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ORIGINAL RESEARCH

RETRACTED ARTICLE: Portulacerebroside A inhibits adhesion, migration, and invasion of human leukemia HL60 cells and U937 cells through the regulation of p38/JNK signaling pathway

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Abstract: Acute myeloid leukemia (AML) is a highly malignant hematopoietic tumor. This study aimed to explore the effect of portulacerebroside A (PCA) on the adhesion, migration, and invasion in human leukemia HL60 cells and U937 cells and clarify the possible mechanisms involved, which could provide potential strategies for the treatment of AML. By methyl thiazolyl tetrazolium analysis, it was found that PCA (1–10 μM) suppressed the cell viability in a time- and dose-dependent manner. A total of 1, 2, and 5 μM of PCA dramatically inhibited the adhesion, migration, and invasion of HL60 cells and U937 cells in a dose-dependent manner. Phosphorylation levels of JNK and P38 protein level was measured by Western blot. After the real-time quantification polymerase chain reaction and Western blot detection of the total RNA and protein, messenger RNA, and protein expression levels of Ras homologous C (RhoC), metastasis-associated gene 1 (MTA1) and matrix metalloproteinase-2/9 (MMP-2/9) were decreased significantly in a dose-dependent manner. The phosphorylation level of c-Jun N-terminal kinase (JNK) and P38 mitogen-activated protein kinase (P38) was decreased dramatically in HL60 cells and U937 cells after PCA treatment. In conclusion, PCA significantly inhibits the adhesion, migration, and invasion of HL60 cells and U937 cells by suppressing the p38/JNK pathway and regulating the expressions of related genes.

Keywords: portulacerebroside A, PCA, p38/JNK, leucocythemia, adhesion, migration, invasion

Introduction

Acute myeloid leukemia (AML) is an aggressive hematopoietic malignancy characterized by the abnormality of marrow hematopoietic stem cells that accumulate in the bone marrow hampering the differentiation capability, which is often originated from certain phase of differentiation of hematopoietic cells and shows disorders of differentiation.[1,2] Massive accumulation of leukemia cells can interfere with hematopoietic function and infiltrate with tissues and organs, which can cause anemia, infections, and bleeding.[2] Chemotherapy and radiotherapy are still some of the key therapeutic strategies against AML, which are essentially modified by integrin-mediated adhesion to extracellular matrix (ECM).[3,4] It shows that the pathogenesis of AML is closely associated with cell migration and invasion. Most of the patients cannot be treated thoroughly; therefore, the major challenge facing the treatment of AML is to increase the cure rate and decrease the recurrence rate.[5] Consequently, the hope is that the serviceable products are screened from medicinal plants to solve the earlier issues.

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Portulaca oleracea L. is widely distributed in the temperate and tropical zones of the world. Its aerial part (Chinese name Ma-Chi-Xian) has been used as both food and medicine for a rather long history in China.[6] Purslane contains many compounds such as alkaloids, omega-3 fatty acids, coumarins, flavonoids, polysaccharides, cardiac glycosides and anthraquinone glycosides;[7] therefore, it can support the treatment and its aerial part can be used as medicine, with regulating lipidemia, clearing heat and anti-swelling, anti-aging, anti-inflammatory, anti-ulcerogenic, detoxifying and analgesic function.[7–9]

Previous research has shown that portulacerebroside A (PCA) markedly inhibited the viability, invasion, and metastasis of liver cancer HCCLM3 cells via activating the p38/JNK signaling pathway,[6,8,9] and p38/JNK signaling pathway belongs to mitogen-activated protein kinase (MAPK) signaling pathway. MAPK signaling pathway as important signal pathways of mammal is stimulated by cytokines and involved in cell proliferation, differentiation, apoptosis, adhesion, invasion, metastasis, immunoregulation and other important biological processes.[10–12] Matrix metalloproteinase-2/9 (MMP-2/9), metastasis-associated gene 1 (MTA1) and Ras homologous C (RhoC) are closely related to cell adhesion, migration, and invasion, which are regulated by related signaling pathways.[13–15] The aim of this study is to investigate whether PCA can suppress the adhesion, migration, and invasion in human leukemia HL60 cells and U937 cells via regulating p38/JNK.

Materials and methods

PCA

The contents of PCA are in white powder form, which was isolated and purified from the aerial parts of *P. oleracea*.[5,8] The molecular formula and molecular weight, respectively, were $C_{48}H_{93}NO_{[illegible]}$ and 84[illegible]/mol, and the purity thereof reached >95%. PCA was dissolved in dimethylsulfoxide (DMSO), and the final concentration of DMSO was kept below 0.5%.

Cell culture

Human HL60 cell line and U937 cell line were purchased from Shanghai Micro Mongolian Life Science Co., Ltd (Shanghai, People's Republic of China). HL60 cells and U937 cells were cultured in RPMI-1640 medium with 10% fetal bovine serum (FBS) (Gibco BRL, Rockville, MD, USA), 100 U/mL penicillin G and 100 µg/mL streptomycin at 37°C in a humidified 5% CO_2 atmosphere. The logarithmic growth phase cells were used for further experiments.

Methyl thiazolyl tetrazolium (MTT) test

The cell proliferation status was assessed by MTT Cell Proliferation and Cytotoxicity Assay Kit (Amyjet Scientific Inc., Wuhan, China). In brief, HL60 cells were seeded in 96-well plates at the density of 2×10^4 cells/well with 100 mL culture medium, and the cells were cultured for 24 h. Then, PCA (0, 1, 2, 5, and 10 µM) was added to the culture medium for another 12, 24, and 48 h. A 20 µL of MTT (5 mg/mL) solution was added to each well, and the culture was incubated for another 4 h at 37°C. The supernatant was discarded after centrifugation, and then 150 µL of DMSO was added to each well and used for dissolving the crystallization. The optical density (OD) values were read at [illegible]60 nm by a microplate reader (Tecan Sunrise, Männedorf, Switzerland). The method of U937 cell testing is same as above.

Adhesion test

All adhesion assays were carried out in 12-plate microplate. The 0.25% trypsin (Gibco BRL) was used for digesting cells in exponential growth period, and then the cells were suspended in RPMI-1640 (Hyclone) medium containing 10% fetal calf serum (Gibco BRL). Cells were seeded in a 12-plate microplate at a density of 1.5×10^5 cells/mL and then incubated for [illegible]. The supernatant was discarded after centrifugation, cells were treated with PCA (0, 1, 2, and 5 µM) for 24 h, and then the cells were washed 2–3 times with PBS (Gibco BRL). A 4% paraformaldehyde (Kemiou Chemical Reagent Co., Ltd, Tianjin, China) was supplemented for 15 min, and the cells were stained by Giemsa (JRDUN) for 20 min. Then the cells were washed several times with PBS (Gibco BRL), and the OD values were read at 590 nm by a microplate reader (Thermo Fisher Scientific, Waltham, MA, USA). Adhesion rate (%) = (OD1/OD0) ×100%, OD1: PCA-treated groups; OD0: control group.

Invasion test

Cell invasion assay was performed by a 24-well transwell chamber with a pore size of 8 µm (Sigma). The inserts were coated with 50 µL Matrigel (dilution at 1:2; BD Biosciences, Franklin Lakes, NJ, USA). Cells treated with PCA (0, 1, 2, and 5 µM) for 24 h and transferred to the upper Matrigel chamber in 100 µL of serum-free medium supplementing 1.5×10^5 cells and incubated for 24 h. The lower chamber was filled with medium containing 10% FBS as chemoattractants. After incubation, the cells that passed through the filter were fixed and stained by Giemsa (dilution at 1:9) for 30 min. Finally, the cells were washed several times with PBS, 5 visual fields were selected and its average invaded cell number was determined under high-power microscope (Olympus Corporation, Tokyo, Japan).

Migration test

After trypsinization (Gibco BRL), human leukemia cell line HL60 cells and U937 cells in logarithmic phase were suspended in RPMI-1640 (Hyclone) medium with 10% fetal calf serum (Gibco BRL). Cells were washed 3 times with PBS to remove cell debris. The cells with PCA (0, 1, 2, and 5 μM) were seeded in a 24-plate microplate at a density of 1.5×10^5 cells/mL and then incubated for 12 h. The supernatant was discarded, and the cells were washed 2–3 times with PBS (Gibco BRL). A 1 mL of 4% paraformaldehyde (Kemiou Chemical Reagent Co., Ltd) was supplemented for 10 min and cells were stained by 0.5% crystal violet (Zhongze, Shanghai, People's Republic of China) for 30 min. The numbers of migrated cells were counted by manual counting under 5 randomly selected high-power fields under a microscope (Olympus Corporation).

$$\text{Migration rate} = \frac{\text{Migrated cell number in treated group}}{\text{Migrated cell number in control group}} \times 100\%$$

Western blot

Cells were collected at a density of 5×10^5 cells/well in 6-well plates after treatment with PCA (1, 2, and 5 μM) for 24 h. Each group of cells was harvested and washed twice with PBS and protein lysed in ice-cold radio immunoprecipitation assay buffer (RIPA; Beyotime, Shanghai, People's Republic of China) with freshly added 0.01% protease inhibitor phenylmethanesulfonyl fluoride (Amresco, Shanghai, People's Republic of China) and incubated on ice for 30 min. Cell lysis was centrifuged at 14,000× g for 5 min at 4°C, and the supernatant (20–30 μg of protein) was run on 10% sodium dodecyl sulfate polyacrylamide gel electrophoresis gel and transferred electrophoretically to a nitrocellulose membrane (Millipore, Shanghai, People's Republic of China), then detected with JNK, phosphorylated (p-) JNK, P38, p-P38, RhoC, MTA1, and MMP-2/9 proteins. Protein loading was estimated using mouse anti-glyceraldehyde 3-phosphate dehydrogenase (anti-GAPDH) monoclonal antibody. Blots were visualized using enhanced chemiluminescence (Thermo Fisher Scientific). Antibodies were purchased from Cell Signaling Technology, Abcam and Santa Cruz.

Real-time quantification PCR (RT-PCR)

Expressions of genes were evaluated using RT-PCR and SYBR Green I chemistry (TransStart Top Green qPCR SuperMix, TransGen Biotech Co., Ltd, Beijing, China). Cells were seeded in 6-well plates at a density of 5×10^5 cells/well, cultured overnight and then treated with PCA (1, 2, and 5 μM) for 24 h. Total RNA (2 μg) was extracted from cells using TRIzol reagent (Invitrogen) according to the manufacturer's protocol, and which was reverse transcribed with the TransCript One-step gDNA Removal and cDNA Synthesis SuperMix (TransGen Biotech Co., Ltd). The expression of RhoC, MTA1, and MMP-2/9 messenger RNA (mRNA) in HL60 cells and U937 cells was detected by RT-PCR with the cycling parameters defined as follows: an initial cycling for 5 min at 95°C, followed by 40 cycles for 15 s at 95°C, 30 s at 60°C, and 30 s at 72°C. Relative expression level $=2^{-\Delta\Delta Ct}$, where $\Delta Ct = Ct$ (gene of interest) − Ct (housekeeping gene). GAPDH as internal control was performed by monitoring the RT-PCR efficiency. All RT reactions were performed in triplicate. The primer sequences for each gene were displayed in Table 1.

Table 1 Primers used in real-time PCR analysis

Gene	Primer sequence	Species
RhoC	Forward: 5′-AAGAAGGACCTGAGGCAAGA-3′	Human
	Reverse: 5′-AGGTAGCCAAAGGCACTGAT-3′	
MTA1	Forward: 5′-TGGAAGACCACCGACAGATA-3′	Human
	Reverse: 5′-TTGTTGACGCTGATTTGGTT-3′	
MMP-2	Forward: 5′-TTGACGGTAAGGACGGACTC-3′	Human
	Reverse: 5′-GGCGTTCCCATACTTCACAC-3′	
MMP-9	Forward: 5′-AAGGGCGTCGTGGTTCCAACTC-3′	Human
	Reverse: 5′-AGCATTGCCGTCCTGGGTGTAG-3′	
GAPDH	Forward: 5′-CACCCACTCCTCCACCTTTG-3′	Human
	Reverse: 5′-CCACCACCCTGTTGCTGTAG-3′	

Abbreviations: PCR, polymerase chain reaction; RhoC, Ras homologous C; MTA1, metastasis-associated gene 1; MMP, matrix metalloproteinase; GAPDH, glyceraldehyde 3-phosphate dehydrogenase.

Statistics

All variables were evaluated using the SPSS 18.0 (SPSS Inc., Chicago, IL, USA). Differences between numerical variables were calculated using the Student's *t*-test, and the results are presented as the mean ± standard deviation. One-way analysis of variance followed by Dunnett's test was used for statistical analysis. All tests performed were 2-sided. Probability (P) values <0.05 were considered significant.

Results

Effect of PCA on HL60 cells and U937 cells proliferation

The change of cell proliferation was observed with MTT in vitro. After 1, 2, 5, and 10 μM of PCA treatment, the proliferation of HL60 cells and U937 cells was decreased significantly compared with that of control group ($P<0.05$). The lower concentrations of PCA (1, 2, and 5 μM) were also dramatically reduced cell viability in a time-dependent and dose-dependent manner ($P<0.05$). The results were shown in Figure 1. There were significant differences between the group given 1 μM and the group exposed to 10 μM. Therefore, the doses of 1, 2, and 5 μM were determined to carry out further adhesion, migration, and invasion investigations.

PCA inhibited the adhesion, migration, and invasion of HL60 cells and U937 cells

As shown in Figure 2Aa, 1, 2, and 5 μM of PCA notably suppressed adhesion of HL60 cells in comparison with the control group in a dose-dependent manner, the adhesion rates of HL60 cells were about 82.23%±8.12%, 54.01%±4.99%, and 35.21%±3.01% (Figure 2Ab). The results showed that the migration abilities of HL60 cells treated with PCA (1, 2, and 5 μM) were decreased dramatically in a concentration-dependent manner compared with that of the control group (Figure 2Ba). The migration rates of 1, 2, and 5 μM of PCA-treated groups were about 75.01%±6.77%, 52.55%±3.25%, and 30.77%±2.69%, respectively, in comparison with the control group (Figure 2Bb). The invasive abilities of HL60 were shown in Figures 2 (Ca and Cb). In the results of this study, the use of PCA significantly decreased the invasion of HL60 cells for 70.45%±5.49%, 50.74%±4.31%, and 27.23%±1.69%, which was evidently lower than that of the control group (100%±4.94%).

As shown in Figure 3Aa, 1, 2, and 5 μM of PCA notably suppressed adhesion of HL60 cells in comparison with the control group in a dose-dependent manner. The adhesion rates of U937 cells were about 80.33%±6.32%, 49.36%±4.17%, and 38.21%±2.99% (Figure 3Ab), compared with the control group. The migration abilities of U937 cells were significantly suppressed by PCA (1, 2, and 5 μM) (Figure 3Ba); compared with the control group, the migration rates of 1, 2, and 5 μM of PCA-treated groups were about 77.71%±6.05%, 55.32%±4.28%, and 28.19%±1.71%, respectively (Figure 3Bb). The invasive abilities of U937 cells were shown in Figures 3 (Ca and Cb). After treatment with PCA (1, 2, and 5 μM), the invasion of U937 cells was about 72.32%±5.28%, 54.32%±4.19%, and 29.31%±1.87% of the control group.

PCA suppressed the expression of adhesion-, migration-, and invasion-related proteins targeting p38/JNK

p38/JNK signaling is involved in the occurrence and metastasis of many diseases through a positive regulatory way.[16] HL60 cells and U937 cells were treated with PCA (1, 2, and 5 μM). In HL60 cells, the expressions of p-P38 and p-JNK proteins were decreased significantly compared to that of the control group (Figure 4). Proteins and mRNA of RhoC, MTA1 and MMP-2/9 were both downregulated by PCA in a dose-dependent manner (Figure 5). The expression of p-P38 and p-JNK in U937 cells was both inhibited dramatically by PCA in a dose-dependent manner, which was evidently lower than that of the control group (Figure 6). In U937 cells, after PCA treatment, significant decreases were observed in protein and mRNA expressions of RhoC, MTA1 and MMP-2/9 in comparison with the control group (Figure 7).

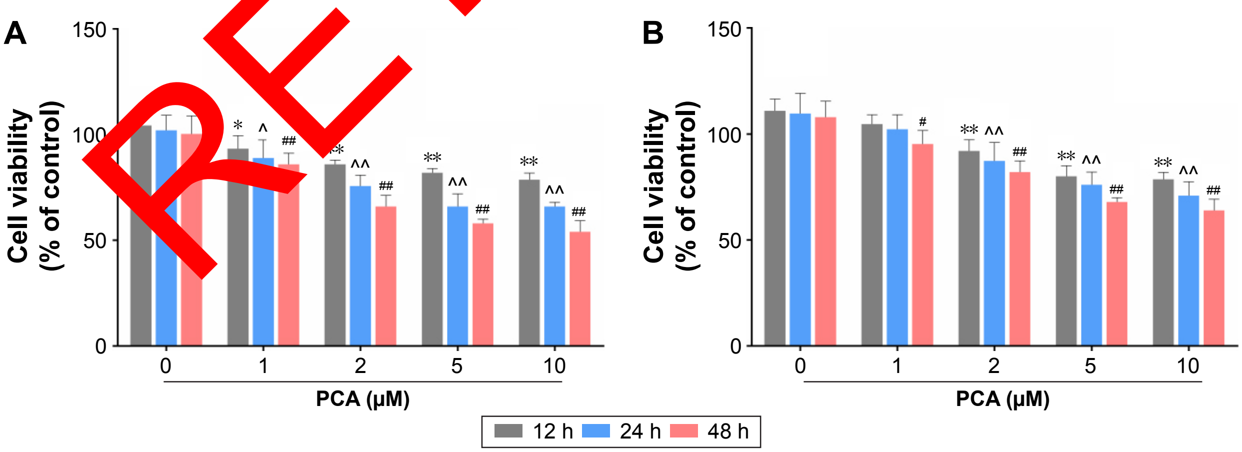

Figure 1 Changes in cell proliferation following PCA (1–10 μM) treatment in human leukemia HL60 cells and U937 cells.
Notes: (**A**) The proliferation of human leukemia HL60 cells was decreased after PCA (0, 1, 2, 5, and 10 μM) treatment. (**B**) The proliferation of human leukemia U937 cells was decreased after PCA (0, 1, 2, 5, and 10 μM) treatment. Data were presented as mean ± SD, n=3, *$P<0.05$ and **$P<0.01$ vs control, ^$P<0.05$ and ^^$P<0.01$ vs PCA (1 μM), and $^{\#}P<0.05$ and $^{\#\#}P<0.01$ vs PCA (2 μM).
Abbreviations: h, hours; PCA, portulacerebroside A; SD, standard deviation.

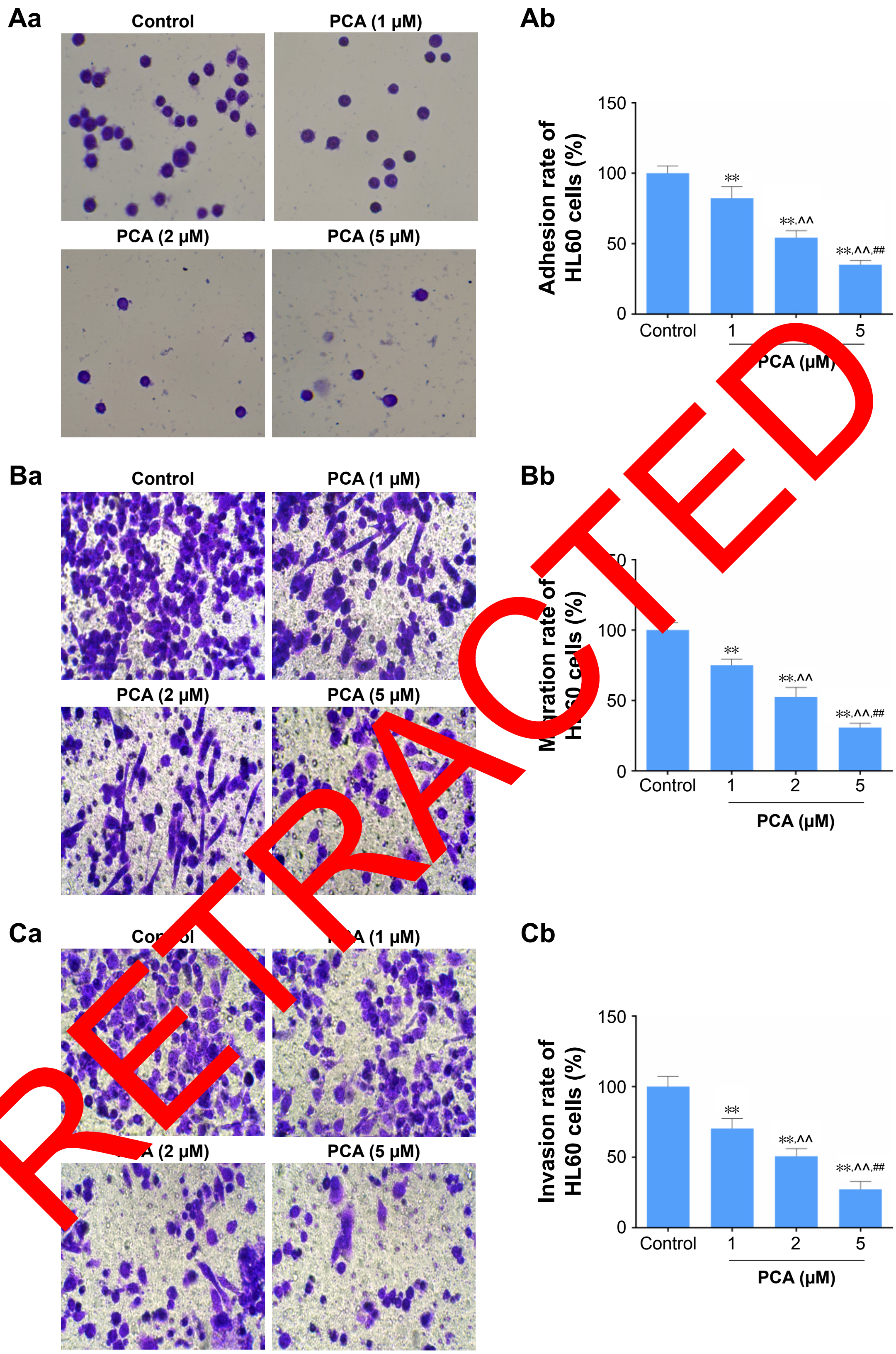

Figure 2 Effect of PCA (1, 2, and 5 μM) treatment on cell adhesion, migration, and invasion in human leukemia HL60 cells.

Notes: Empty treatments were done in the control group. (**A**a and **A**b) Cells were treated with 1, 2, and 5 μM of PCA for 24 h, and cell adhesion was evaluated by Giemsa staining and cell counting; (**B**a and **B**b) cells were treated with 1, 2, and 5 μM of PCA for 24 h, and cell migration was evaluated by Giemsa staining and cell counting; (**C**a and **C**b) after 1, 2, and 5 μM of PCA treatment for 24 h, cell invasion was identified by transwell assay. Data were presented as mean ± SD, n=3, $^{**}P<0.01$ vs control, $^{\wedge\wedge}P<0.01$ vs PCA (1 μM), $^{\#\#}P<0.01$ vs PCA (2 μM). **Aa**, **Ba**, and **Ca**: magnification 20×.

Abbreviations: h, hours; PCA, portulacerebroside A; SD, standard deviation.

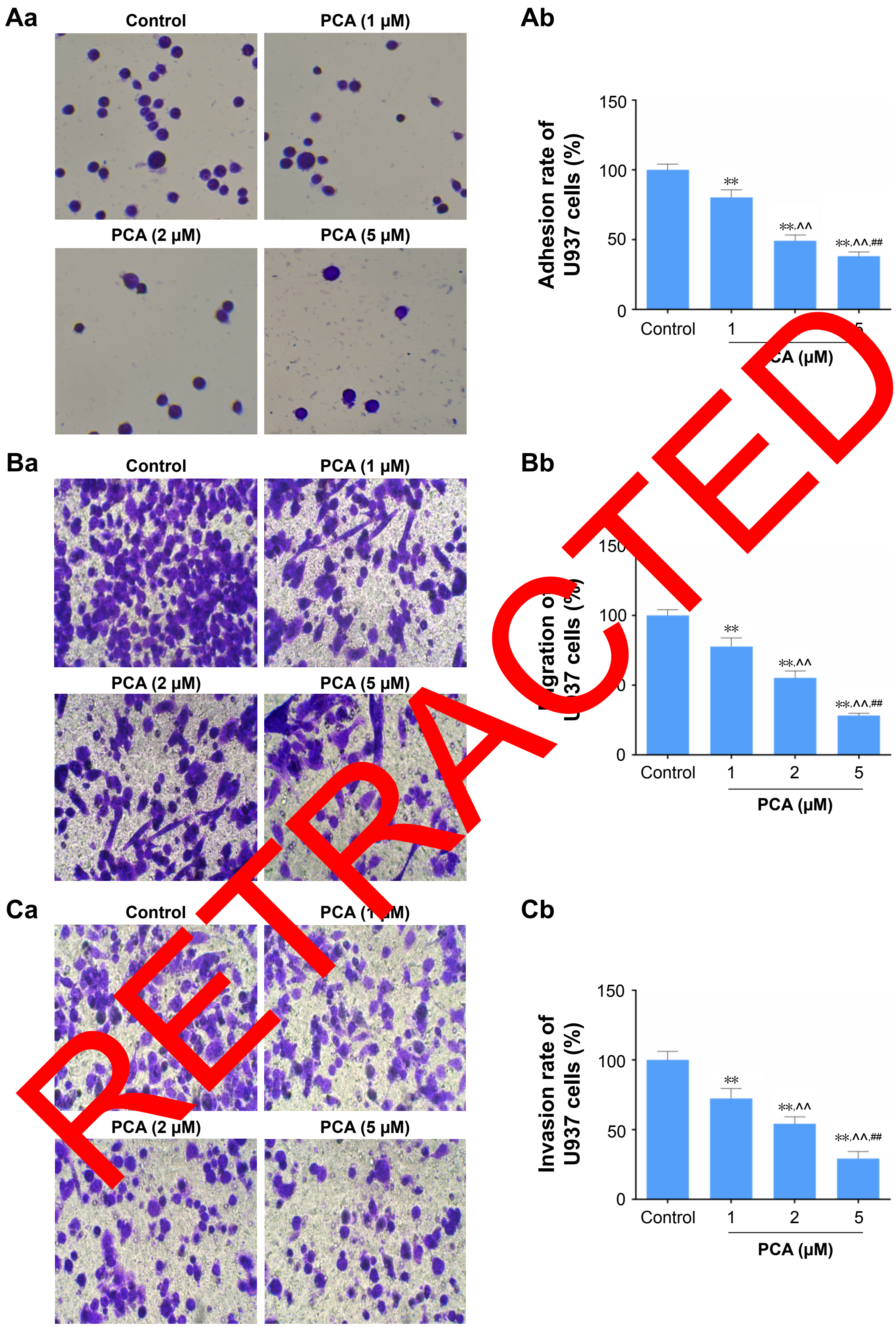

Figure 3 Effect of PCA (1, 2, and 5 µM) treatment on cell adhesion, migration, and invasion in human leukemia U937 cells.

Notes: Empty treatments were done in the control group. (**A**a and **A**b) Cells were treated with 1, 2, and 5 µM of PCA for 24 h, and cell adhesion was evaluated by Giemsa staining and cell counting; (**B**a and **B**b) cells were treated with 1, 2, and 5 µM of PCA for 24 h, and cell migration was evaluated by Giemsa staining and cell counting; (**C**a and **C**b) after 1, 2, and 5 µM of PCA treatment for 24 h, cell invasion was identified by transwell assay. Data were presented as mean ± SD, n=3, $^{**}P<0.01$ vs control, $^{\wedge\wedge}P<0.01$ vs PCA (1 µM), and $^{\#\#}P<0.01$ vs PCA (2 µM). **Aa**, **Ba**, and **Ca**: magnification 20×.

Abbreviations: h, hours; PCA, portulacerebroside A; SD, standard deviation.

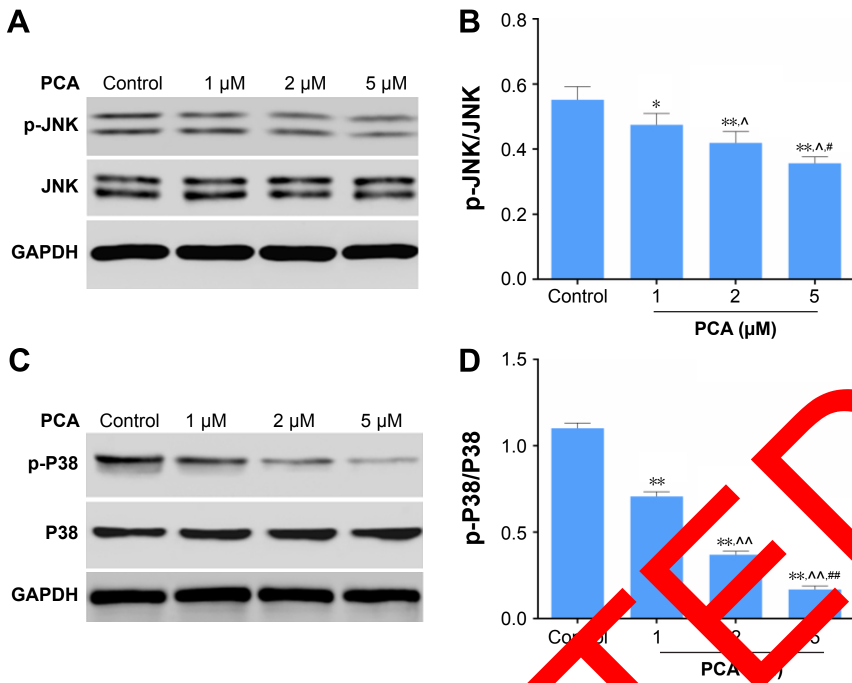

Figure 4 Western blot analysis of phosphorylation level of JNK and P38 after PCA (1, 2, and 5 μM) treatment in human leukemia HL60 cells.

Notes: (**A** and **B**) Cells were treated with different doses of PCA (1, 2, and 5 μM) for 6 h, and the antibodies were used for indicating the expression levels of JNK and p-JNK proteins by Western blot. (**C** and **D**) Cells were treated with different doses of PCA (1, 2, and 5 μM) for 6 h, and the antibodies were used for indicating the expression levels of P38 and p-P38 proteins by Western blot. GAPDH was also detected as the control of sample loading. Data were presented as mean ± SD, n=6, *$P<0.05$ and **$P<0.01$ vs control, ^$P<0.05$ and ^^$P<0.01$ vs PCA (1 μM), and #$P<0.05$ and ##$P<0.01$ vs PCA (2 μM).

Abbreviations: h, hours; PCA, portulacerebroside A; GAPDH, glyceraldehyde 3-phosphate dehydrogenase; SD, standard deviation.

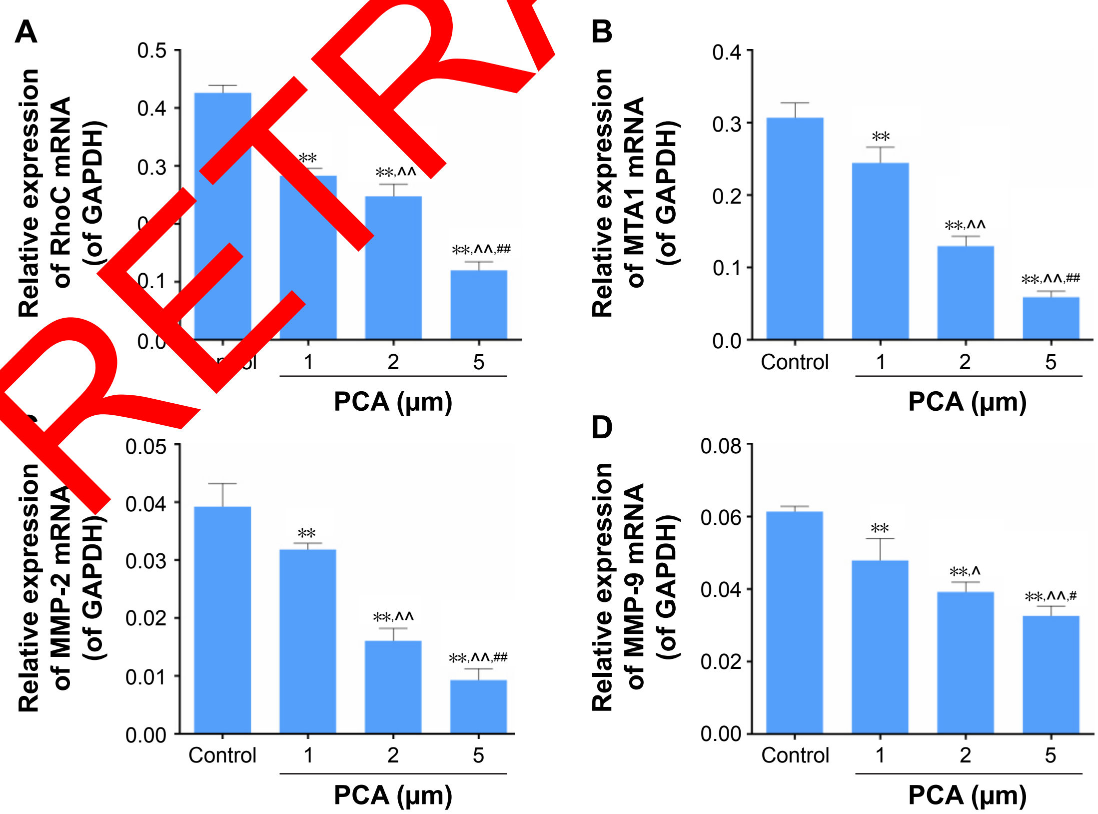

Figure 5 (*Continued*)

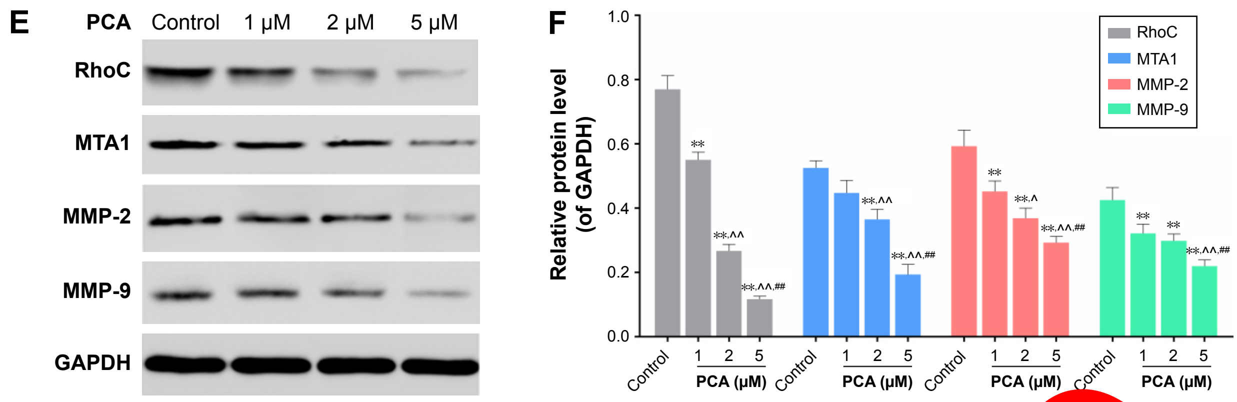

Figure 5 RT-PCR and Western blot analysis of RhoC, MTA1 and MMP-2/9 expressions after PCA (1, 2, and 5 µM) treatment in human leukemia HL60 cells.
Notes: (**A**–**D**) Cells were treated with 1, 2, and 5 µM of PCA for 12 h, and RhoC, MTA1 and MMP-2/9 mRNA expressions were detected by RT-PCR. (**E** and **F**) Cells were treated with 1, 2, and 5 µM of PCA for 24 h, and the antibodies were used for indicating the expression levels of RhoC, MTA1, and MMP-2/9 proteins by Western blot. The expression of each protein was normalized to that of GAPDH. Data were presented as mean ± SD, n=6, ***P*<0.01 vs control, ^*P*<0.05 and ^^*P*<0.01 vs PCA (1 µM), and #*P*<0.05 and ##*P*<0.01 vs PCA (2 µM).
Abbreviations: h, hours; RT-PCR, real-time quantification polymerase chain reaction; RhoC, Ras homologous C; MTA1, metastasis associated gene 1; MMP, matrix metalloproteinase; PCA, portulacerebroside A; mRNA, messenger RNA; GAPDH, glyceraldehyde 3-phosphate dehydrogenase; SD, standard deviation.

Discussion

Adhesion, migration, and invasion are the essential processes toward the progression of cancer.[6,13] A leading cause of tumor recurrence in cancer patients is a poor outcome of traditional treatment, due to chemotherapy resistance and failure of complete removal of tumor tissue during surgery and radiotherapy, and chemotherapy carries side effects on the quality of patients' life; hence, it is necessary to search for appropriate antitumor agents. PCA is a natural compound, which isolated from *P. oleracea*. Previous studies showed that PCA (2.5, 5, and 10 µg/mL) can inhibit the invasion and metastasis of human liver

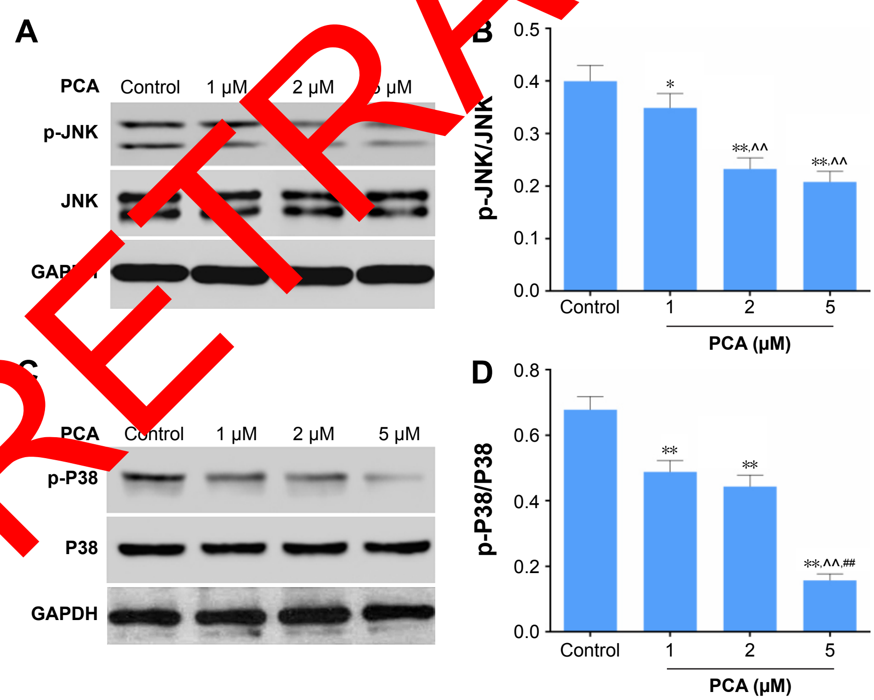

Figure 6 Western blot analysis of phosphorylation level of JNK and P38 after PCA (1, 2, and 5 µM) treatment in human leukemia U937 cells.
Notes: (**A** and **B**) Cells were treated with different doses of PCA (1, 2, and 5 µM) for 6 h, and the antibodies were used for indicating the expression levels of JNK and p-JNK proteins by Western blot. (**C** and **D**) Cells were treated with different doses of PCA (1, 2, and 5 µM) for 6 h, and the antibodies were used for indicating the expression levels of P38 and p-P38 proteins by Western blot. GAPDH was also detected as the control of sample loading. Data were presented as mean ± SD, n=6, **P*<0.05 and ***P*<0.01 vs control, ^^*P*<0.01 vs PCA (1 µM), and ##*P*<0.01 vs PCA (2 µM).
Abbreviations: h, hours; PCA, portulacerebroside A; GAPDH, glyceraldehyde 3-phosphate dehydrogenase; SD, standard deviation.

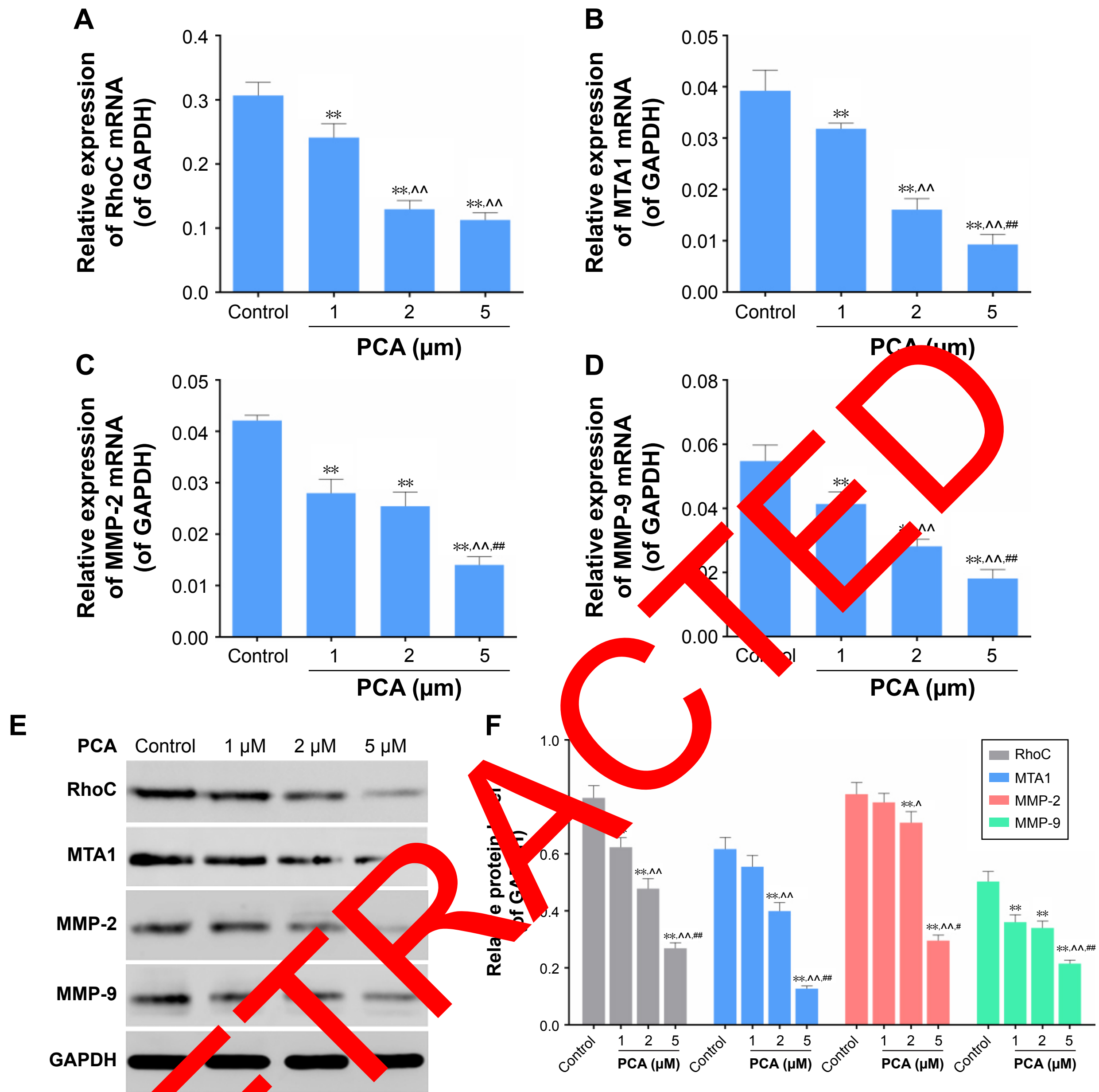

Figure 7 RT-PCR and Western blot analysis of RhoC, MTA1, and MMP-2/9 expressions after PCA (1, 2, and 5 μM) treatment in human leukemia U937 cells.
Notes: (**A**–**D**) Cells were treated with 1, 2, and 5 μM of PCA for 12 h, and RhoC, MTA1, and MMP-2/9 mRNA expressions were detected by RT-PCR. (**E** and **F**) Cells were treated with 1, 2, and 5 μM of PCA for 24 h, and the antibodies were used for indicating the expression levels of RhoC, MTA1, and MMP-2/9 proteins by Western blot. The expression of each protein was normalized to that of GAPDH. Data were presented as mean ± SD, n=6, $^{**}P<0.01$ vs control, $^{\wedge}P<0.05$ and $^{\wedge\wedge}P<0.01$ vs PCA (1 μM), and $^{\#}P<0.05$ and $^{\#\#}P<0.01$ vs PCA (2 μM).
Abbreviations: h, hours; RT-PCR, real-time quantification polymerase chain reaction; RhoC, Ras homologous C; MTA1, metastasis-associated gene 1; MMP, matrix metalloproteinase; PCA, portulacerebroside A; mRNA, messenger RNA; GAPDH, glyceraldehyde 3-phosphate dehydrogenase; SD, standard deviation.

cancer cells,[6] and PCA (1–100 μM) induced the apoptosis of human leukemia cells,[5] which suggested that PCA has antitumor activity. We speculated whether a low concentration of PCA could inhibit the adhesion, migration, and invasion of human leukemia cells. The results showed that PCA (1, 2, 5, and 10 μM) suppressed the cell viability of HL60 cells and U937 cells in a time- and dose-dependent manner, and 1 μM of PCA could also significantly inhibit the cell proliferation of HL60 cells and U937 cells at 48 h (Figure 1). Therefore, in this study, the effect of PCA (1, 2, and 5 μM) on the adhesion, migration, and invasion of HL60 cells and U937 cells was investigated and the possible molecular mechanism involved was elucidated. The results showed that PCA treatment from 1 to 5 μM dose dependently inhibited the adhesion, migration, and invasion of HL60 cells and U937 cells (Figures 2 and 3).

By combining all the analysis results, a low concentration of PCA could prevent metastasizing by affecting the adhesion and migration abilities of human leukemia cells, which indicated that PCA was beneficial for the treatment of AML; subsequently, in further experiments, the relative molecular mechanism involved was investigated.

MAPK pathway has been one of the most extensively studied protein kinase pathways, which can be subdivided into three subtypes, including extracellular regulated protein kinase (ERK1/2), P38, and JNK.[17] Accumulating evidence indicates that activation of JNK and p38 signaling can promote exorbitant cell proliferation and tumor cell migration.[14,18] Compared with the control group, PCA (1, 2, and 5 μM) stimulation dramatically declined the phosphorylation level of JNK and P38 proteins in HL60 cells and U937 cells (Figures 4 and 5). The high expression of p-JNK and p-P38 protein is closely associated with the metastasis of tumor, which has collaborative effect between them.[19] It showed that a low concentration of PCA inhibited the activation of p38/JNK signaling pathway. MMPs are a family of zinc-dependent proteolytic enzymes. Degradation of ECM is performed by MMPs, especially MMP-2 and MMP-9.[20] Other research has reported that the activation of MAPK signaling pathway can upregulate the expression of MMP-2/9, and the massive research confirmed that the increased activity and expression of MMP-2/9 can promote the invasion and metastasis of the tumors in many cancers.[14,21] This is an indication that the activation of JNK and p38 signaling may upregulate the expression of MMP-2/9 to promote the invasion and metastasis of the tumor. After PCA (1, 2, and 5 μM) treatment, mRNA and protein expression levels of MMP-2/9 were significantly downregulated than that of the control group in HL60 cells and U937 cells (Figures 6 and 7). The results confirmed the previous inference.

MTA1 as an integral part of the nucleosome remodeling and histone deacetylation complex is increased in malignancies and increases the metastatic and invasive potential of carcinoma.[22,23] RhoC are GTPases and are part of the extensive Ras superfamily, which involves in regulating invasion, metastasis, cell proliferation, and survival of cells.[24,25]

The arrangement of cytoskeleton is changed by RhoC to enhance adhesion for ECM. In the results, mRNA and protein expression of RhoC and MTA1 were significantly downregulated by PCA (1, 2, and 5 μM). The over-expression of RhoC can cause the expression of MMP-2/9 and MTA1 to increase the ability to degrade ECM and promote the metastasis of tumor cells.[15] It illustrates that the high expression of RhoC, MMP-2/9, and MTA1 increases the depth of local tumor invasion and promote tumor metastasis. According to the earlier results, the p38/JNK signaling pathway was suppressed by a low concentration of PCA to decrease the expression of RhoC; meanwhile, the expression of MMP-2/9 was inhibited.

Conclusion

A low concentration of PCA significantly inhibited the adhesion, migration, and invasion of HL60 cells and U937 cells by suppressing the p38/JNK pathway to decrease the expressions of invasion- and migration-related genes.

Disclosure

The authors report no conflicts of interest in this work.

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