasion and Proliferation of GC Cells

Then, we investigated the effect of Axl on the invasion and proliferation of GC cells. RT-PCR and Western blot assays showed that the expression level of Axl was upregulated in BGC-823 and SGC-7901 cells after transfection with Axl overexpressing plasmid (Figure 2A and B). Then cell invasion and proliferation were examined. Since epithelial-mesenchymal transition (EMT) is crucially implicated in tumor invasion and metastasis,[24] we first determined the effect of Axl on EMT in GC cells. We found that ectopic expression of Axl downregulated the expression of epithelial marker E-cadherin, while upregulated the expression of mesenchymal marker vimentin in BGC-823 and SGC-7901 cells (Figure 2B and C). Then, Transwell invasion assay was performed to evaluate the effect of Axl on GC cell invasion. We found that the number of invaded GC cell was increased by 1.5- to 2-fold after transfection with Axl overexpressing plasmid compared with vector (Figure 2D). In addition, we also detected the effect of Axl on proliferation by CCK-8 and EdU cell proliferation assays. When compared with cells transfected with vector, the overexpression of Axl significantly enhanced GC cell proliferation, as indicated by the significantly increased number of EdU-positive GC cells (Figure 2E). CCK-8 assay also revealed that overexpressed Axl dramatically promoted the proliferation rate of GC cells from 24 to 96 h (Figure 2F). Taken together, our results indicate that ectopic expression of Axl induces EMT and promotes the invasion and proliferation of GC cells.

Silencing Axl Blocks EMT and Inhibits the Invasion and Proliferation of GC Cells

We next explored the effect of Axl knockdown on GC cell EMT, invasion, and proliferation. We found that Axl

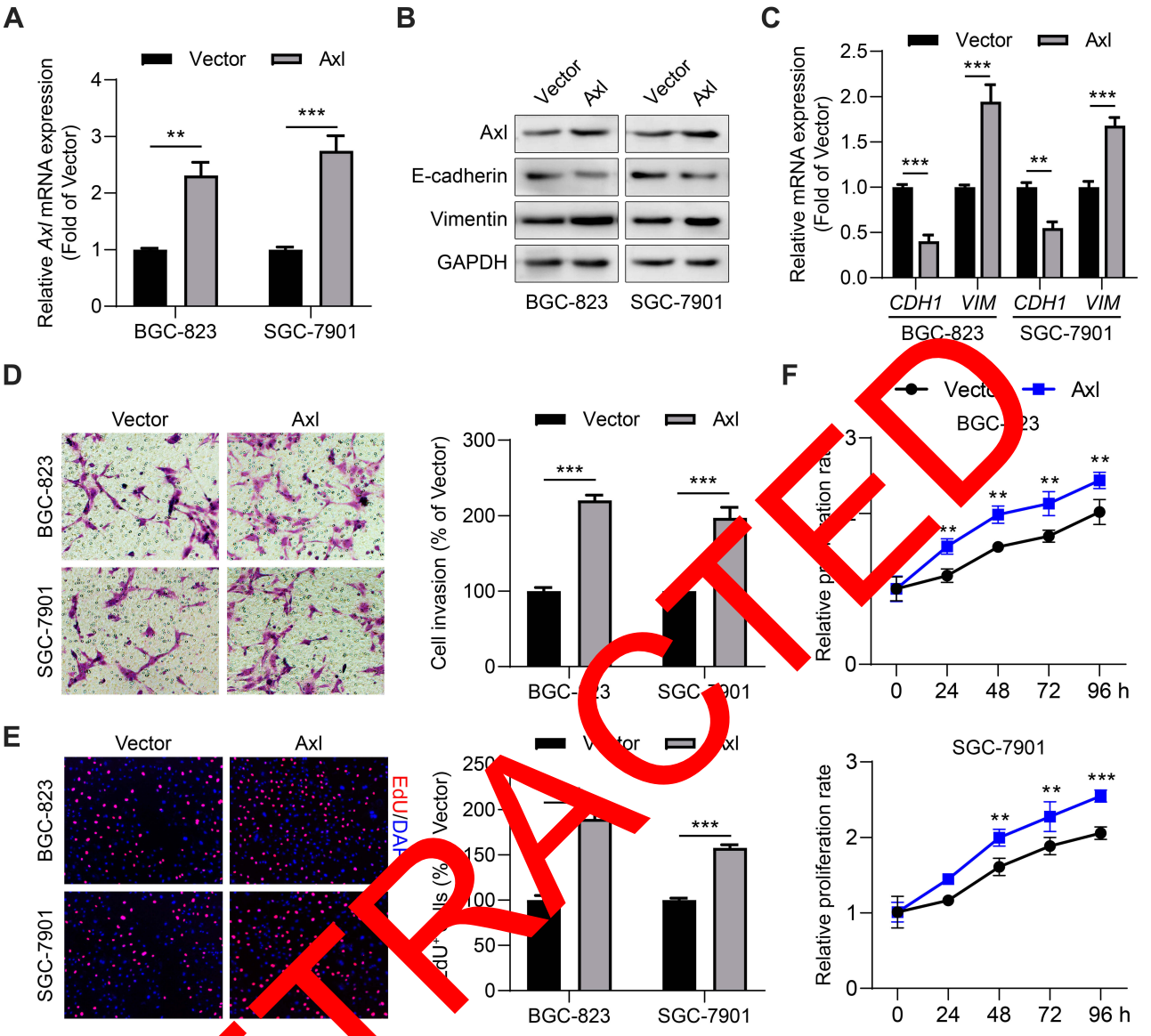

Figure 2 Axl overexpression induces EMT and promotes the invasion and proliferation of GC cells. BGC-823 and SGC-7901 cells were transfected with Axl overexpressing plasmid. (**A**) The expression of *Axl* mRNA in GC cells was determined RT-PCR assay. (**B**) The expression of Axl, E-cadherin, and vimentin in GC cells were measured by Western blot assay. Representative blots are shown and GAPDH serve as a loading control. (**C**) The mRNA expression of E-cadherin (*CDH1*) and vimentin (*VIM*) expression levels were examined by RT-PCR assay. (**D**) Transwell invasion assay was used to detect cell invasion capacities. Representative images and quantification of invaded cells are shown. Scar bar, 200 μm. (**E**) EdU cell proliferation assay and (**F**) CCK-8 assay were performed to examine GC cell proliferation. Representative images and quantification of EdU-positive cells are shown. Scar bar, 100 μm. Data are shown as mean ± SEM, n = 3. $^{**}P < 0.01$ and $^{***}P < 0.001$ compared with the vector groups.

specific siRNA significantly downregulated the expression of Axl in GC cells including BGC-823 and SGC-7901 cells (Figure 3A and B). Western blot and RT-PCR assays showed that the knockdown of Axl dramatically upregulated E-cadherin expression, while downregulated the expression of vimentin in GC cells (Figure 3B and C). Moreover, silencing Axl significantly reduced the invasion capacities of GC cells and decreased the number of invaded GC cells (Figure 3D). We also found that silencing Axl decreased the number of EdU-positive GC cells (Figure 3E). Also, CCK8 assay showed that Axl siRNA significantly attenuated the proliferation rate of BGC-823 and SGC-7901 cells (Figure 3F). Collectively, our data demonstrate that the knockdown of Axl impairs EMT and inhibits the invasion and proliferation of GC cells.

Axl Regulates ZEB1 Expression in GC Cells

Then, we investigated the mechanisms of Axl-mediated EMT, invasion and proliferation in GC cells. It has been reported that multiple transcription factors are closely related to EMT and tumor invasion,[24,25] then we further determined which transcription factor was responsible for Axl-induced GC

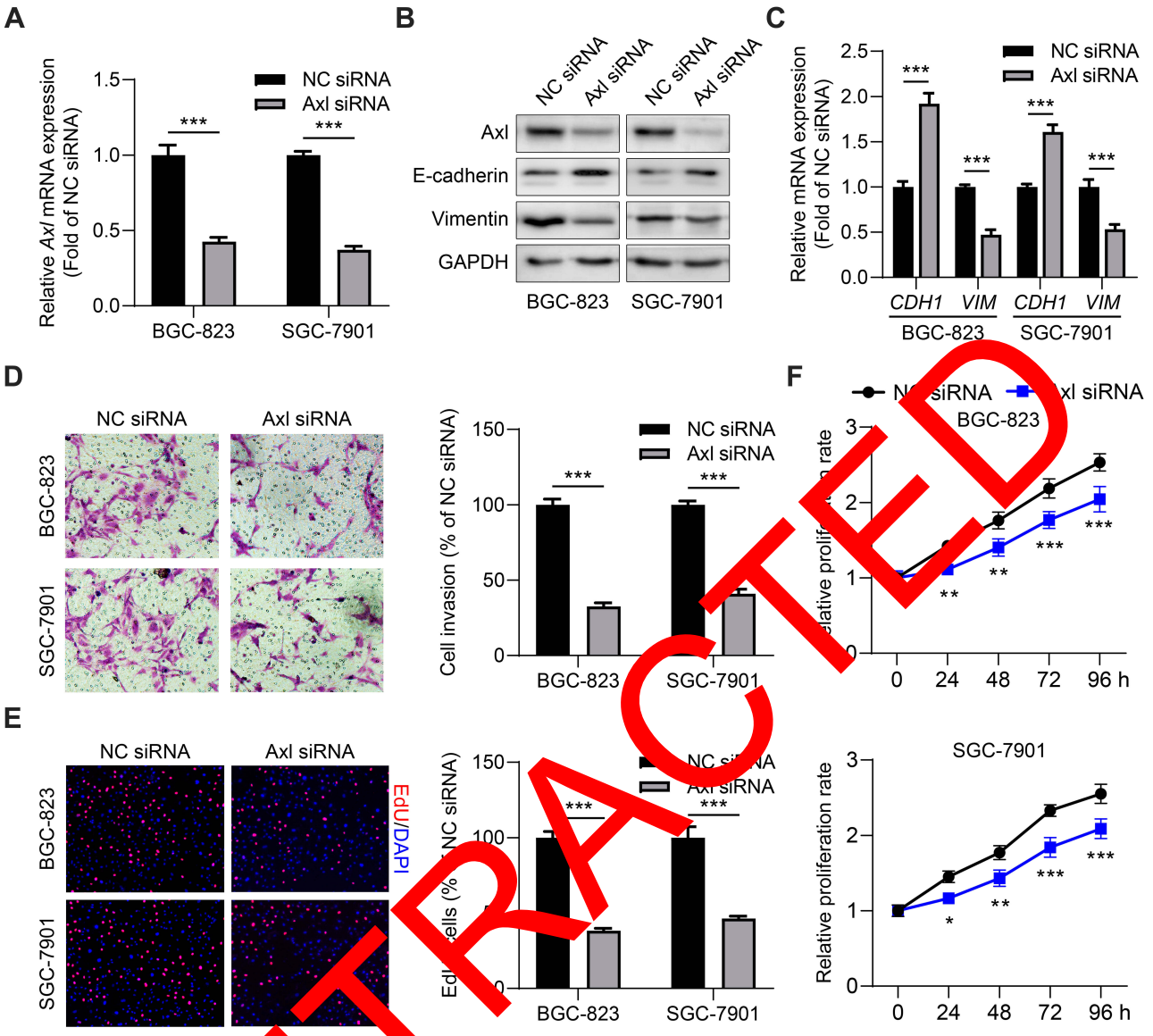

Figure 3 Silencing Axl inhibits EMT and suppresses the invasion and proliferation of GC cells. BGC-823 and SGC-7901 cells were transfected with Axl specific siRNA. (**A**) The expression of Axl in cells was determined by RT-PCR assay. (**B**) The expression of Axl, E-cadherin, and vimentin in GC cells were detected by Western blot assay. Representative blots are shown and GAPDH serve as a loading control. (**C**) RT-PCR assay for the expression of *CDH1* and *VIM* expression levels in GC cells. (**D**) The invasion of GC cells was detected by transwell invasion assay. Representative images and quantification of invaded cells are shown. Scar bar, 200 μm. (**E** and **F**) The proliferation of GC cells was examined by (**E**) EdU incorporation proliferation assay and (**F**) CCK-8 assay. Scar bar, 100 μm. Representative images and quantification of EdU-positive cells are shown. Data are shown as mean ± SEM, n = 3. *$P < 0.05$, **$P < 0.01$, and ***$P < 0.001$ compared with the NC siRNA groups.

progression. We found that Gas6 expression was positively associated with ZEB1 expression in GC tissues (Figure 4A. R = 0.41, $P < 0.001$). There was also a significantly positive correlation between Axl expression and ZEB1 level in GC (Figure 4B. R = 0.56, $P < 0.001$). Of note, high level of ZEB1 was related to decreased OS in patients with GC (Figure 4C. HR = 1.54, $P < 0.001$). Then, we detected the expression of ZEB1 in GES-1 cells and GC cell lines. RT-PCR assay showed that the expression of ZEB1 was much higher in four GC cells than GES-1 cells (Figure 4D). We further examined whether Axl regulated the expression of ZEB1 in GC cells. As shown in Figure 2A and B, GC cells transfected with Axl overexpressing plasmid revealed dramatical increases in Axl expression. And consistent with the correlation analyses in database, ectopic expression of Axl dramatically promoted *ZEB1* mRNA expression in BGC-823 cells (Figure 4E). Axl overexpression also upregulated the protein level of ZEB1 in GC cells (Figure 4F). In contrast, Axl siRNA significantly downregulated the expression of Axl in GC cells (Figure 3A and B) and also dramatically reduced the mRNA and protein levels of ZEB1 in GC cells (Figure 4G and H). Taken together, these results indicate that ZEB1 expression in GC cells is regulated by Axl.

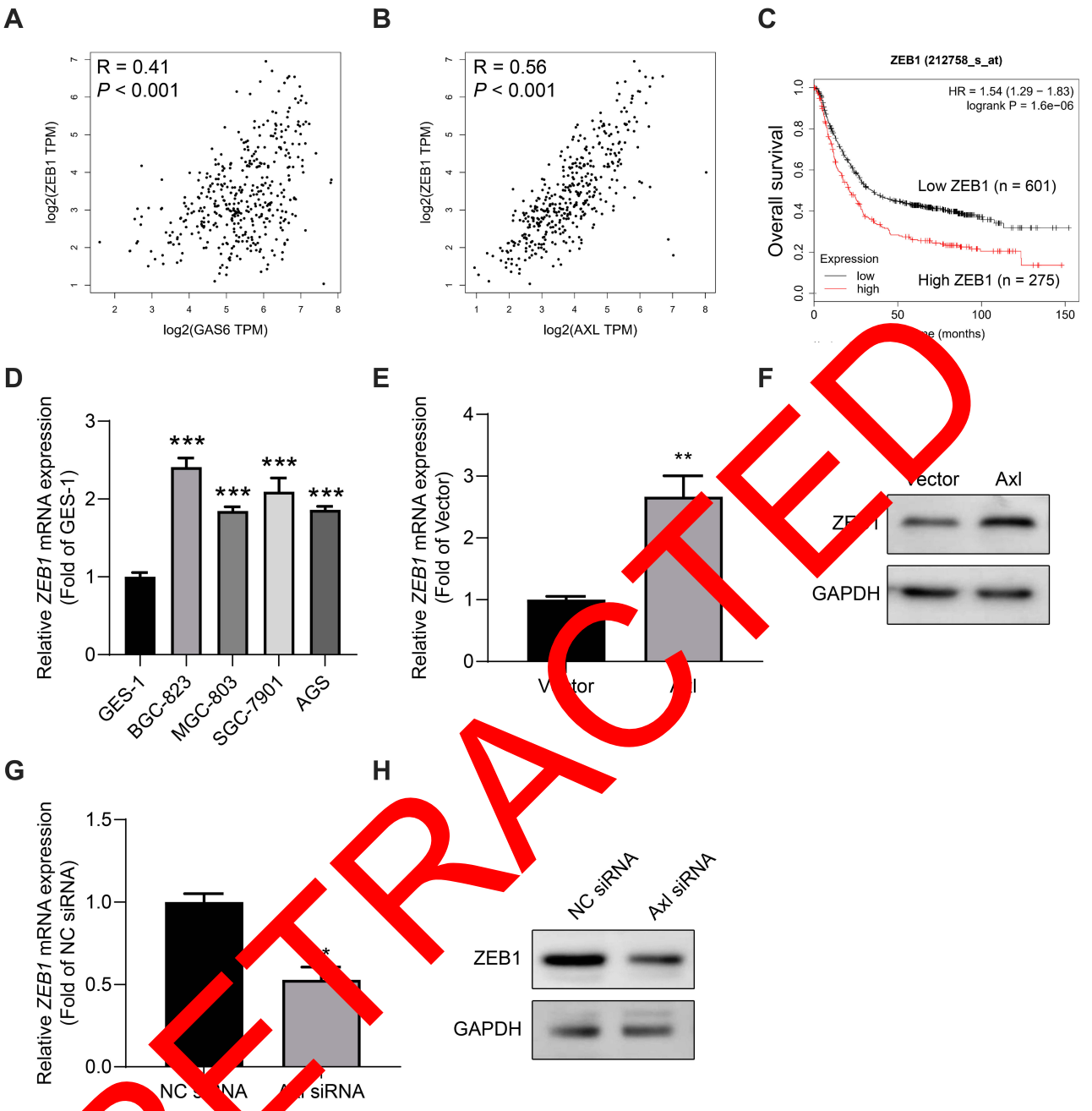

Figure 4 Axl regulates ZEB1 expression in GC tissues and cell lines. (**A** and **B**) Pearson correlation analysis of ZEB1 expression between (**A**) Gas6 or (**B**) Axl level in GC by using GEPIA database. (**C**) Kaplan–Meier analysis of the correlation between ZEB1 expression and OS in GC patients. (**D**) The expression of ZEB1 in human normal gastric epithelial GES-1 cell and four GC cells were determined by RT-PCR assay. (**E** and **F**) Axl overexpression upregulated the mRNA and protein levels in MGC-823 cells. (**G** and **H**) Silencing Axl inhibited the expression of ZEB1 in MGC-823 cells. Data are shown as mean ± SEM, n = 3. $^{**}P < 0.01$, $^{***}P < 0.001$.

The Knockdown of ZEB1 Suppresses EMT and Reduces the Invasion and Proliferation Capacities of GC Cells

Next, to further detect the effect of ZEB1 on EMT, invasion and proliferation in GC cells, ZEB1 specific siRNA was used. We found that ZEB1 siRNA significantly downregulated the expression of ZEB1 mRNA in BGC-823 and SGC-7901 cells (Figure 5A and B). Western blot and RT-PCR assays showed that the knockdown of ZEB1 increased the mRNA and protein level of E-cadherin and reduced vimentin expression in GC cells (Figure 5B and C). Then the effect of ZEB1 on GC cell invasion and proliferation was determined. Transwell invasion assay revealed that ZEB1 siRNA significantly decreased the number of invaded cells when compared with GC cells transfected with NC siRNA (Figure 5D). Moreover, the knockdown of ZEB1 also dramatically reduced the number

of EdU-positive GC cells including BGC-823 and SGC-7901 cells (Figure 5E). Together, our data suggest that ZEB1 siRNA suppresses EMT and decreased the invasion and proliferation capacities of GC cells.

Axl Inhibition Suppresses the Growth and Lung Metastasis of GC Cells

Then, to investigate whether the knockdown of Axl inhibited tumor growth and lung metastasis in vivo, tumor xenografts and lung metastasis models were established. BGC-823-shCTL or BGC-823-shAxl cell were subcutaneously or intravenously injected into Balb/c Nude mice. We found that the knockdown of Axl significantly inhibited the growth of SGC-7901 xenograft tumors (Figure 6A). We also found that the average weight of BGC-823-shAxl tumors was lower than BGC-823-shCTL tumors (Figure 6B). Furthermore, Axl inhibition also decreased the number of lung metastasis foci and blocked the lung metastasis of BGC-823 cells (Figure 6C). Taken together, our results indicate that blockage of Axl impairs the growth and lung metastasis of GC.

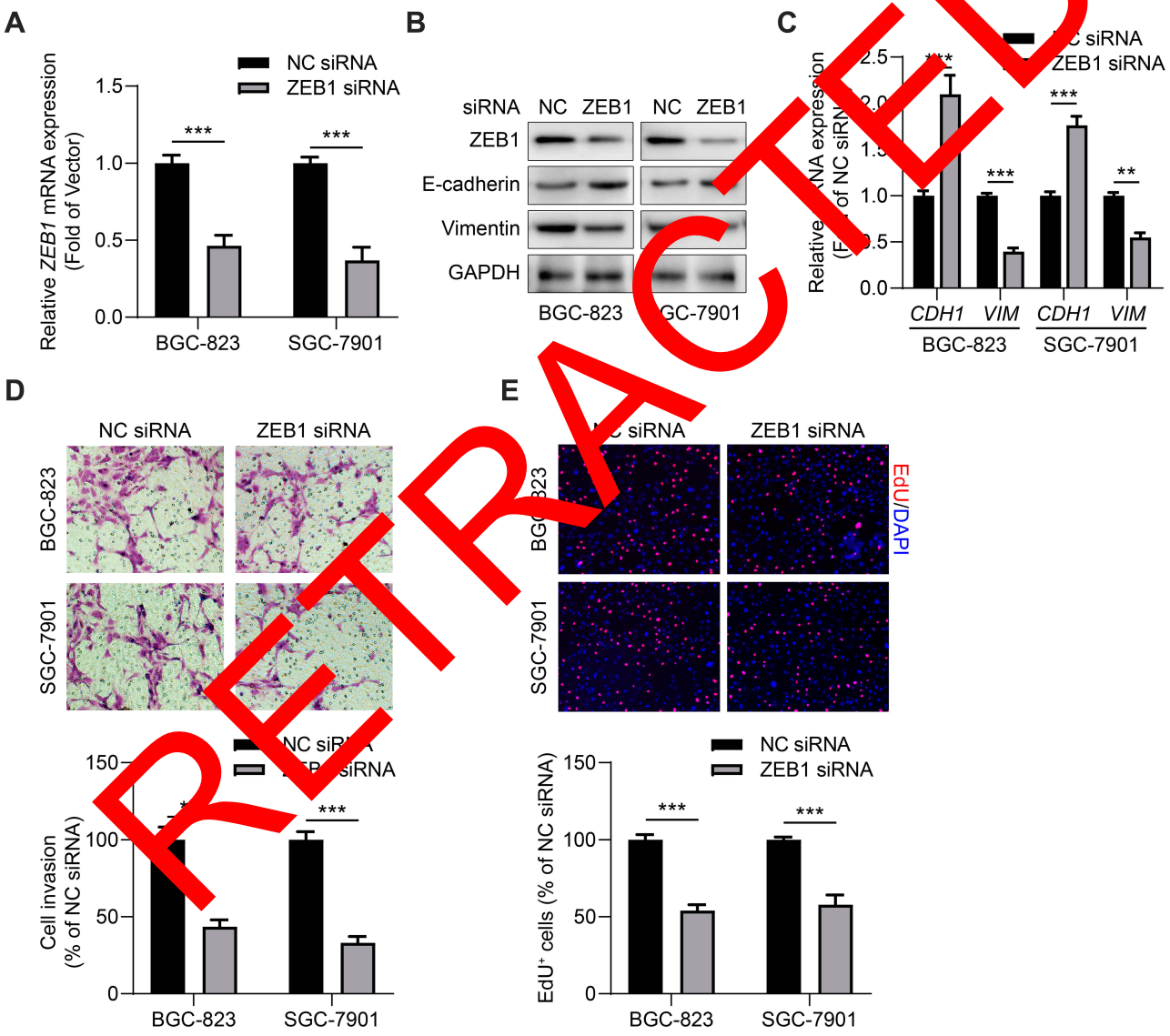

Figure 5 The knockdown of ZEB1 impairs EMT and blocks the invasion and proliferation in GC cells. BGC-823 and SGC7901 cells were transfected with ZEB1 specific siRNA. (**A**) RT-PCR assay was used to examine ZEB1 level in GC cells. (**B**) The expression of ZEB1, E-cadherin and vimentin in GC cells were detected by Western blot assay. Representative blots are shown and GAPDH serve as a loading control. (**C**) *CDH1* and *VIM* expression levels in GC cells were determined by RT-PCR assay. (**D**) Transwell invasion assay was performed to detect GC cell invasion. Representative images and quantification of invaded cells are shown. Scar bar, 200 μm. (**E**) Cell proliferation was examined by EdU cell proliferation assay. Representative images and quantification of EdU-positive cells are shown. Scar bar, 100 μm. Data are shown as mean ± SEM, n = 3. $^{**}P < 0.01$, and $^{***}P < 0.001$ compared with the NC siRNA groups.

Discussion

In the present study, we found that the Gas6/Axl/ZEB1 signaling pathway was upregulated in GC lines and overexpressed Gas6, Axl, and ZEB1 predicted poor OS in patients with GC. The overexpression of Axl induced EMT and promoted the invasion and proliferation of GC cells, while silencing Axl exhibited the opposite effects and inhibited tumor growth and lung metastasis. Mechanistic investigations revealed that the Gas6/Axl pathway upregulated ZEB1 expression and conferred EMT, invasion, and proliferation in GC cells.

The overexpression of Axl has been reported in many types of cancer[18,19,21,26] and Gas6 overexpression was an important mechanism for the activation of the Gas6/Axl pathway.[27,28] However, in chronic lymphocytic leukemia, Axl constitutive activation was not due to Gas6 overexpression, where Axl can be phosphorylated in a ligand-independent way.[29] In our study, we found that the expression of Gas6 and Axl were higher in GC cells than normal gastric epithelial cells by Western blot and RT-PCR assays. We also observed that the phosphorylated levels of Axl were increased in GC cells. Our study indicated that Axl activation and the increases in invasion and proliferation might be triggered by autocrine Gas6 in GC cells.

Several studies have reported that the Gas6/Axl pathway promoted the invasion and proliferation in GC cells, but the molecular mechanisms remain elusive. Of note, the Gas6/Axl axis enhanced survival and invasion and decreased apoptosis in GC cells via activati[illegible]athway.[23] One of the important mechanisms of [illegible]mor invas[illegible]n is EMT.[30–32] Whether Axl/Akt-induced inva[illegible]n in GC c[illegible]ls was due to EMT was unknown. V[illegible]ous signa[illegible]g path[illegible]ays are proved to regulate tumor c[illegible] EMT, s[illegible]n as TG[illegible]β/Smad[33] and Wnt/β-catenin.[34] EMT is [illegible]ar[illegible]terized a[illegible] the downregulation in epithelial m[illegible]kers includ[illegible]g E-c[illegible]dherin and ZO-1, but the upregula[illegible]on i[illegible]esenchyma[illegible]markers, such as vimentin and

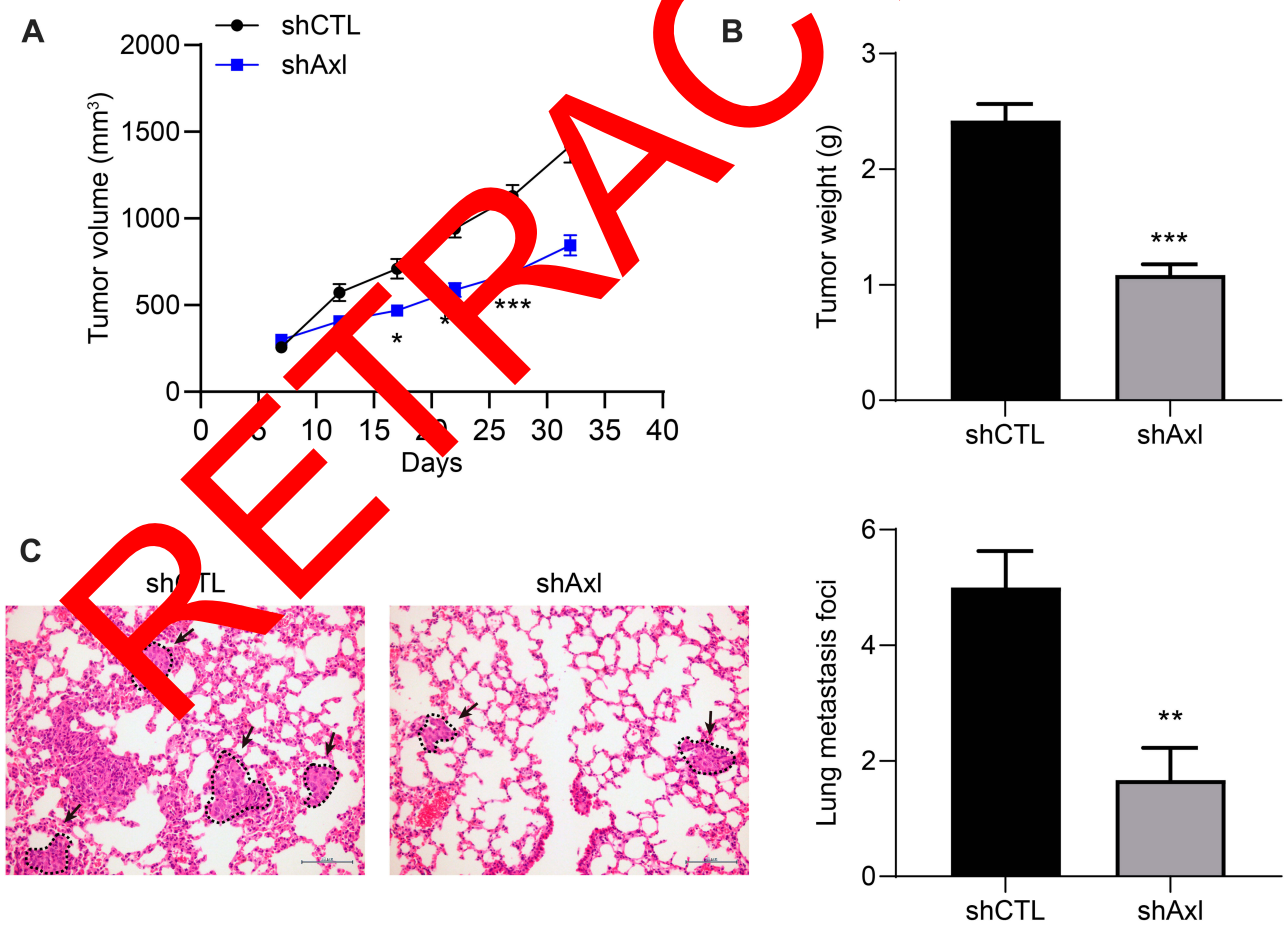

Figure 6 Axl knockdown inhibits the growth and lung metastasis of GC cells. (**A** and **B**) Tumor volume and tumor weight of BGC-823-shCTL and BGC-823-shAxl. (**C**) Lung tissues were obtained from mice after tail vein injection of BGC-823-shCTL or BGC-823-shAxl cells, followed by H&E staining assay. Black arrows indicate lung metastasis foci. Scar bar, 50 μm. Data are shown as mean ± SEM, n = 6. *$P < 0.05$, **$P < 0.01$, and ***$P < 0.001$ compared with the shCTL groups.

N-cadherin.[25,35] In addition, some transcription factors are also critically associated with EMT, such as ZEB1, TWIST1, and Slug.[35] Previous studies revealed that Axl activation upregulated Slug expression and promoted the invasion capacities of hepatocellular carcinoma cells.[13] The Gas6/Axl pathway was also reported to promote breast cancer metastasis and chemoresistance via the Akt/GSK-3β/β-catenin pathway.[10] However, the role of ZEB1 in Axl-mediated invasion and proliferation was unknown. Herein, we found that Axl positively regulated the expression of ZEB1 in GC cell lines. The knockdown of Axl suppressed EMT, invasion, and proliferation in GC cells through down-regulating ZEB1 expression. Our results provided a deeper insight into Gas6/Axl/ZEB1 axis in GC progression.

In addition to invasion, Axl pathway can regulate chemoresistance in tumor cells, such as breast cancer,[10] thyroid cancer,[36] and uterine serous cancer.[21] Axl-induced EMT or upregulation in ATP-binding cassette B1 can lead to the decreased chemosensitivity in cancer cells.[12,20,21] In GC, chemotherapeutic drugs are commonly applied in clinic, such as 5-Fu, platinum, and docetaxel. However, patients frequently developed drug resistance and consequently resulted in poor survival benefits. Thus, the effect of Axl in orchestrating GC resistance to chemotherapeutic drugs could be further investigated. Moreover, we only analyzed the relationship between Gas6/Axl/ZEB1 axis and OS in GC patients by using Kaplan-Meier plotter database and found that high levels of Gas6, Axl or ZEB1 expression were negatively correlated with OS in patients with GC. It has been reported that the expression and role of some genes were discrepant in different Lauren subtypes of GC including intestinal GC and diffuse GC, which was associated with cancer progression.[37,38] Besides Lauren subtypes, other clinicopathological parameters, such as age, gender and TNM stages might also be relevant to OS and Gas6/Axl/ZEB1 pathway in GC. Therefore, we could further investigate the relationship between Gas6/Axl/ZEB1 pathway and these clinicopathological parameters by multivariate Cox regression analysis.

Conclusions

In conclusion, our study suggested an important role of the Gas6/Axl axis in GC EMT, invasion, and proliferation via upregulating ZEB1 expression. Moreover, our data also indicated that targeting Gas6/Axl/ZEB1 pathway could be a promising therapeutic strategy for GC patients.

Abbreviations

GC, gastric cancer; OS, overall survival; EMT, epithelial-mesenchymal transition; RTKs, receptor tyrosine kinases; siRNA, small interfering RNA; shRNA, short hairpin RNA.

Author Contributions

Lirui He, Yunpeng Lei, Jianing Hou, Jianlong Wu, and Guoqing Lv contributed to conception and design, acquisition of data, or analysis and interpretation of data. Lirui He, Yunpeng Lei, and Jianlong Wu drafted and wrote the manuscript, which was edited and revised by Jianing Hou and Guoqing Lv. Each author made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; gave final approval of the version to be published; and agree to be accountable for all aspects of the work.

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Disclosure

The authors declare that they have no competing interests.

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