

RETRACTED ARTICLE: Resveratrol Reverses Cigarette Smoke-Induced Urocytic Epithelial–Mesenchymal Transition via Suppression of STAT3 Phosphorylation in SV-HUC-1-Immortalized Human Urothelial Cells

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Purpose: Bladder cancer is a malignant tumor of the urinary tract and cigarette smoke (CS) is closely related to tumorigenesis. Resveratrol, a plant-derived bioactive nutrient, possesses multiple anticancer effects. However, the mechanism of CS-induced tumorigenesis is still not clear. The role of resveratrol in CS-mediated bladder cancer development has not been reported.

Methods: MTT assay showed the toxicity of cigarette smoke extract (CSE) on the cell viability of SV-HUC-1 cells. Western blotting detected the expression levels of related proteins. Transwell migration or invasion assay evaluated the capacity of cell migration or invasion after treatment. Wound healing assay revealed the effect of cell migratory capacity. The cell cycle was detected by flow cytometry.

Results: Our study demonstrated that CSE-triggered epithelial–mesenchymal transition (EMT) in SV-HUC-1 immortalized human urothelial cells via the STAT3/TWIST1 pathway. Furthermore, the results showed resveratrol effectively inhibited STAT3 phosphorylation, thus reversing EMT triggered by CSE. Meanwhile, the cell proliferation was also suppressed.

Conclusion: In conclusion, inhibition of the STAT3 in CSE-induced EMT on bladder cancer may be a promising cancer treatment target for suppression by resveratrol.

Keywords: bladder cancer, cigarette smoke, resveratrol, STAT3/TWIST1

Introduction

Urothelial carcinomas are the fifth most common tumors in western society.¹ It can be classified into the lower (bladder and urethra) or upper (pyelocaliceal cavities and ureter) urinary tract. Specifically, bladder cancer accounts for 90% of urothelial carcinomas and is the most common cancer of the urinary tract.² The International Agency for Research on Cancer (IARC) proclaimed that bladder cancer is the ninth most common cancer in the world, with 430,000 new cases and 165,000 deaths in 2012.³ Although the etiology of bladder cancer has not been elucidated, a large number of epidemiological studies abroad have confirmed that cigarette smoke (CS) increases the incidence of bladder cancer, with the risk for smokers increasing approximately twofold to sixfold from that of nonsmokers.^{4,5} It is commonly reported that the incidence of bladder cancer in men is much higher than that in women, which is strongly associated with CS.⁶ There are more than 60 established carcinogens, which have been classified into five major groups: polycyclic aromatic hydrocarbons (PAH), nicotine-derived nitrosamines, azaarenes, miscellaneous

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organic compounds, and inorganic compounds. Various molecular mechanisms have been proposed for CS-induced carcinogenesis, but the underlying mechanisms of smoking leading to bladder cancer development are still not well understood.

Signal transducer and activator of transcription 3 (STAT3) is considered to be an oncogene and plays a necessary role in cancer cell metastasis, recurrence, progression, and angiogenesis.⁷ In response to cytokines or environmental factors, STAT3 phosphorylates and leads to the activation of downstream signaling molecules, such as PCNA and C-MYC, improving cell proliferation, invasion, and metastasis. STAT3 can enhance the expression of matrix metalloproteinases (MMPs) that are responsible for the degradation of the basement membrane and extracellular matrix (ECM) in cancer invasion and metastasis.⁸

Epithelial–mesenchymal transition (EMT) is a fundamental process by which cells change from epithelial-like state to a more mesenchymal-like phenotype. Thus, epithelial cells lose cell junction and gain the ability to invade and metastasize. Increasing evidence has shown that EMT is closely related to tumor invasion and metastasis and is involved in the initiation of tumorigenesis.^{9–11}

A variety of cytokines or environmental factors can promote the occurrence of EMT. Studies have reported that cigarette smoke is associated with the development of EMT in bladder epithelial cells.¹² However, the specific mechanism of cigarette-induced EMT and the effective measures to prevent EMT are still unclear. Our study further explored the molecular mechanism of cigarette-induced EMT and sought effective drugs to inhibit its occurrence.

Resveratrol, a natural polyphenol compound found in grapes, peanuts, and nuts, is widely recognized as an antioxidant. Resveratrol has various pharmacological effects including anti-inflammatory and antioxidant activities, along with inhibiting cancer growth and invasion.¹³ In ovarian cancer, resveratrol inhibits cell survival in a time-dose-dependent manner and is less toxic to normal cells.¹⁴ A large number of studies have shown that resveratrol inhibits the initiation and progression of various tumors including breast cancer, prostate cancer, ovarian cancer, liver cancer, and lung cancer.^{15,16} As a plant extract, clinical studies showed that resveratrol consumed at 5 g per day for 14 days in colon cancer patients with liver metastasis had no obvious side effects. In healthy people, 4 g a day of resveratrol for 14 days is tolerable.¹⁷ This study is the first to explore the role and potential molecular mechanism of resveratrol in CS-induced EMT in urinary epithelial cells.

Materials and Methods

Cell Culture and Treatments

Human normal bladder cell line (SV-HUC-1) was obtained from the Chinese Academy of Typical Culture Collection Cell Bank (Shanghai, China). The SV-HUC-1 was cultured in F12K supplemented with 10% fetal bovine serum (FBS) and 1% of penicillin/streptomycin at 37 °C in humidified air containing 5% CO₂. CSE was prepared daily according to the reported method. A cigarette was smoked by a vacuum at the rate of 5 mins/cigarette, mainstream smoke was drawn through 10 mL of pre-warmed (37°C) FBS-free F12K medium. Then, CSE stock solution was adjusted to pH 7.4 and was filtered through a 0.22- μ m pore size filter. The cell was treated with various concentrations of CS extract (CSE) when it reached 80–90% confluence.

Antibodies and Reagents

F12K medium was obtained from the Gibco. 3-(4,5-Dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) was purchased from Sigma-Aldrich. Resveratrol (Res) was purchased from Sigma and statin was obtained from Selleck. They were dissolved in DMSO to form a stock solution. STAT3, phosphorylated STAT3, E-Cadherin, N-Cadherin, Vimentin, PCNA, and C-MYC were obtained from Cell Signaling Technology. The antibody for ZO-1 was obtained from Santa Cruz Biotechnology. The TWIST1 antibody was purchased from ABclonal. The GAPDH antibody was obtained from Biogot Technology used at the dilution of 1:1000.

Cell Viability Assay

To assess the toxicity of various concentrations of CSE to the SV-HUC-1, MTT was preformed using a cell counting kit according to the manufacturer's instructions. Cells were seeded in 96-well plates (2000 cells/well) and cultured for 24hrs, and then exposed to all kinds of concentrations of CSE (0, 0.1, 0.25, 0.5, 0.75, 1, and 2) for 5 days. Absorbance was measured at 490 nm using a microplate reader (Tecan, Switzerland).

Wound-Healing Assay

Cells were cultured in 24-well plates to 80% confluence. Using a pipette tip to create a uniform wound. And then the cells were incubated with serum-free medium (SFM). The images of the wound area closure were taken under inverted microscope (Nikon, Japan). The open space was calculated to evaluate the migratory ability.

Transwell Invasion and Migration Assay

Twenty-four-well matrigel-coated Transwell invasion assay was used to assess the invasion capability of cells. Briefly, cells (2.5×10^5 cells) were suspended in the upper chamber with 200 μ L of SFM while the lower chamber was filled with 500 μ L of medium supplemented with 15% FBS. After incubation at 37 °C for 48 hrs, cells were removed from the upper chamber with cotton swabs. Cells on the lower membrane surface were fixed using 4% paraformaldehyde for 20 mins followed by staining with 0.1% crystal violet for 15 mins. Randomly selected 5 fields were counted under bright field microscopy (Nikon, Japan).

Western Blots Analysis

The cells were cultured in 6-well plates treated with CSE or Res. Cells were harvested and lysed in RIPA buffer containing a cocktail of phosphatase and protease inhibitors. Concentrations of the precipitated proteins were quantified using the BCA protein assay. The proteins were diluted to equal concentrations and boiled for 5 mins. Equal amounts of protein were separated by 8–12% SDS-PAGE and transferred to NC membranes. Membranes were blocked with 5% nonfat milk for 1 h and then washed three times with 1X TTBS, followed by incubation overnight at 4°C with the primary antibodies. The membranes were then incubated with HRP conjugated secondary antibodies for 1 h at room temperature.

RNA Extraction and Quantitative Reverse Transcription-Polymerase Chain Reaction (qRT-PCR)

Total RNA from the cell was isolated by TRIzol reagent, and reverse transcription was performed according to the manufacturer's protocols. A total of 1 μ g total RNA reverse transcribed into cDNA was used for PCR with the Power SYBR Green Master Mix (Applied Biosystems, Foster City, CA, USA) and an LC96 real-time PCR detection system (Roche, Biosystems). GAPDH was used as an internal control for sample normalization. The primer sequences were:

E-Cadherin, forward, 5'-TCGACACCCGATTCAAAG TGG-3' and reverse, 5'-TTCCAGAAACGGAGGCCTG AT-3';

ZO-1, forward, 5'-GCAGCCACAACCAATTCATAG -3' and reverse, 5'-GCAGACGATGTTTCATAG TTTC-3';

Vimentin, forward, 5'-CCTTGACATTGAGATTGCCA -3' and reverse, 5'-GTATCAACCAGAGGGAGTGA -3';

N-Cadherin forward, 5'-ATCAAGTGCCATTAGCC AAG-3' and reverse, 5'-CTGAGCAGTGAATGTTGTC A-3';

GAPDH, forward, 5'-GCTGCCCAACGCACCGAATA -3' and reverse, 5'-GAGTCAACGGATTTGGTCGT-3'.

The PCR cycle conditions were as follows: 95 °C for 15 mins, 94 °C for 60 s, 58 °C for 30 s, and 72 °C for 60 s, for a total of 40 thermal cycles. Each experiment was repeated in triplicate. Fold change of gene expression was calculated based on Ct values.

Cell Cycle Analysis

The cells were treated with CSE or Res, collected, and fixed in ethanol at 4°C. Cells were washed twice and resuspended in PBS and treated with propidium iodide (Invitrogen), 0.1% Triton X-100 (Invitrogen), and RNase (Invitrogen) in the dark for 1 h. Flow cytometry analyzed the DNA content in different phases.

Statistical Analysis

All experiments were independently performed at least three times. Statistical analysis was performed using SPSS 16.0. Data were presented as mean \pm standard deviation. Shapiro–Wilk test was used to test whether it obeys normal distribution, followed by the Man–Whitney *U*-test. Unpaired Student's *t*-test was also used for the comparison between the two groups. Statistical significance was set at $p < 0.05$ (* or #) or $p < 0.01$ (** or ##).

Results

CSE Induces EMT in SV-HUC-1 Cells

CS is a major cause of bladder cancer. Our results showed that cells exposed to 1% or higher CSE concentrations were significantly reduced compared to those in the control group (Figure 1A). Therefore, we selected 0.25% and 0.5% CSE for the following experiments. As shown in results, in the absence of CSE, SV-HUC-1 cells maintained a classic epithelial morphology. However, SV-HUC-1 cells acquired spindle and fibroblastoid shapes with increased cell gaps following CSE treatment for 5 days (Figure 1B). Additionally, the protein expression of E-Cadherin and ZO-1 of the epithelial markers were progressively decreased as the CSE concentration increased. Whereas conversely, N-Cadherin and Vimentin of mesenchymal markers expression were increased (Figure 2A). Meanwhile, qRT-PCR of mRNA levels of epithelial and mesenchymal markers showed similar changes (Figure 2B). As the CSE

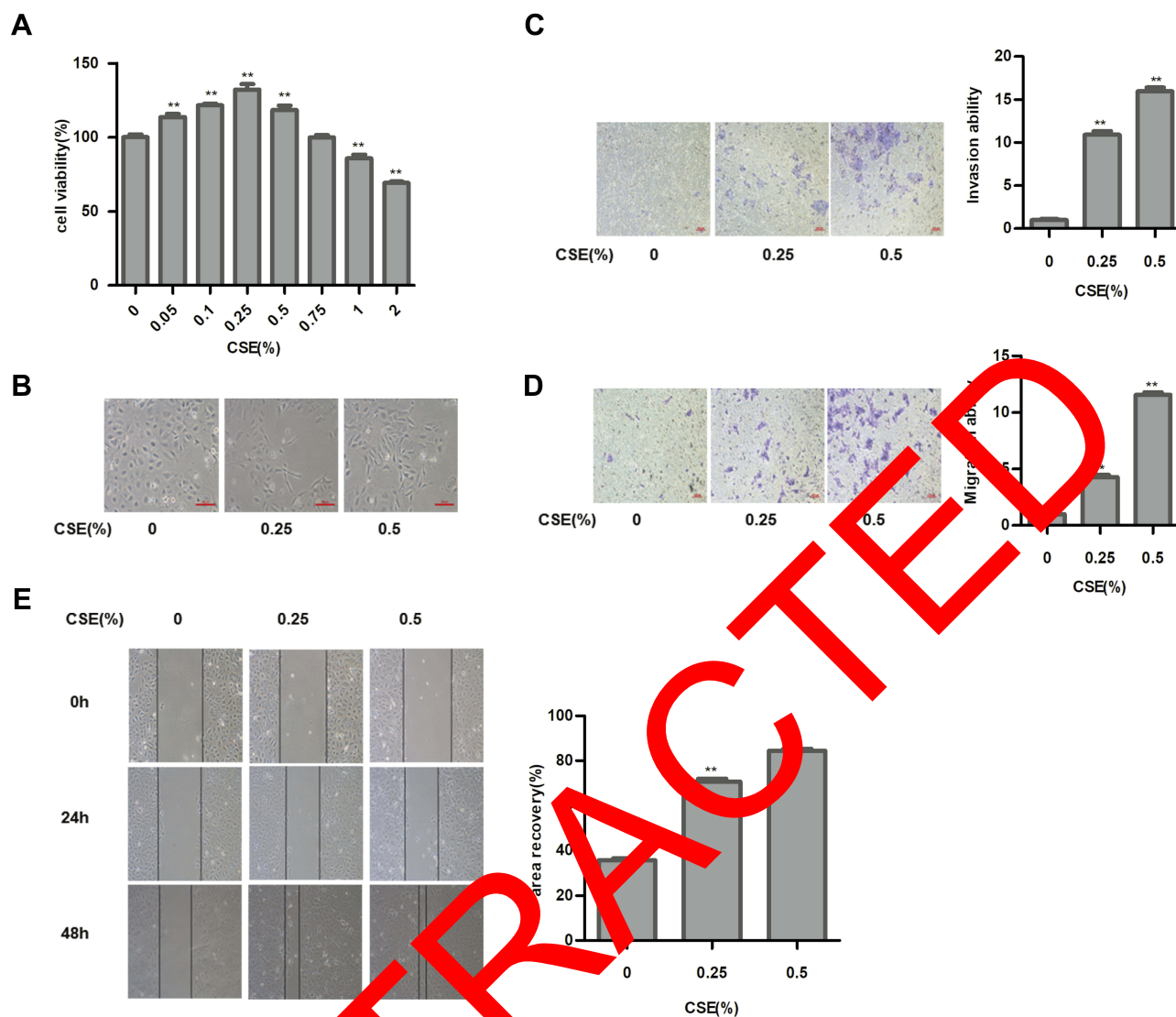


Figure 1 Cigarette smoke extract (CSE) exposure induces epithelial-mesenchymal transition (EMT) in SV-HUC-1 cells. **(A)** MTT assay showed the toxicity of CSE on the cell viability of SV-HUC-1 cells. **(B)** Images of the cell morphology indicated the morphological change following CSE treatment. **(C)** Cell invasion capacity was shown by the results of the transwell invasion assay. **(D)** Transwell migration assay indicated the migratory capacity of the SV-HUC-1 cells. **(E)** Wound-healing assay revealed the effect of CSE on cell migratory capacity. Data are expressed as mean \pm SD. The values of P show a statistical level of significance. ** $P < 0.01$, indicates a statistical level of significance when data were compared against the control group.

concentration increased, the migration and invasion of SV-HUC-1 cells also increased in a concentration-dependent manner (Figure 1C-E). These results strongly suggest that CSE induced the EMT and invasiveness in SV-HUC-1 cells.

STAT3 Phosphorylation Is Required for CSE-Induced EMT in SV-HUC-1

STAT3 is certainly the most eminent among cancers and plays a vital role in regulating EMT during tumor progression. As a result, CSE treatment stimulated the expression of p-STAT3. Meanwhile, CSE markedly increased TWIST1 expression (Figure 2C). So CSE-induced EMT

is associated with STAT3 activation in SV-HUC-1 cells. And then Western blot assay, as expected, illustrated that statin could significantly depress the phosphorylation of STAT3, while total STAT3 was almost intact. In addition, TWIST1 expression was also abolished simultaneously (Figure 3E). More importantly, suppressing STAT3 expression significantly inhibited CSE-induced change in cell morphology toward a mesenchymal phenotype (Figure 3A). Moreover, statin, a STAT3 activation inhibitor, reversed CSE-induced EMT marker expression by blocking Vimentin and N-Cadherin expressions, restoring E-Cadherin expression (Figure 3F). Statin inhibited both

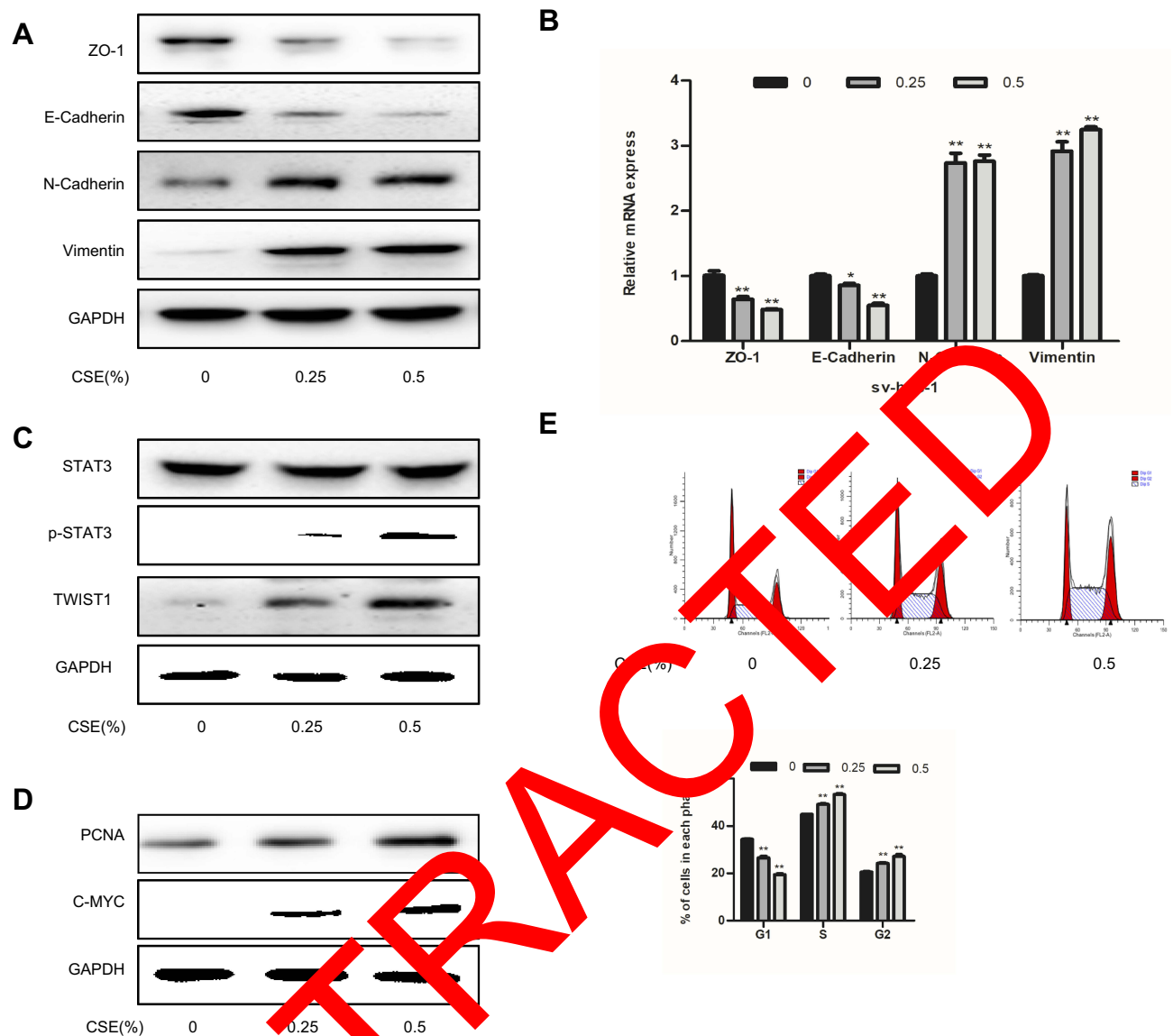


Figure 2 CSE exposure induces EMT in SV-HUC-1 cells. (A) Western blotting detected the protein expression of epithelial markers and mesenchymal markers. (B) The mRNA expression level of SV-HUC-1 cells following CSE treatment was measured by qRT-PCR. (C) Western blotting reveals the expression of STAT3 phosphorylation in the SV-HUC-1 cells following CSE treatment for 5 days. (D) The protein expression of cell proliferation protein was measured by Western blotting. (E) Cell cycle was detected by flow cytometry. Data are expressed as mean \pm SD. The values of * $P < 0.05$, ** $P < 0.01$ show a statistical level of significance when data were compared against the control group.

basal and CSE-stimulated cell migration and invasion (Figure 3B–E). These findings indicate that STAT3/TWIST1 signaling was required for CSE-induced migration and invasion.

Resveratrol Attenuates CSE-Induced EMT via Suppression of STAT3/TWIST1

To assess the cytotoxicity of resveratrol, immortalized human urothelial cells and bladder cancer cells were treated with different concentrations of resveratrol. MTT assay found that the viability of SV-HUC-1 cells was insensitive, the IC₅₀ value (IC₅₀=70.79 μ M) of Res was calculated

to evaluate the cytotoxicity of Res in bladder cancer cells (Figure 4A). Thus, resveratrol at 50 μ M was chosen for the subsequent experiments. Resveratrol reversed the cell morphology induced by CSE (Figure 4B). Meanwhile, the CSE-enhanced capacity of migration and invasion were weakened by resveratrol (Figure 4C–4E). The CSE-induced activity of STAT3/TWIST1 was inhibited by resveratrol (Figure 5A). Subsequently, Western blot analysis indicated that CSE-induced EMT was suppressed by resveratrol treatment. The protein level of E-Cadherin and ZO-1 was elevated, while Vimentin and N-Cadherin were markedly reduced after resveratrol treatment (Figure 5B). These results

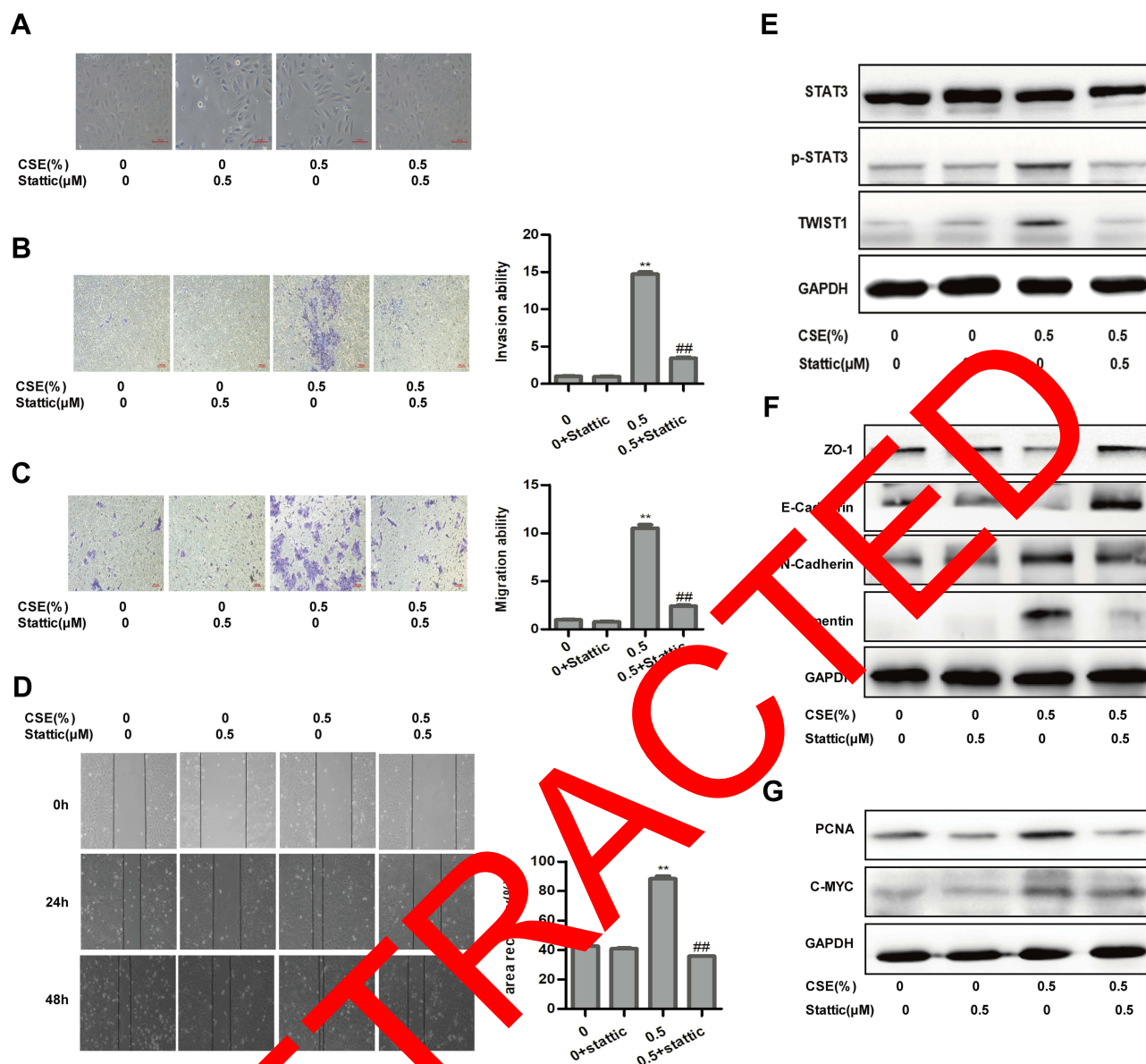


Figure 3 Inhibition of STAT3 attenuates CSE-induced EMT in SV-HUC-1. **(A)** Images of morphological alterations of SV-HUC-1. **(B)** Invasive capacity of inhibition of STAT3 detected by transwell invasion assay. **(C)** Migratory capacity of inhibition of STAT3 determined by transwell migration assay. **(D)** Stattic affected the migratory capacity of SV-HUC-1, as determined by the wound healing assay. **(E)** Western blotting showed the protein change of the STAT3 pathway. **(F)** The protein expression of epithelial markers and mesenchymal markers was displayed by Western blotting. **(G)** Western blotting detected the STAT3 downstream protein expression of SV-HUC-1. Data are expressed as mean \pm SD. The values of P show a statistical level of significance, ** or ## $P < 0.01$, comparison between the group of exposed 0.5% CSE and the control group or the group of exposed to 0.5% CSE add stattic.

demonstrated that resveratrol inhibited the STAT3 phosphorylation to reversed CSE-triggered SV-HUC-1 cell EMT.

STAT3/TWIST1 Activates PCNA/C-MYC to Promote Cell Proliferation and Is Suppressed by Resveratrol

We further explored the interventional influences of resveratrol on proliferation. The expression of the proliferation-related protein, such as PCNA and C-MYC, was

significantly increased compared to the non-smoking group (Figure 2D). Flow cytometry showed that the percent of cells, exposed to 0.25% and 0.5% cigarette concentrations, in the G2/M phase was higher compared to the control group (Figure 2E). The proteins of PCNA and C-MYC were inhibited by stattic (Figure 3G). Cells were treated with Res or DMSO for 48 hrs and then exposed to 0.25% and 0.5% cigarette concentrations for 5 days. The results showed that Res inhibited cell viability was associated with the suppression of STAT3 phosphorylation, as

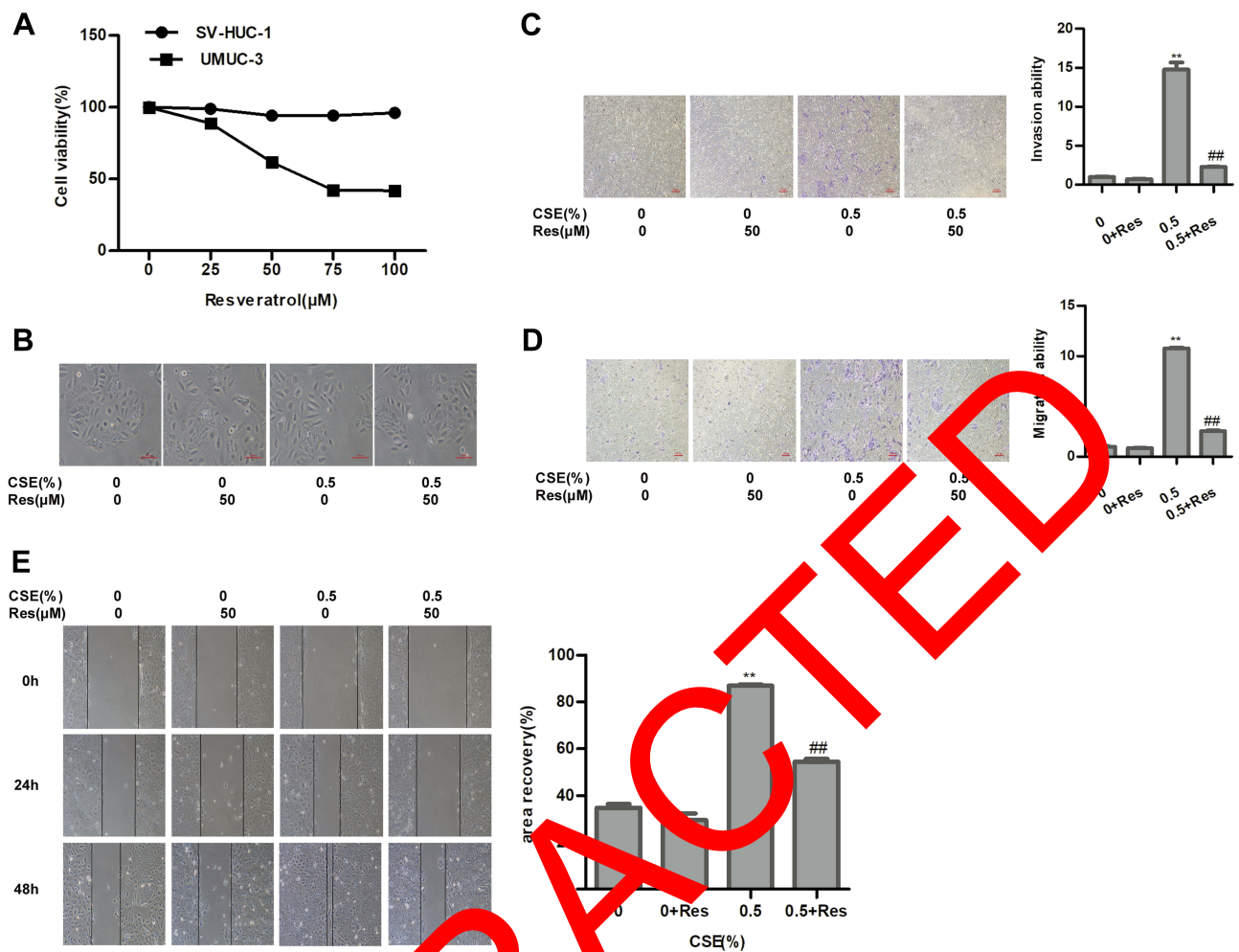


Figure 4 Resveratrol repairs CSE-induced SV-HUC-1 EMT via suppression of STAT3 phosphorylation. **(A)** MTT assay detected the viability of cell toxicity to SV-HUC-1 and bladder cancer cell UMUC-3 following resveratrol treatment. **(B)** Images of cell morphological change following resveratrol treatment. **(C)** Transwell invasion assay measured invasive capacity of SV-HUC-1. **(D)** Migratory capacity of SV-HUC-1 was detected by transwell migration assay. **(E)** Wound-healing assay demonstrated the effect of resveratrol on cell migratory capacity. Data are expressed as mean \pm SD. The values of P show a statistical level of significance, ** or ###P<0.01, comparison between the group of exposed 0.5% CSE and the control group or the group of exposed to 0.5% CSE add resveratrol.

well as subsequent downregulation of its downstream effector PCNA and C-MYC (Figure 5C). MTT assay showed that exposure to 0.5% CSE significantly accelerated the proliferation of cells, while resveratrol reduced CSE-induced proliferation (Figure 5D). Cells in the G2/M phase were suppressed by Res (Figure 5E). In conclusion, Res inhibited CSE-induced cell proliferation via suppression of the STAT3/TWIST1 signal pathway.

Discussion

Bladder cancer is the most common tumor of the urinary and reproductive systems in China and is the major malignant cancer causing human death.¹⁸ Cigarettes play an important role in the development of human cancers and are closely related to bladder cancer.¹⁹ This study explored

the effects of tobacco-induced epithelial–mesenchymal transformation in bladder cancer and explored the anti-cancer effects of resveratrol in cigarette-induced bladder cancer. Previous studies have found that cigarettes induced EMT in urinary tract epithelial cells, but the exact mechanism remained unclear.^{12,20} We further investigated the specific mechanism of cigarette-induced EMT in bladder cancer and studied the effect of the plant chemical resveratrol on cigarette-induced EMT in urinary tract epithelial cells. This effect was mediated by inhibiting STAT3 phosphorylation, which led to a suppression of the downstream target genes of STAT3, such as PCNA, cyclin D1, C-MYC, Bcl-XL, and Bcl2. Therefore, resveratrol can inhibit the proliferation, invasion, and metastasis of bladder cancer cells through the STAT3 signaling pathway.

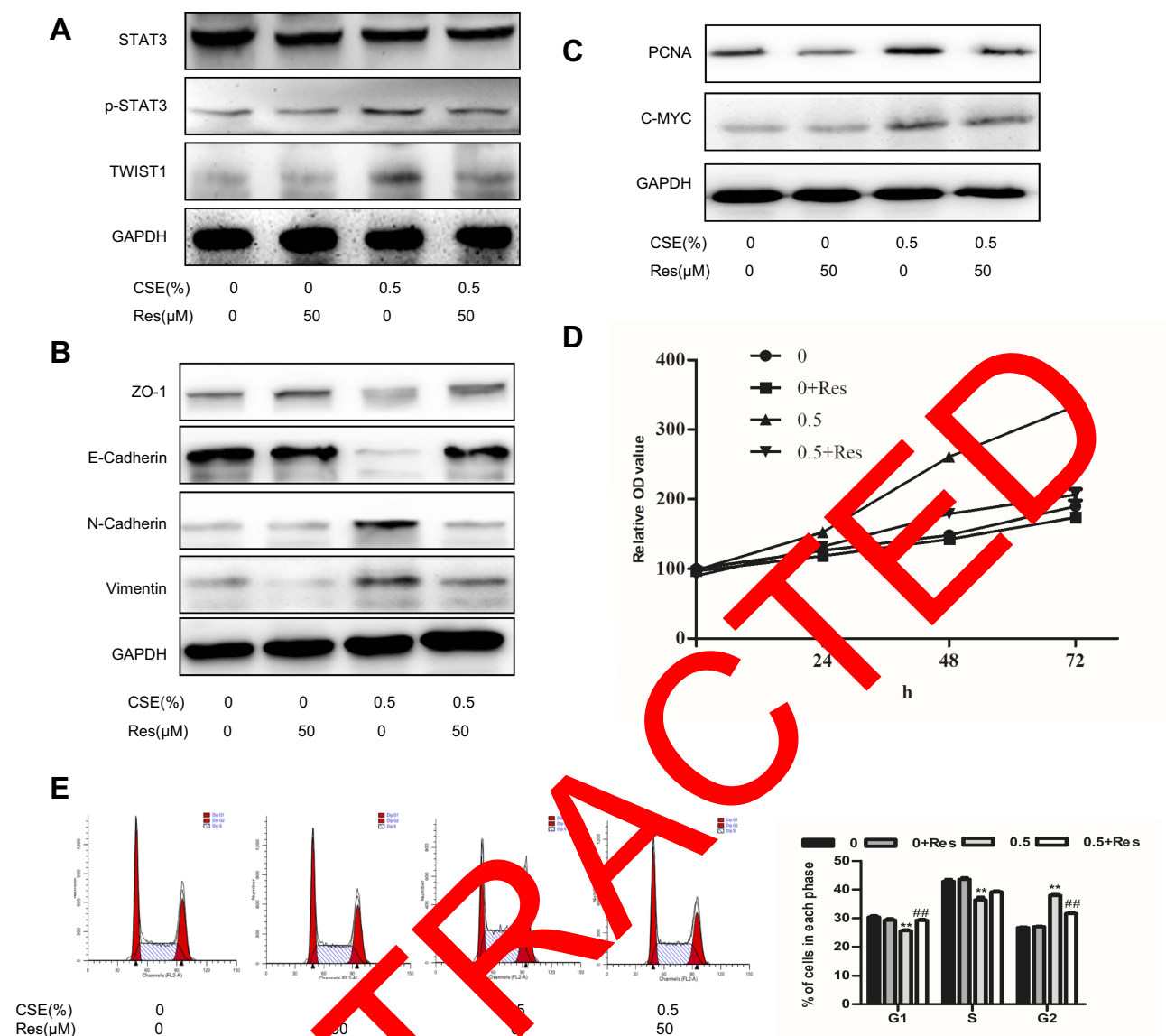


Figure 5 Resveratrol repairs CSE-induced SV-HUC-I EMT via suppression of STAT3 phosphorylation. **(A)** The protein change of the STAT3 pathway was determined by Western blotting. **(B)** Western blotting detected the protein expression of epithelial markers and mesenchymal markers. **(C)** The STAT3 downstream protein expression of SV-HUC-I as shown by Western blotting. **(D)** MTT assay was used to detect cell viability at 0, 24, 48, 72hrs. **(E)** Cell cycle was detected by flow cytometry. Data are expressed as mean \pm SD. The values of P show a statistical level of significance, ** or ###P<0.01, comparison between the group of exposed 0.5% CSE and the control group or the group of exposed 0.5% CSE and resveratrol.

Smoking increases the incidence of lung cancer has been confirmed by studies, and the effect of smoking on the incidence of bladder cancer has received increasing concern from scholars.²¹ A large number of epidemiological studies abroad have proved that smoking can increase the incidence of bladder cancer.^{22,23} Liang et al demonstrated that long-term cigarette exposure could induce cancer action of normal urinary tract epithelial cells. Cigarette exposure not only increases cell malignancy but also increases the expression of cancer stem cells, which make cancer cells more prone to metastasis and recurrence.^{4,24} Studies have shown that

cigarettes promote the initiation, development, and metastasis of bladder cancer.^{19,21,25} Clinical studies have found that compared with non-smokers, smokers with bladder cancer have significantly increased cancer recurrence rates and a reduced non-tumor survival period, which may be related to cigarette-induced EMT in bladder cancer cells and promoted cancer stem cells.²⁶⁻²⁸ Therefore, we have to further understand the molecular mechanism of tobacco in bladder cancer and explore effective preventive drugs.

Many pathways are involved in the EMT process, including PI3K, NF- κ B, MAPK, and STAT3.²⁹ Tyrosine

kinase-signal transduction and transcriptional activator pathway is a newly discovered signal transduction pathway from recent years. It is widely involved in the process of cell proliferation, differentiation, apoptosis, and immune inflammation regulation, and is an important pathway of many cytokine signal transductions.^{7,8} STAT3 plays an important role in pathological processes, such as inflammatory signaling and immunosuppression. STAT3 is certainly the most eminent among cancers and plays a vital role in regulating EMT during cancer progression. When STAT3 is phosphorylated on tyrosine 705, it drives the transcription of a variety of genes which affect numerous aspects of cell survival and growth. In general, STAT3 has a striking ability to promote cancer survival and invasion. By regulating cell cycle proteins, angiogenic factors, and anti-apoptotic genes, STAT3 promotes the occurrence of cancers. Many studies in McF-7 breast cancer cells showed that increased expression levels of cytokine IL-6 further activated STAT3, thus inducing EMT in cells.^{30,31} This also persists in the study of ovarian cancer, where activated STAT3 was found to regulate EMT through the STAT3-Snail signaling pathway.¹¹ However, there are few studies on the role of the STAT3 signaling pathway in cigarette carcinogenesis. Up to now, the role of the STAT3 signaling pathway in cigarette-induced bladder cancer has not been reported. Our study found that cigarette smoking induced EMT in bladder cancer cells while the STAT3 signaling pathway and its downstream target gene were activated. STAT3 inhibitors significantly reverse cigarette-induced EMT, reduce the ability of cell invasion and metastasis, and inhibit cell proliferation. Inhibition of the STAT3 signaling pathway is a novel target for cancer therapy.

STAT3 signaling has been found to be activated in diverse human malignancies and is associated with cancer progression, lymph node metastasis, and poor prognosis.³² Chen et al found phosphorylation of STAT3 increased in bladder cancer tissues. The expression of the phosphorylated STAT3 protein in tumor tissue was associated with TNM tumor staging in bladder cancer patients.³³ To clarify the new biological function of STAT3 signaling in bladder cancer metastasis, a series of in vitro and in vivo experiments were conducted. STAT3 downstream transcription factors TWIST1 and Snail are indirect and direct transcription inhibitors of E-Cadherin. The correlation between STAT3 and TWIST was analyzed by biluciferase, and the results showed that STAT3 could improve the transcriptional activity of TWIST1 and promote EMT,

thus enhancing the invasion and metastatic capacity of liver cancer cells.³⁴ TWIST1 expression was significantly reduced after a STAT3 inhibitor was used. TWIST1 is considered to be an important factor in the regulation of E-Cadherin, which plays a role mainly through the STAT3/TWIST1 signaling pathway axis. Our study found statice (a STAT3-specific inhibitor) reversed cigarette-induced EMT, resulting in a significant decrease in STAT3 protein accompanied by TWIST1, PCNA, C-MYC, and Vimentin, but an increase in E-Cadherin. These data showed that STAT3/TWIST1 plays an important role in CSE-induced bladder cancer.

It is widely accepted that dietary habits have a powerful influence on cancer risks. Emerging evidence substantiated the anti-cancer effect of resveratrol in various human cancers. Furthermore, resveratrol has potential inhibitory effects on cells and prevents cancer invasion and metastasis by down-regulating STAT3 signaling.^{35,36} Shen et al found resveratrol impeded the stemness, EMT, and metabolic reprogramming of cancer stem cells in nasopharyngeal carcinoma.³⁷ Hu et al reported that resveratrol inhibited cancer stem-like property and reversed the EMT in head and neck cancer.³⁸ Moreover, the suppression of STAT3 led to the reversal of EMT in cancer by resveratrol treatment.³⁹ In the present study, we found that resveratrol prevented cell morphological change following CSE treatment. Meanwhile, resveratrol inhibited STAT3 phosphorylation, reversed EMT, and prevented cancer migration and invasion after CSE treatment. These data revealed that resveratrol reverses cigarette smoke-induced urocytic epithelial–mesenchymal transition via suppression of STAT3 phosphorylation in SV-HUC-1-immortalized human urothelial cells.

In conclusion, this study identified the positive role of STAT3 in CSE-induced EMT, as well as the suppression role of resveratrol in CSE-related bladder malignancy. These findings indicate new mechanisms of CSE-induced bladder malignancy and provide a potential strategy for the prevention and intervention of bladder cancer.

Ethical Approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Acknowledgments

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Disclosure

The authors report no conflicts of interest in this work.

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