

Tripartite motif-containing 14 regulates cell proliferation and apoptosis in cervical cancer via the Akt signaling pathway

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Abstract. Tripartite motif-containing (TRIM) 14 is a protein of the TRIM family. Studies have indicated that TRIM14 may be used as an oncogene in tumor cells, such as osteosarcoma, non-small cell lung cancer and breast cancer through different pathways. However, the functions of TRIM14 in cervical cancer cells remain unclear. Therefore, this study aimed to investigate the functions of TRIM14 in cervical cancer cells and its underlying mechanism. Caski cells stably expressing TRIM14 and SiHa, and HeLa cells stably expressing TRIM14 short hairpin RNA were constructed by lentivirus-mediated overexpression or knockdown systems. The effects of TRIM14 on proliferation and apoptosis of cervical cancer cells were detected by Cell Counting Kit-8 (CCK-8) assay and flow cytometry, respectively. In addition, reverse transcription-quantitative (RT-q) PCR and western blotting were used to investigate the expression levels of TRIM14 and of signaling pathway marker protein including P21, caspase-3, cleaved caspase-3, Akt and phosphorylated Akt. The results of RT-qPCR and western blotting revealed that TRIM14 was highly expressed in human cervical cancer

tissues and cell lines compared with adjacent normal tissues and normal cervical epithelial cells. TRIM14 also regulated cell proliferation and apoptosis of human SiHa, HeLa and Caski cervical cancer cell lines through the Akt signaling pathway. Additionally, TRIM14 protein levels were related to the clinical and pathological features of cervical cancer. CCK-8 assay and flow cytometry demonstrated that TRIM14 expression could promote cervical cancer cell proliferation and autophagy suppression. Taken together, TRIM14-induced cell proliferation and apoptosis inhibition may be evoked by the activation of the Akt pathway. This study demonstrated the role of TRIM14 in cervical cancer, and reveals its mechanism of action as a potential therapeutic target for cervical cancer.

Introduction

Cervical cancer ranks as the second most malignant tumor among women worldwide, with >500,000 new cases every year (1). There are ~131,500 new cases in China each year, accounting for 28.8% of the world's new cases (1). Thus, the search for more effective cervical cancer prevention measures and methods for early diagnosis and treatment are important topics in the field of gynecology research in China. A previous study has shown a variety of squamous cell carcinomas in different parts of the human body are associated with human papillomavirus (HPV) infection, suggesting the excessive activation of Akt/mTOR signaling (2). Additionally, studies have reported that the aberrant activation of this signaling pathway and HPV-encoded E-series oncoproteins work synergistically in promoting malignant transformation of cervical cells (3,4).

Triple-motif protein (TRIM) participates in post-transcriptional modification, cell proliferation, apoptosis of proto-oncogene and tumor suppressor gene-related proteins (5). TRIM can regulate nuclear receptors in a displacement manner, which serves an important role in tumorigenesis (5). TRIM14, one of the members of the TRIM family, has physiological functions such as regulating innate immune responses and affecting cell differentiation (6). Su *et al* (7) reported that the expression levels of TRIM14 mRNA and TRIM14 protein in oral squamous cell carcinoma tissues and cell lines are higher compared with those in normal tissues and cell lines. In addition, they also suggested that overexpression of TRIM14

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Abbreviations: TRIM, triple-motif protein; RT-qPCR, reverse transcription-quantitative polymerase chain reaction; IHC, immunohistochemistry; GSEA, gene set enrichment analysis; TBS, Tris-buffered saline; shRNA, short hairpin

Key words: tripartite motif-containing 14, cervical cancer, Akt signaling pathway, cell proliferation, apoptosis

was related to late clinical stage, late tumor-node-metastasis (TNM) stage and shorter overall survival time in patients with oral squamous cell carcinoma (7). Xu *et al* (6) reported that TRIM14 is highly expressed in osteosarcoma tissues and cell lines, whereas the silencing of TRIM14 expression triggered the inhibition of proliferation, metastasis and infiltration ability in osteosarcoma cells. Additionally, Dong and Zhang (8) observed high expression levels of TRIM14 mRNA and TRIM14 protein in liver cancer tissues. At the same time, the expression level of TRIM14 is related to the tumor size, the number of lesions, the presence or absence of vascular invasion, Barcelona stage and TNM stage (8). Zhou *et al* (9) reported that the expression levels of TRIM14 mRNA and protein in breast cancer tissues and cell lines are higher compared with those in normal breast tissues and cell lines. After inhibiting the TRIM14 gene in breast cancer cell lines, the proliferation of the cell line was inhibited and the number of apoptotic cells was increased (9). However, studies focusing on the role of TRIM14 in the cervical cancer have not been investigated in-depth. It is not clear whether TRIM14 affects the biological behavior of cervical cancer, and whether the biological behavior of cervical cancer affected by TRIM14 is related to the Akt signaling pathway.

Therefore, the present study was designed to investigate the role of TRIM14 in cervical cancer and to explore its potential regulatory mechanism, in order to determine whether TRIM14 could be used as a target for the treatment of cervical cancer.

Materials and methods

Patient samples. A total of 40 pairs of cervical cancer specimens and adjacent normal tissues were obtained from Obstetrics and Gynecology Hospital, Fudan University (Shanghai, China). The specimens (mean age, 49 years; age range, 30-71 years) were placed in liquid nitrogen for storage. The patients did not receive any chemotherapy, immunotherapy or radiotherapy before collecting the specimen. According to the pathological analysis, the samples were considered as cancer tissues if the cell broke through the basal layer and developed within the interstitial area. Written informed consent was obtained from all participants and the procedure was approved by the Ethics Committee of the Obstetrics and Gynecology Hospital, Fudan University (Shanghai, China).

Cell culture. Human cervical cancer cell lines (SiHa, C-33A, HeLa and Caski) and normal cervical epithelial cells (HcerEpic) were purchased from American Type Culture Collection. The cell lines were cultured in high glucose DMEM (Hyclone; Cytiva) containing 10% fetal calf serum (Gibco; Thermo Fisher Scientific, Inc.) and 1% double antibody (cyan streptomycin mixture) at 37°C in a humidified atmosphere containing 5% CO₂. The adherent cells were observed under an Eclipse Ni upright optical microscope (Nikon Corporation; magnification, x200).

Reverse transcription-quantitative (RT-q) PCR. Total RNA from tissues or cells were extracted using TRIzol® reagent (Invitrogen; Thermo Fisher Scientific, Inc.) and stored in a -80°C freezer for later use. Next, cDNA synthesis was carried out using a reverse transcription kit (Fermentas; Thermo Fisher Scientific, Inc.) at 37°C for 60 min, 85°C for 5 min, 4°C for

5 min. The RT-qPCR amplification was performed using SYBR Green PCR kit (Thermo Fisher Scientific, Inc.). The thermocycling conditions consisted of an initial denaturation at 95°C for 10 min, followed by 40 cycles of 95°C for 15 sec and 60°C for 45 sec, then 95°C for 15 sec, 60°C for 1 min, 95°C for 15 sec, and 60°C for 15 sec. Data were analyzed using the ABI Prism 7300 SDS software (SDS V1.3.1, Applied biosystems) on a Real-Time PCR detector (Applied Biosystems). The primers for RT-qPCR amplification were as follows: TRIM14 forward, 5'-GGATTTGTGTCTCCGTTCTG-3' and reverse, 5'-TCTGTCTGCCTGGTATTCTG-3'; GAPDH forward, 5'-AATCCCATCACCATCTTC-3' and reverse, 5'-AGGC TGTGTCATACTTC-3'. The relative mRNA expression was calculated using 2^{-ΔΔC_q} method (10).

Western blotting. Cells were fully lysed at 4°C with RIPA histiocyte rapid lysate (P0013, Beyotime Biotechnology, Inc.), and supplemented with protease and phosphatase inhibitors. The cell suspension was centrifuged at 12,000 x g for 10 min at 4°C, the supernatant was collected, and the protein was quantified and incubated in a -80°C refrigerator. Similarly, tissue samples were lysed with the same lysate after shredding, and the pyrolysis products were then centrifuged at 12,000 x g for 15 min at 4°C and stored at -80°C. Protein concentrations were determined using a Bicinchoninic Acid Protein Quantitation kit (Thermo Fisher Scientific, Inc.). A total of 25 μg protein were separate by 12% polyacrylamide SDS-PAGE and transferred to PVDF membranes. Subsequently, blots were blocked in 5% milk in TBST at room temperature for 1 h and incubated with primary antibody overnight at 4°C. Primary antibodies against TRIM14 (1:1,000; cat. no. ab185349; Abcam), P21 (1:1,000; cat. no. ab109520; Abcam), caspase-3 (1:5,000; cat. no. ab32351; Abcam), cleaved caspase-3 (1:500; cat. no. ab32042; Abcam), Akt (1:1,000; cat. no. 4691; Cell Signaling Technology, Inc.), phosphorylated (p)-Akt1 (1:2,000; cat. no. 4060; Cell Signaling Technology, Inc.) and GAPDH (1:2,000; cat. no. 4060; Cell Signaling Technology Inc.) were used for blotting. The membranes were then washed in TBS containing 1% Tween-20, and incubated with horseradish peroxidase (HRP)-labeled goat anti-rabbit secondary antibody (1:1,000; cat. no. A0208; Beyotime Institute of Biotechnology). Finally, bands were detected using an ECL chemiluminescence system (Tanon Science and Technology Co., Ltd.), and scanned and analyzed by ImageJ (version 1.8.0; National Institutes of Health).

Immunohistochemistry (IHC). The tissues were fixed with 10% formalin at 4°C for 48 h, embedded in paraffin, and cut into 4-μm sections. Then, the paraffin-embedded sections were dewaxed, rehydrated, and then subjected to heat-induced epitope repair in 0.01 M sodium citrate (pH 6.0). The activity of endogenous peroxidase was blocked with 0.3% hydrogen peroxide for 30 min at room temperature. Sections were washed with Tris-buffered saline (TBS), followed by incubation with primary antibody against TRIM14 (1:1,000; cat. no. Ab185349; Abcam) overnight at 37°C. After three washes with PBS, sections were incubated with HRP-labeled broad-spectrum secondary antibody (1:1000; cat. no. D-3004; Shanghai Changdao Biotechnology Co., Ltd.) for 20-30 min at room temperature. Sections were stained with DAB reagent (cat. no. FL-6001; Shanghai Changdao Biotechnology Co., Ltd.), and then

counterstained with hematoxylin for 3 min at room temperature. The stained sections were observed under an Eclipse Ni upright optical microscope (Nikon Corporation; magnification, x200) and analyzed using the VistarImage microscopic image analysis system (VIHENT).

Transfection assay. Short hairpin RNA (shRNA) targeting TRIM14 was designed and synthesized by Genewiz, Inc. The targeting RNAi sequences of sh-TRIM14 were as follows: 5'-GCAGCACATTGACAACATA-3' (shTRIM14-1), 5'-GCCC GTCAAGAGCTTCTTT-3' (shTRIM14-2), 5'-GCGATCGCTA TTGCTGAAA-3' (shTRIM14-3). The resultant single-stranded oligonucleotides were annealed and the corresponding shRNA was integrated into the interfering vector to get the recombinant interfering vector (pLKO.1-shTRIM14). The primers and restriction site targeting the coding sequence region and selected vector were designed according to the TRIM14 mRNA sequence data gathered from NCBI. The transfer plasmid was synthesized by Genewiz, Inc and sent to Shanghai Majorbio for DNA sequencing. The sequencing result was compared with the TRIM14 sequence data from National Center for Biotechnology Information (<https://www.ncbi.nlm.nih.gov/>; accession no. NM_014788.4). The bacterium solution of the plasmid of 100% matching rate was preserved and the plasmid was extracted from the preserved solution. Then, the 293T cells (American Type Culture Collection) were transfected by the recombinant vector (1 mg), psPAX2 (interference, 900 ng; overexpression, 100 ng) and pMD2G (interference, 100 ng; overexpression, 900 ng) to get the packaging viruses, and the interference effect or overexpression ability of the resultant packaging viruses was verified by infecting 293T cells. Then, 48 h after transfection, lentivirus was harvested and purified by ultra-centrifugation at 3,000 x g for 2.5 h at 4°C. SiHa and HeLa cells were transduced by lentivirus-mediated knockdown system at 37°C. In addition, the oeTRIM14 Caski cell line was also established by infecting Caski cells with TRIM14 overexpressing lentivirus. Blank vector was transduced in control group. In a separate experiment, the empty vector and oeTRIM14 Caski cell line were treated with Akt inhibitor LY294002 (10 µmol/l; cat. no. S1105; Selleck Chemicals) for 48 h at 37°C in a 5% CO₂ incubator. Subsequent experiments were performed 96 h after transfection.

Cell proliferation assay. Cells in the logarithmic growth phase were counted by trypsinization, and seeded in 96-well plates at a density of 2x10³ cells/well. After transfection, cells were cultured for 0, 24, 48 or 72 h at 37°C in a 5% CO₂ incubator. According to the manufacturer's protocol, Cell Counting Kit-8 (Signalway Antibody LLC) and serum-free essential medium were mixed in a volume ratio of 1:10, and subsequently, 100 µl of the mixtures were added to each well. The culture plates were incubated for 1 h at 37°C in a 5% CO₂ incubator. Absorbance at 450 nm was detected on a microplate reader.

Cell cycle assay. Cells in the logarithmic growth phase were counted by trypsinization and seeded in a 6-well plate at a density of 3x10⁵ cells/well. Cells were transfected after 24 h of culture and collected by trypsinization 48 h after transfection. After that, cells were washed with PBS and treated with 100 µl RNase A (1 mg/ml) for 30 min at 37°C, then 400 µl propidium

iodide staining (50 µg/ml; cat. no. C001-200; Shanghai 7sea PharmTech Co., Ltd.) was used to detect the cell cycle for 10 min at room temperature, followed by using an Accuri C6 flow cytometer (BD Biosciences) to detect red fluorescence at a wavelength of 488 nm excitation wavelength, as well as light scattering. Cell cycle analysis was then performed using FlowJo software (version 7.6.1; FlowJo LLC).

Apoptosis assay. Cells in the logarithmic phase were counted after trypsinization, and then seeded in a 6-well plate at a density of 3x10⁵ cells/well. The original medium was discarded after adherent growth for 24 h, and the cells were subsequently transfected. The transfected cells were counted after trypsinization. A total of 5x10⁴-1x10⁵ resuspended cells were obtained and incubated with reagents from the Annexin V-FITC apoptosis detection kit (cat. no. C1063, Beyotime Institute of Biotechnology). Then, the cells were incubated with 5 µl propidium iodide (cat. no. C001-200; Shanghai 7sea PharmTech Co., Ltd.) at 4°C for 5 min. Cell apoptosis (at early and late phase) was detected using an Accuri C6 flow cytometer (BD Biosciences) and analyzed by BD Accuri C6 Software (version 1.0.264.21; BD Biosciences).

Gene set enrichment analysis (GSEA). The TRIM14 mRNA expression dataset of cervical cancer was downloaded from The Cancer Genome Atlas (TCGA; <http://tcga.data.nci.nih.gov/Tcga/>; accession no. TCGA-CESC) using the Bioconductor/TCGA Biolinks function package (11). Based on the dataset, samples were stratified in three groups according to their TRIM14 gene expression (low, intermediate, high). The 25th and 75th percentiles were used as cut-off thresholds. Survival analysis was performed to compare the samples with low and high expression of TRIM14 (mRNA expression below the 25th percentile and above the 75th percentile, respectively). The effects of TRIM14 expression level on other gene sets were analyzed using GSEA version 2.2.3 (<http://software.broadinstitute.org/gsea/index.jsp>; Broad Institute, Inc.). The genetic data set was obtained from the GSEA website MsigDB database (<http://www.broadinstitute.org/gsea/msigdb/>), followed by enrichment analysis according to the default weighted enrichment statistics method. A false discovery rate <0.01 was used as threshold to determine significance. The random combination number was set to 1,000 times.

Statistical analysis. Each experiment was performed at least in triplicate, and continuous variables were presented as means ± standard deviations (SD), while categorical variables are presented as absolute numbers (percentages). GraphPad Prism 7.0 software (GraphPad Software, Inc.) and SPSS version 20.0 (IBM Corp.) were used for statistical analysis. Comparison of categorical variables was performed with χ^2 test and comparison of continuous variables was performed using paired Student's t-test or one-way analysis of variance (ANOVA) followed by Tukey's post hoc test. P<0.05 was considered to indicate a statistically significant difference.

Results

TRIM14 is highly expressed in human cervical cancer tissues and cell lines. To investigate if TRIM14 served an important biological role in cervical cancer, RT-qPCR and western

Table I. Clinicopathologic variables and the expression status of tripartite motif-containing 14 in patients with cervical cancer (n=40).

Clinical pathologic parameters	n	TRIM14 low expression, n (%)	TRIM14 high expression, n (%)	P-value
Clinical stage (39)				
I/II	21	7 (33.33)	14 (66.67)	0.567
III	19	8 (42.11)	11 (57.89)	
Age, years				
≥45	26	9 (34.62)	17 (65.38)	0.608
<45	14	6 (42.86)	8 (57.14)	
Sex				
Female	40	15 (37.50)	25 (62.50)	-
Pathology diagnosis				
Squamous cell carcinoma	40	15 (37.50)	25 (62.50)	-

TRIM14, tripartite motif-containing 14.

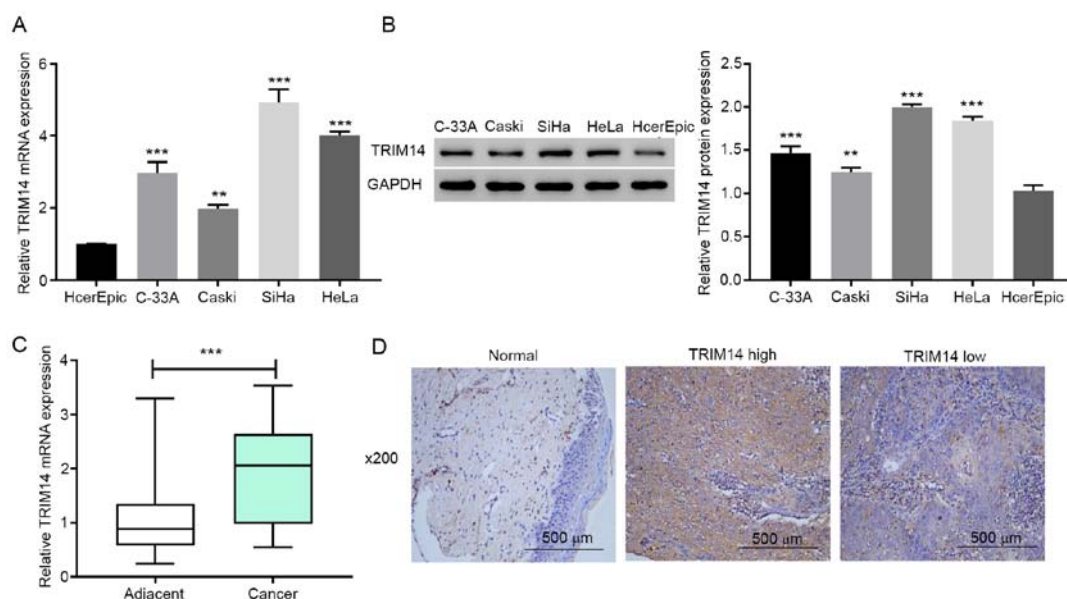


Figure 1. TRIM14 is highly expressed in human cervical cancer tissues and cell lines compared with adjacent normal tissues and normal cervical epithelial cells. The expression levels of TRIM14 in cervical cancer cell lines including C-33A, Caski, SiHa, HeLa and normal cervical cancer cell line HcerEpic was detected using (A) reverse transcription-quantitative PCR and (B) western blotting. (C) TRIM14 mRNA expression levels in 40 cervical cancer specimens and adjacent normal tissues. (D) Representative images of TRIM14 expression in cervical cancer and normal tissues examined by immunohistochemistry. ** $P < 0.01$ vs. HcerEpic; *** $P < 0.001$ vs. HcerEpic. TRIM14, tripartite motif-containing 14.

blotting were applied to detect the expression levels of TRIM14 in multiple cervical cancer cell lines (HeLa, C-33A, Caski and SiHa) and normal cervical epithelial cells HcerEpic. The results demonstrated that the expression levels of TRIM14 in cervical cancer cell lines were significantly higher compared with those in normal cervical epithelial cells ($P < 0.001$; Fig. 1A and B). Next, TRIM14 mRNA expression levels in human cervical cancer tissues and adjacent normal tissues were measured using RT-qPCR. The results demonstrated that the TRIM14 mRNA expression levels were significantly increased in cervical cancer tissues compared with adjacent normal tissues ($P < 0.001$; Fig. 1C). These results suggested that TRIM14 is overexpressed in human cervical cancer tissues and cell lines.

To determine whether the overexpression of TRIM14 was associated with the clinicopathological features of cervical cancer, the protein levels of TRIM14 were examined using IHC in 40 paraffin-embedded human cervical cancer tissues. Compared with the corresponding adjacent normal tissues, the expression levels of TRIM14 in cervical cancer tissues was significantly higher (Fig. 1D). Among the cervical cancer tissues, 62.5% (25/40) cases were classified as TRIM14-high, whereas 37.5% (15/40) stained low for TRIM14 (Fig. 1D). The associations between TRIM14 expression and clinicopathological features of cervical cancer were further studied. The percentage of TRIM14-high expression among patients <45 years old was 57.14%, whereas that of patients >45 years old was 65.38% (Table I). The results demonstrated

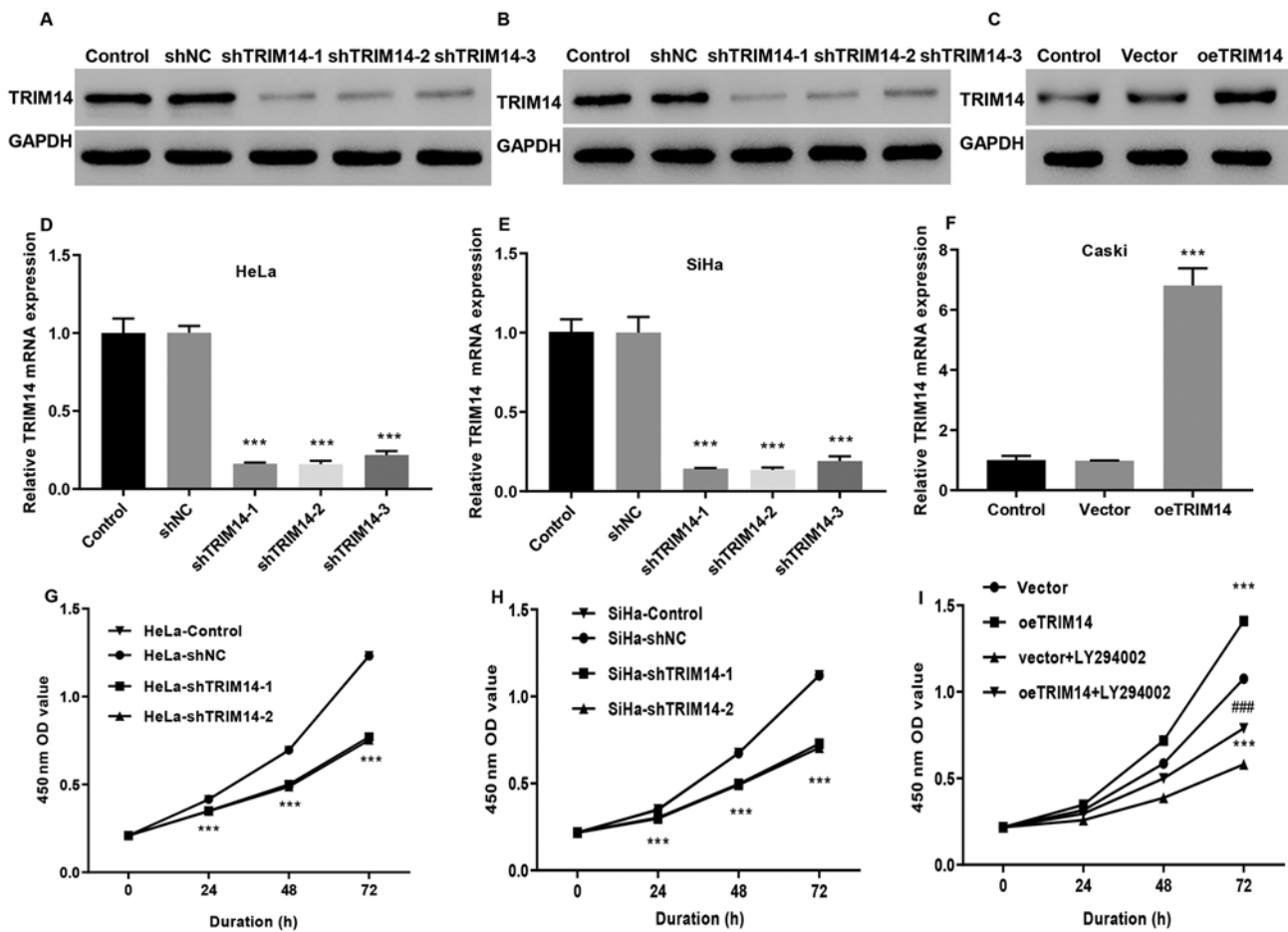


Figure 2. TRIM14 promotes the proliferation of cervical cancer cells. TRIM14 expression in HeLa cells infected with shRNA and lentivirus (shNC, negative control) against TRIM14 (shTRIM14) was detected using (A) western blotting and (D) RT-qPCR. *** $P < 0.001$ vs. shNC. TRIM14 expression in SiHa cells infected with shRNA and lentivirus (shNC) against TRIM14 (shTRIM14) was detected using (B) western blotting and (E) RT-qPCR. *** $P < 0.001$ vs. shNC. The overexpression of TRIM14 in Caski cells infected with TRIM14 overexpressing lentivirus and lentivirus (vector, negative control) against TRIM14 (oeTRIM14) was detected using (C) western blotting and (F) RT-qPCR. *** $P < 0.001$ vs. vector. Cell Counting Kit-8 assay was performed to determine the proliferation of HeLa (G) and SiHa (H) cells with or without TRIM14 shRNA for 72 h. *** $P < 0.001$ vs. HeLa-shNC or SiHa-shNC. (I) Cell Counting Kit-8 assay analysis of the proliferation activity of Caski cells. *** $P < 0.001$ vs. vector; ### $P < 0.001$ vs. oeTRIM14. TRIM14, tripartite motif-containing 14; sh, short hairpin; RT-qPCR, reverse transcription-quantitative PCR; NC, negative control; OE, overexpression.

that TRIM14 protein expression levels were higher in patients above the age of 45 years, but there was no significant difference in the TRIM14 protein levels between two groups.

TRIM14 promotes cervical cancer cell proliferation. To investigate the effect of TRIM14 expression on the development of cervical cancer, the stable expression of TRIM14 in Caski cells, and siTRIM14-1, siTRIM14-2 and siTRIM14-3 cell lines from SiHa and HeLa cells were constructed by lentivirus-mediated overexpression or knockdown system. In addition, the oeTRIM14 cell line was also established by infecting Caski cells with TRIM14 overexpressing lentivirus. RT-qPCR and western blotting indicated that the knockout efficiency of the cell lines was significantly higher ($P < 0.001$) compared with the control group, indicating that the SiHa and HeLa cell models interfered by the TRIM14 gene were successfully constructed (Fig. 2A, B, D and E). TRIM14 expression levels were significantly increased in the oeTRIM14 group compared with those in the control and vector groups ($P < 0.001$; Fig. 2C and F), suggesting that the TRIM14 overexpressed Caski cell model was also well constructed. In addition, compared

with the control group, the proliferation of siTRIM14-1 and siTRIM14-2 (SiHa and HeLa cells) were significantly reduced ($P < 0.001$; Fig. 2G and H); whereas the proliferation activity of the TRIM14 overexpressed cells (Caski cells) was significantly increased (Fig. 2I). Next, cell cycle assays were performed on TRIM14 overexpressing cells and TRIM14 silenced cells. The results demonstrated an increased percentage of TRIM14 silenced cells (SiHa and HeLa cells) in the G_1/G_0 phase compared with that of control cells (Fig. 3A and B). By contrast, overexpression of TRIM14 significantly reduced the percentage of Caski cells in the G_0/G_1 phase compared with that of control cells, but increased the percentage of Caski cells in S phase (Fig. 3A and B). These findings suggested that TRIM14 promotes the proliferation of cervical cancer cells.

TRIM14 suppresses apoptosis of cervical cancer cells. Tumor is a disease with abnormal apoptosis, in which the surrounding non-tumor cells provide a living environment for the tumor cells by providing abnormal signals (12). To investigate the relationship between TRIM14 and cervical cancer morphology, apoptosis was examined in TRIM14

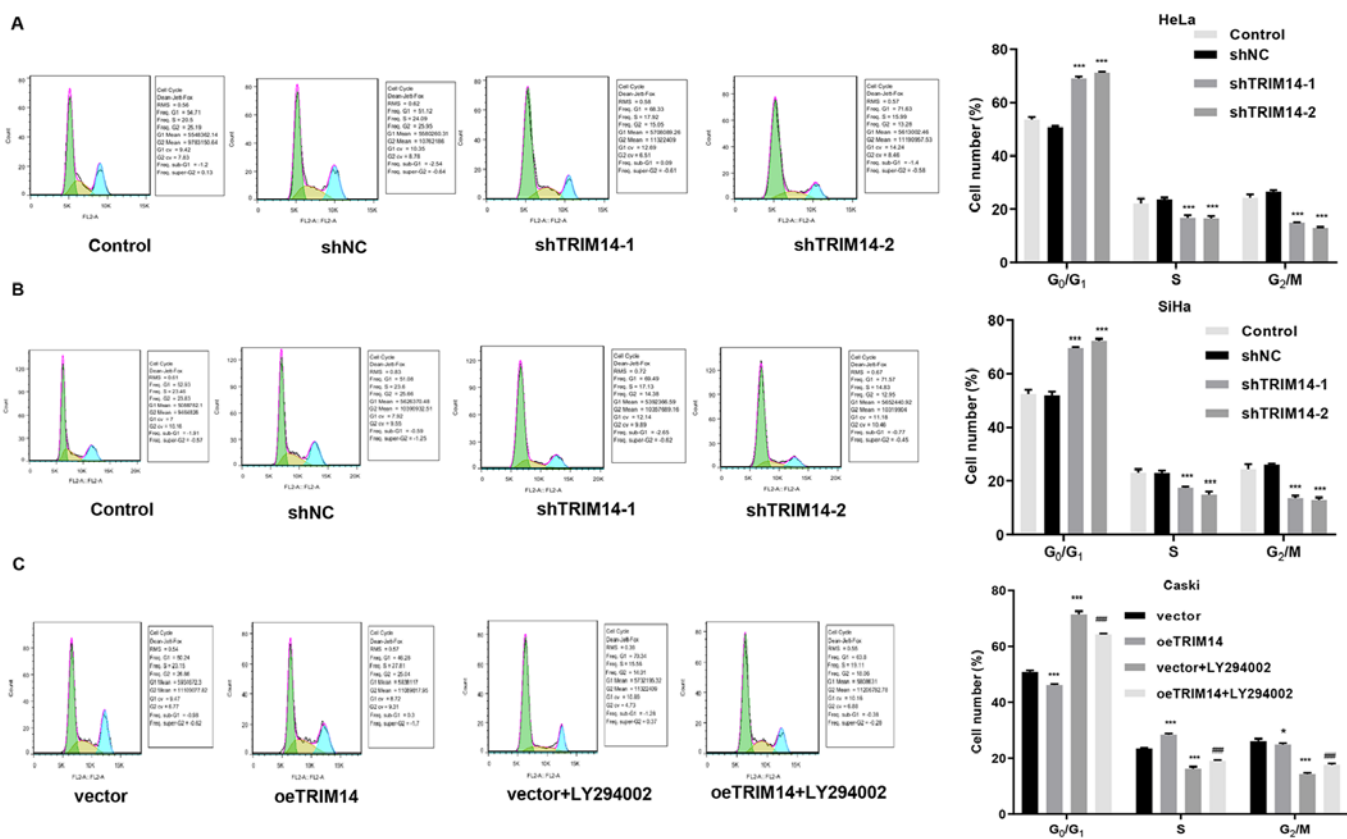


Figure 3. TRIM14 regulates the cell cycle of cervical cancer cells. Flow cytometry was used to measure the percentage of (A) HeLa cells and (B) SiHa cells in the G₀/G₁ phase and S phase. ***P<0.001 vs. shNC. (C) The percentage of Caski cells in G₀/G₁ phase and S phase after the overexpression of TRIM14 was detected by flow cytometry. *P<0.05, ***P<0.001, vs. vector; ###P<0.001 vs. oeTRIM14. TRIM14, tripartite motif-containing 14; sh, short hairpin; NC, negative control; OE, overexpression; OD, optical density.

overexpressing and silenced cells, and the normal cervical cancer cells. Compared with the control group, the apoptotic rate of human TRIM14 silenced cells (SiHa and HeLa cells) was significantly increased (P<0.001; Fig. 4A and B). By contrast, the apoptotic rate of human TRIM14 overexpressing cells (Caski cells) was significantly reduced compared with that of the control group (P<0.001; Fig. 4C). Collectively, these findings suggested that TRIM14 suppresses apoptosis of cervical cancer cells.

TRIM14 regulates cell proliferation and apoptosis via the Akt signaling pathway. Phenotypic analysis of cervical cancer cells demonstrated that TRIM14 promoted the biological behavior of cervical cancer. To investigate which signaling pathway contributed to this function, the TCGA database was used to aggregate cervical cancer-related data, TRIM14 expression data was downloaded from cervical cancer tissue and processed into an expression matrix, and the TRIM14 correlation signaling pathway was predicted by GSEA. GSEA analysis demonstrated that the samples with high expression of TRIM14 were enriched into BIOCARTA_AKT_PATHWAY signaling pathway [false discovery rate (FDR)=0.010] and REACTOME_APOPTOSIS signaling pathway (FDR=0.010; Fig. 5A and B).

The data from GSEA suggested that the signaling pathway associated with TRIM14 expression in cervical cancer is the Akt signaling pathway and the apoptosis signaling pathway. In

order to validate these assumptions, the relationship between the expression of TRIM14 with Akt signaling pathway, and the apoptotic signaling pathway was examined. Notably, TRIM14 overexpression increased the expression levels of the Akt signaling pathway marker protein p-Akt, and inhibited the expression levels of the apoptosis-related proteins P21 and cleaved caspase-3, whereas TRIM14 silencing reversed these effects (Fig. 5C, D and E).

To determine whether TRIM14-induced cell proliferation and apoptosis inhibition of cervical cancer cells were activated by the Akt pathway, Akt inhibitor LY294002 was used to examine the cell proliferation, cycle and apoptosis abilities of overexpressed TRIM14. CCK-8 assay revealed that the cell proliferation was significantly decreased in the vector+LY294002 and oeTRIM14+LY294002 groups compared with the vector and oeTRIM14 group, respectively (P<0.001; Fig. 2I). The cell cycle assay demonstrated that the percentage of cells was increased in G₀/G₁ phase and decreased in S phase in the vector+LY294002 and oeTRIM14+LY294002 groups compared with the vector and oeTRIM14 group, respectively (Fig. 3C). In addition, the apoptotic rate was significantly increased in the vector+LY294002 and oeTRIM14+LY294002 groups compared with the vector and oeTRIM14 group, respectively (Fig. 4C). Collectively, these findings suggested that the activation of the Akt pathway mediated the effects for TRIM14-induced cell proliferation and apoptosis inhibition.

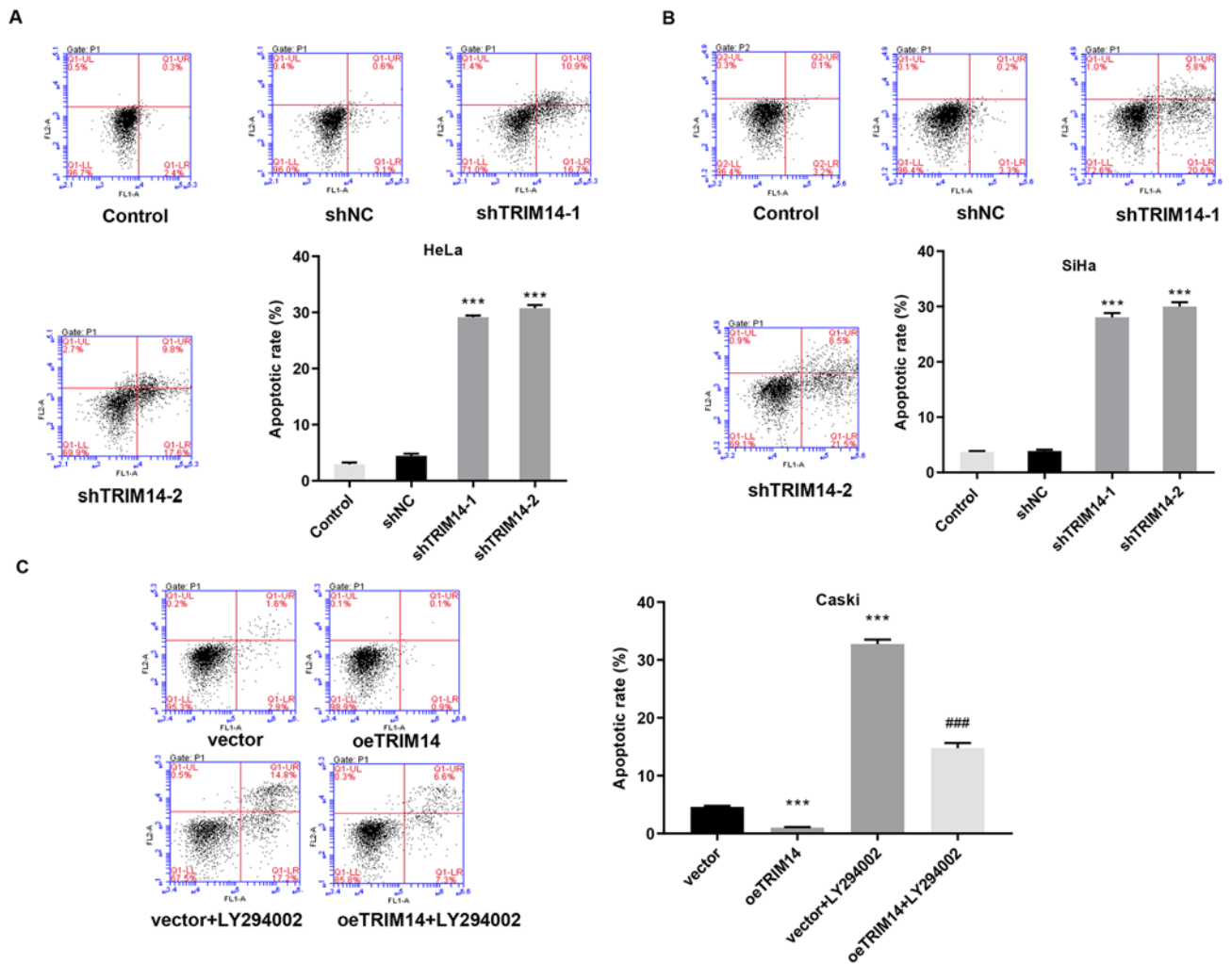


Figure 4. TRIM14 suppresses apoptosis of cervical cancer cells. The apoptotic rate of TRIM14 silenced (A) HeLa and (B) SiHa cells was measured using flow cytometry. *** $P < 0.001$ vs. shNC. (C) The apoptotic rate of human TRIM14 overexpressing cells (Caski cells) was detected by flow cytometry. *** $P < 0.001$ vs. vector; ### $P < 0.001$ vs. oeTRIM14. TRIM14, tripartite motif-containing 14; sh, short hairpin; NC, negative control; OE, overexpression.

Discussion

To the best of our knowledge, the present study demonstrated the expression of TRIM14 in cervical cancer cells and its role in promoting proliferation and inhibiting apoptosis of cervical cancer cells for the very first time. The present study also demonstrated that TRIM14 regulates cell proliferation and metastasis via the Akt signaling pathway. These findings fill the gap in the impact of TRIM14 on cervical cancer. Akt/mTOR is a very important cell signaling pathway, which results in the occurrence and development of various tumors (13-15). The use of Akt/mTOR inhibitors can significantly inhibit or kill tumor cells (16). The activation of Akt phosphorylation serves a role in promoting tumor cell proliferation, antiapoptosis and chemotherapy tolerance, and has been defined as an oncogene (17). The results of the present study demonstrated that activation of the Akt signaling pathway significantly promoted the proliferation and antiapoptotic effect in cervical cancer cells, which was consistent with earlier findings (13,18,19). Several studies have reported that TRIM14, a core protein, regulates the biological behavior of tumors through various signaling pathways, such as the SPHK1/STAT3 and Akt

signaling pathways (20-25). The results of the present study revealed that TRIM14 was differentially expressed in cervical cancer, suggesting that TRIM14 may regulate the biological behavior of a tumor through one or more signaling pathways. In addition, in the present study GSEA was used to predict and confirm the signaling pathways involved in cervical cancer, which suggested that TRIM14 regulated cell proliferation and apoptosis via the Akt signaling pathway. The findings of the present study demonstrated that TRIM14 could promote tumor cell proliferation and had an antiapoptotic effect.

Targeted therapy has been a research focus in the field of cancer in the past decade (26). However, studies on cervical cancer are still at the initial stage, which may explain the lack of understanding of the pathogenesis of cervical cancer. Thus, it is vital to clarify the underlying mechanism of cervical cancer.

In recent years, studies have reported the signaling pathway inhibitors have synergistic effects on radiotherapy and chemotherapy, which can significantly enhance the sensitivity of cancer therapy (27-29). Lee *et al* (30) have demonstrated that LY294002 improves the sensitivity of cervical cancer cells to radiotherapy in a significant time-dependent manner.

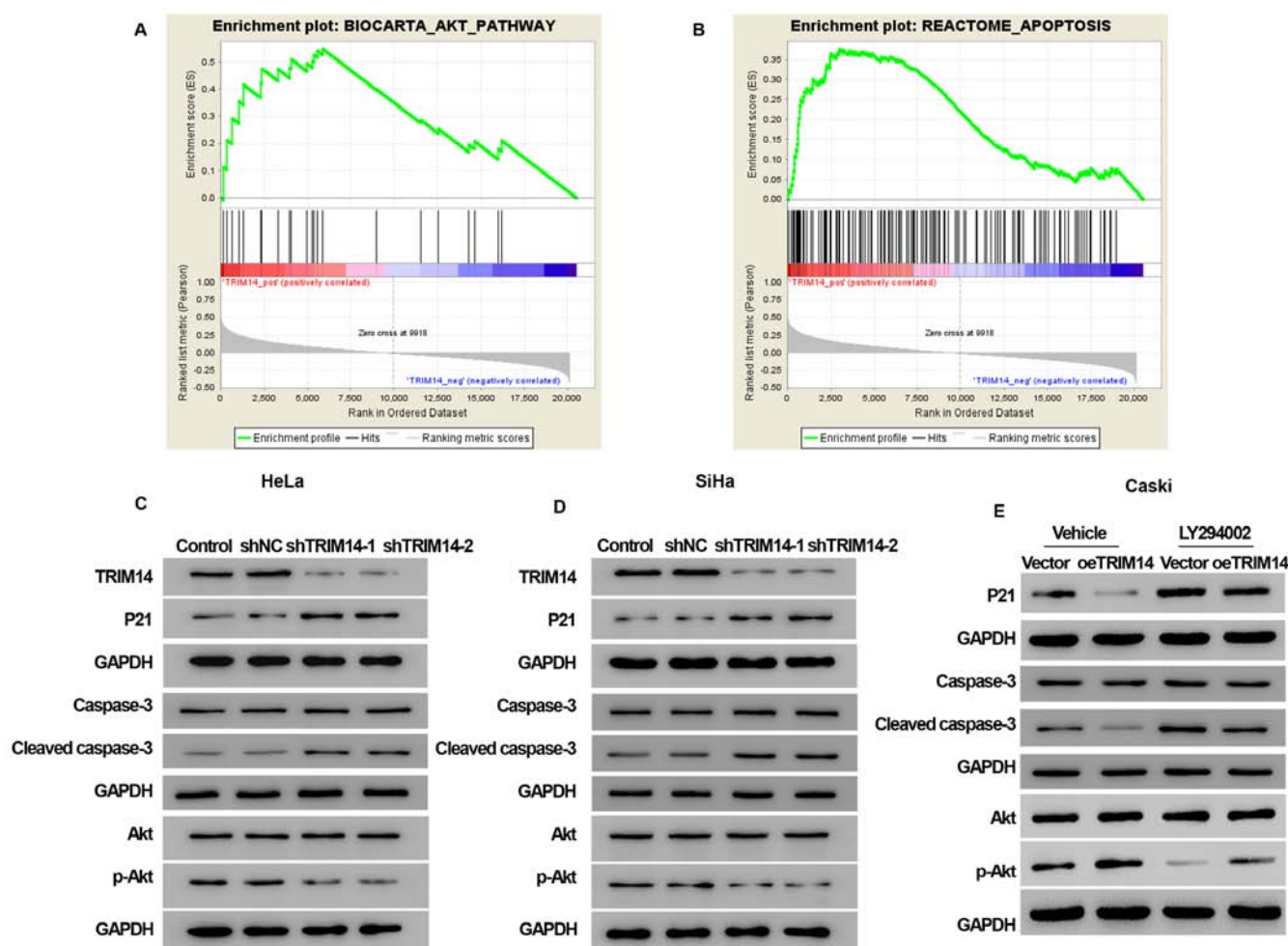


Figure 5. TRIM14 regulates cell proliferation and apoptosis via the Akt signaling pathway. The TRIM14 correlation signaling pathway was predicted by gene set enrichment analysis. The high expression TRIM14 sample enrichment to (A) BEICARTA_AKT_PATHWAY signaling pathway (FDR=0.010) and (B) REACTOME_APOPTOSIS signaling pathway (FDR=0.010). Western blotting was performed to analyze the expression levels of apoptosis indicators (P21, cleaved caspase-3 and caspase-3) and Akt indicators (Akt and phosphorylated-Akt) in HeLa (C), SiHa (D) and Caski cells (E) infected with shRNA. TRIM14, tripartite motif-containing 14; FDR, false discovery rate; p-Akt; phosphorylated-Akt; sh, short hairpin; NC, negative control; OE, overexpression.

However, due to the rapid metabolism of LY294002, this inhibition is transient and Akt activity returns to basal levels after 30 min (31). Thus, as a new Akt-related protein, TRIM14 may be a novel therapeutic target for the treatment of malignant tumors.

It has been reported that the high-risk age of carcinoma *in situ* is 30-50 years old and of invasive cancer is 45-55 years old (32). TRIM14 overexpression is associated with advanced clinical stage, TNM stage and shorter overall survival time in patients with oral squamous cell carcinoma (7). Consistent with this, the results of the present study demonstrated that high expression levels of TRIM14 in cervical cancer tissues was associated with clinical characteristics of patients with cervical cancer, mainly the age of patients. The high incidence of invasive cancer is 45-55 years old, which may explain the higher expression levels of TRIM14 in patients aged >45 years old.

It is well known that TRIM14 acts as an antiviral limiting factor and participates in regulating the natural immune response caused by the virus (33). However, it has been discovered that TRIM protein has another function. Nenasheva *et al* (34) observed that the stable expression

of TRIM14 gene in cells enhanced the transcription of a number of immune genes, such as IFN- α , IL-6, Akt1, etc., and inhibited the reproduction of alphavirus Sindbis, but the virus Sindbis infection of HEK-TRIM14 cells promoted the suppression of some genes involved in the innate immune system. Wang *et al* (20) also reported that microRNA-195-5p may inhibit the proliferation, migration and invasion of oral squamous cell carcinoma by interacting with TRIM14. Cyclic GMP-AMP synthase (cGAS) is a cytosolic viral DNA sensor that monitors abnormal cytoplasmic DNA, which is related to viral infection and tumorigenesis, and activates the immune response (35). Chen *et al* (36) observed that TRIM14 was upregulated upon viral infection and to recruit the deubiquitinating enzyme ubiquitin specific peptidase 14 to revert degradative ubiquitination of cGAS, improving its stability and enhancing the antiviral response against herpes simplex virus-1. HPV is a spherical DNA virus that can cause the proliferation of squamous epithelium of human skin and mucous membranes (37). High-risk HPV infection is closely related to the incidence of cervical cancer (38). However, in this study, the antiviral effect of TRIM14 was not examined, which is a limitation of this study. In addition, the effect of

TRIM14 on cervical cancer should be further verified through *in vivo* experiments.

In conclusion, TRIM14 regulates cell proliferation and apoptosis in cervical cancer via the Akt signaling pathway. Additionally, the expression of TRIM14 in cervical cancer tissue is related to the clinical features of patients with cervical cancer, mainly the age of patients. Combined with previous studies, these findings are of great significance for the pathological mechanisms of cervical cancer development. Moreover, as a new Akt-related protein, TRIM14 may be a novel therapeutic target for the treatment of malignant tumors.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

PL and XX made substantial contributions towards the conception and design of the study, and experiments. WD and CZ performed the histological examination of the cervical cancer, analysis and interpretation of data. QG performed the major bioinformatics analysis of the gene database. YC and HF performed molecular biological construction of TRIM14 gene and related molecular biology experiments and analysis. YS and JL performed cell experiments and analysis. HF and JL drafted the manuscript, aggregated the figures and discussed the results. All authors read and approved the final manuscript.

Ethics approval and consent to participate

This study was approved by the Ethics Committee of Obstetrics and Gynecology Hospital, Fudan University (Shanghai, China). All individual participants of the study provided their written informed consent.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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