miR-937 regulates the proliferation and apoptosis via targeting APAF1 in breast cancer

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**Background:** Previous research had shown that an imbalance in cell proliferation and apoptosis is a vital mechanism for tumorigenesis and cancer progression that may directly influence biological behaviors of cancer. microRNAs are associated with the occurrence and development of tumors. This study aimed to explore the influence of miR-937 on breast cancer regulation of APAF1 expression.

**Methods:** Cancer Genome Atlas microarray analysis (fold change > 2, p<0.05) was used to verify differentially expressed microRNAs and RT-qPCR was used to detect miR-937 mRNA level in breast cancer. Cell viability and proliferation were measured using CCK8 and colony formation assays, respectively, after the miR-937 mimics/inhibitors and their negative control were transfected into MCF7 cells. The variations in cell cycle and apoptosis were examined using flow cytometry. DAVID database was used to perform GO enrichment analysis. We use dual luciferase report system to detect the effect of miR-937 on the transcriptional activity of APAF1. APAF1 protein level was determined by Western blot assay.

**Results:** miR-937 was up-regulated in breast cancer cell lines and high miR-937 expression is associated with a poorer survival rate in cancer patients. miR-937 overexpression promoted the viability, down-regulated the G1 phase ratios and increased the ability of colony formation in breast cancer cells. miR-937 inhibition inhibited the viability and the ability of colony formation, promoted the apoptosis and up-regulated the G1 phase ratios. Our results showed that miR-937 targeted bind to the APAF1-3’UTR. APAF1 overexpression inhibited the viability and the ability of colony formation, promoted the apoptosis and up-regulated the G1 phase ratios. After cells were co-transfection miR-937 mimics and APAF1, cell apoptosis level was increased.

**Conclusion:** APAF1 up-regulation or APAF1 down-regulation in breast cancer may regulate cell proliferation and apoptosis.

**Keywords:** miR-937, APAF1, cell proliferation, apoptosis, breast cancer

**Introduction**

Breast cancers constitute a group of frequently occurring malignant tumors in women. They pose a serious threat to the lives of women worldwide. The data showed that breast cancers accounted for 25% of all cancers. The occurrence and progression of breast cancer particularly involve complex pathological processes caused by various biological, physical and chemical factors. Cells with clonal abnormal growth lead to the occurrence and development of tumors. According to a report, the cancer was characterized by genome mutation, persistent proliferative signals, suppressed cell apoptosis, and increased cell metastasis, inducing angiogenesis, immune escape, inflammation responses, and imbalance in cellular energy metabolism. Briefly, the development and progression of tumors result...
from loss of apoptosis in tumor cells, therefore, inducing or restoring cell apoptosis can have an anticancer effect.

miRNAs single-stranded, endogenous 19–22-nucleotide-long noncoding RNAs. They regulate post-transcriptional silencing by binding to the 3’-untranslated region (3’-UTR) of the target mRNAs with partial complementarity and affect the expression and regulation of genes.\(^3\),\(^4\) Furthermore, miRNAs are highly conserved and regulate ~30% of human genes.\(^5\) miRNAs are reported to be closely associated with cell proliferation, apoptosis, invasion, and migration, and miRNAs, including miR-200, let-7 and miR-10b, are abnormally expressed in breast cancer.\(^6\) To develop effective strategies to prevent and treat tumors, miRNA expression and the associated regulatory mechanisms that control the occurrence and progression of tumors must be studied further.

Cancer has a molecular map that includes somatic mutations, copy number variations, gene expression profile variations, and epigenetic variations.\(^7\) The rapid development of high-speed sequencing technologies and biotechnology has ushered in a new era of cancer genomes research. The Cancer Genome Atlas (TCGA) (http://cancergenome.nih.gov/) consists of genome, proteome, transcriptome, epigenome and clinical data from 32 tumor types that are not limited or restricted by the NHGRI and NCI.\(^8\) Subsequently, differential expression analysis performed by the Database for Annotation, Visualization and Integrated Discovery (DAVID) (https://david.abcc.ncifcrf.gov/) identified gene ontology (GO) terms.\(^9\) Target genes were predicted using miRDB (http://mirdb.org/) and Targetscan (http://www.targetscan.org/).\(^10\),\(^11\)

**Materials and methods**

**Bioinformatics analysis**

The TCGA database provided 5-year survival profiling data sets and miRNA expression data (http://cancergenome.nih.gov/). The gene list was then submitted to DAVID Bioinformatics Resources 6.8 (http://david.abcc.ncifcrf.gov) for GO pathway enrichment analysis. \(p<0.05\) was set as the threshold to screen for significant molecular function, cellular component and biological process terms.

**Cell culture and transient of miRNA mimics/inhibitors**

The Cell Bank of the Chinese Academy of Sciences provided human breast cancer cell lines (MCF7, MDA-MB-231, HER-2, and MDA-MB-415) and human mammary epithelial cells (MCF10A). Cells were incubated at 37°C in a humidified atmosphere containing 5% CO\(_2\). Next, the cells were cultured in DMEM (Gibco, ThermoFisher Scientific, Inc., Grand Island, NY, USA) containing 10% fetal bovine serum (FBS).\(^2\)\(\times\)\(10^5\) MCF7 cells were seeded in 60-mm plates 24 hrs prior to transfection. Synthetic miRNA mimics/inhibitors and their negative control (from Genepharma Technology Co. LTD) (Shanghai, China) were transfected into cells using HiPerFect reagent (QIAGEN, Germany) in OPTI-MEM media (Gibco; ThermoFisher Scientific, Inc.). The final concentrations of miR-937 mimic/inhibitors and their negative control were 50 nM. The transfected cells were incubated at 37°C with 5% CO\(_2\), and the subsequent experiments were performed 48 hrs after transfection. All experiments were repeated 3 times. The sequences for the primers were as follows: miR-937 mimics, sense 5’-AUCGGCGCUCUGA CUCUCUGCC-3′ and antisense 5’-GGCAGAGAGUGA CACGCGGAAUUU-3’; mimic controls, sense 5’-UUCUC CGACGUGUCACGTT-3’ and antisense 5’-ACAG UACGGAAGAATT-3’; miR-937 inhibitors, sense 5’-GGCAGAGAGUGACGCGGAA-3’ and inhibitor controls, sense 5’-CAGUA CUGUUUGUUGUGAAGAC-3’.

**Lentiviral transfection**

The lentivirus vector carrying miR-937APAF1 (pLV-APAF1), the negative control vector (pLV-NC), and the corresponding viruses (1×10\(^8\) PFU) were provided by Genepharma. The cells were inoculated into a 6-well plate at a density of 5×10\(^5\)/well. When 50–60% cells were fused, the lentivirus was added for transfection using 8 µg/mL polybrene (Sigma-Aldrich; Merck KGaA, Darmstadt, Germany). After the transfection of APAF1 in MCF7 cells for 48 hrs, the cells underwent the selection with the use of puromycin (2.0 µg/mL; Sigma-Aldrich; Merck KGaA) for 48 hrs. Then, cells were harvested, and the efficacy of transfection was tested by RT-qPCR or Western blot analysis. All experiments were repeated 3 times. APAF1 sequences: sense, 5’-ATGGATGCAAAGCTCG-3’ and antisense, 5’-TTATTCTAAAGTCTGTAAAATTA -3’. Negative control (NC) sequences: sense, 5’-UUCUGCGAACGUGUCACGTT-3’; and antisense, 5’-A CAGUGACACGUGUAAGAC-3’.

**Co-transfection of cells with APAF1-overexpression plasmid vector and miR-937 mimics**

The APAF1 overexpression and negative control plasmids were obtained from Genepharma (pLVX-APAF1-Zsgreen and pLVX-ires-Zsgreen, respectively). Cells (5 × 105 per well in 6-well plates) were cultured to 80% confluence in complete growth medium; then, co-transfection of miR-
937 mimics and APAF1 expression vector into MCF7 cells was performed using Lipofectamine 2000 (Thermo, Massachusetts, USA) according to the manufacturer’s instructions.

**Cell viability analysis**

Cell viability was assayed using a Cell Counting Kit 8 (CCK8) (Beyotime Institute of Biotechnology, Jiangsu, China), according to the manufacturer’s instructions. In brief, nearly $1 \times 10^3$ cells were seeded 96-well plates and were grown overnight in complete DMEM (HyClone; GE Healthcare) at 37°C. the next day, 10 µL CCK8 solution was added to each well, and the solution was incubated for 2 hrs. The absorbance in every well was evaluated using a microplate reader at 450 nm (Bio-Rad Laboratories, Inc., Hercules, CA, USA). After cell transfection with miR-937 mimic/inhibitors and their negative control or APAF1 overexpression and negative control plasmids, OD values were detected using CCK8 kit at 12, 24, 48, and 72 hrs. All experiments were performed 3 times. The viability was calculated using the OD ratio of a transfection group relative to the control.

**Cell cycle and apoptosis and analysis**

MCF7 cells were seeded in 6-well plates and then transfected with miR-937 mimics/inhibitors/NC or APAF1/NC for 24–48 hrs. For cell apoptosis detection, 5 µL Annexin V-phycocerythrin and 5 µL 7-aminoactinomycin D (Beyotime Institute of Biotechnology) were added to the cells, followed by incubation for 20 mins at room temperature. Cell apoptosis was evaluated by flow cytometer (BD Biosciences; Becton, Dickinson and Company) and apoptosis rates were analyzed with FlowJo software (FlowJo LLC, Ashland, OR, USA).

To synchronize cell cultures, cells were cultured in medium supplemented with 10% FBS overnight, rinsed with PBS, and then transferred to serum-free medium for 24 hrs. To test the cell cycle distribution, transfected cells were digested using trypsin, centrifuged at 425× g (cell density, $1 \times 10^6$ cells/mL), washed twice with PBS and fixed in −20°C ethanol for 2 hrs. For cell cycle distribution detection, 1 µL DAPI was added per 100 µL cell suspension, and the cells were incubated for 40 mins in the dark. All samples were evaluated by flow cytometry (BD Biosciences; Becton, Dickinson and Company).

**Caspase activity assays**

Caspase-3/9 activity was assayed using the Caspase-3/9 activity assay kit (Beyotime, Beijing, China) according to the manufacturer’s instructions. After transfection, the cells were washed with cold PBS and centrifuged at 800× g. The cell pellet was then lysed by the addition of 50 µL of chilled cell lysis buffer and incubation on ice for 10 mins. The lysed mixture was clarified by centrifugation at 10,000× g for 1 mins and the supernatant was transferred to a new microcentrifuge tube. The protein concentration in the supernatant of each sample was measured using the Bradford assay and then adjusted to 100 µg of protein per 50 µL of cell lysis buffer for subsequent application to each well of a 96-well plate. Next, 50 µL of 2x reaction buffer containing dithiothreitol at a final concentration of 10 mM was added into each sample well. After mixing, the respective substrate of each caspase was added to each well and the plate was incubated at 37°C for 1–2 hrs. Finally, the absorbance of each reaction at 400–405 nm was measured on a microplate reader. Each experiment was performed in triplicate.

**Colony formation assay**

After MCF-7 cells were transfected with miR-937 mimic/inhibitors and their negative control or APAF1 overexpression and negative control plasmids for 48 hrs, nearly $1 \times 10^3$ cells were plated in 6-well plates and incubated in a serum-free medium. Fourteen days later, cells were washed thrice PBS and fixed in 4% paraformaldehyde for 10 mins at 37°C. Cells were stained with 0.1% crystal violet (Sigma-Aldrich Co.).

The number of colonies were counted using ImageJ software (National Institutes of Health, Bethesda, MD, USA). All experiments were performed in triplicates.

**Luciferase reporter assay**

In the luciferase reporter assay, MCF7 cells were transfected with 10 ng Renilla luciferase vector with Lipofectamine® 2000 and 200 ng of APAF1-3-UTR or APAF1-mut and 20 mM miR-937 mimics/inhibitors/control (Invitrogen; Thermo Fisher Scientific, Inc.). The cells were collected 48 hrs after transfection and were analyzed using the Dual-Luciferase Reporter Assay System (Promega Corporation, Madison, WI, USA). The luciferase activity was detected using the GloMax fluorescence reader (Promega Corporation), and the authors detected luciferase activity. The pRL-CMV Renilla luciferase
reporter was used for contrast correction in transfection efficiency. Each experiment was performed in triplicate.

**Protein extraction and western blotting assay**

Total protein was obtained from cells using a protein extraction kit (Solarbio, Beijing, China). The protein sample concentrations were measured using a BCA kit (Solarbio) according to the manufacturer’s instructions. A total of 50 μL of cell lysate was loaded and run on 8% SDS-PAGE gel and then transferred onto a polyvinylidene difluoride membrane. After blocking with 5% nonfat dry milk, the membrane was incubated using the indicated antibodies at 4°C overnight. After washing with Tris-buffered saline-Tween 20 (TBST) 3 times, the membrane was incubated with horseradish peroxidase-conjugated secondary antibodies at 37°C for 1 hr and washed with TBST 3 times. Finally, the proteins were visualized using an ECL Western blotting detection kit (Amersham Biosciences, Little Chalfont, UK) according to the manufacturer’s instructions. The authors used the following antibodies and dilutions: APAF1 (1:1000, ab2001; Abcam, UK); β-actin (1:3,000; ab124964; Abcam, Cambridge, UK). Each experiment was performed in triplicate.

**RNA extraction and RT-qPCR**

Total RNA was extracted from cells using TRIzol reagent (Thermo Fisher Scientific) according to the manufacturer’s protocol. Next, 2 μg of extracted total RNA was used to synthesize cDNA using a one-step RT-PCR kit (TaKaRa, Dairaku, Tokyo, Japan). Then, SYBR Green Mix (Roche Biosciences, Little Chalfont, UK) according to the manufacturer’s instructions. A total of 50 μL of cell lysate was loaded and run on 8% SDS-PAGE gel and then transferred onto a polyvinylidene difluoride membrane. After blocking with 5% nonfat dry milk, the membrane was incubated using the indicated antibodies at 4°C overnight. After washing with Tris-buffered saline-Tween 20 (TBST) 3 times, the membrane was incubated with horseradish peroxidase-conjugated secondary antibodies at 37°C for 1 hr and washed with TBST 3 times. Finally, the proteins were visualized using an ECL Western blotting detection kit (Amersham Biosciences, Little Chalfont, UK) according to the manufacturer’s instructions. The authors used the following antibodies and dilutions: APAF1 (1:1000, ab2001; Abcam, UK); β-actin (1:3,000; ab124964; Abcam, Cambridge, UK). Each experiment was performed in triplicate.

**Statistical analysis**

For statistical analyses, SPSS software v13.0 (SPSS, Inc., Chicago, IL, USA) was used. The data are reported as the mean ± SD. For comparison of protein or miRNA expression, a paired sample t-test was employed. Spearman’s correlation analysis was used to analyze the correlation between miR-937 and APAF1. *p<0.05 was considered statistically significant.

**Results**

**Bioinformatics analysis of miR-937 expression in breast cancer and miR-937 highly expressed in breast cancer cell lines**

Firstly, microRNA expression was analyzed in 1096 breast cancer tissues and 112 normal breast tissues based on the breast cancer gene expression profiles in the TCGA database. A total of 86 genes were identified as differentially expressed genes (DEGs) (Figure 1A and B, *p<0.05, logFC>2), including 67 up-regulated and 19 downregulated genes. Survival analysis revealed that miR-301b, miR-204, miR-3677, miR-105, miR-133a-2, miR-1258, miR-937, and miR-449c were strongly associated with breast cancer survival rate (*p<0.05). The survival rate of high miR-937 expression was lower than that of low miR-937 expression in breast cancer patients (Figure 1C, *p<0.05). Thus, this indicates that miR-937 may be involved in the related biological functions. To confirm the above idea, the expression level of miR-937 was detected by RT-qPCR assay. miR-937 was significantly highly expressed in breast cancer cell lines (Figure 1D, *p<0.05). After MCF-7 cells underwent the transfection using miR-937 mimics/inhibitors/control for 48 hrs, RT-qPCR assay was performed to identify the transfection efficiency (Figure 1E and F).

**The role of miR-937 mimics in the proliferation and apoptosis of MCF7 cells**

According to results from CCK8 assay, up-regulation of miR-937 could increase cell viability (Figure 2A). The caspase-3/9 activities measured using biochemical analysis were consistent with the results of the flow cytometric analysis (Figure 2B and C). Flow cytometric analysis indicated that overexpression of miR-937 could significantly down-regulate the G1 phase ratios and increase G2 phase ratios (Figure 2D and E, *p<0.05). However, cell apoptosis in MCF7 cells
transfection with miR-937 mimics did not differ between these three groups (Figure 2F and G, p<0.05). Further studies showed that MCF7 cells with high miR-937 had stronger continuous colony forming ability (Figure 2H and I, p<0.05).

The role of miR-937 inhibitors in the proliferation and apoptosis of MCF7 cells
According to results from CCK8 assay, down-regulation of miR-937 decreased cell viability (Figure 2A). Caspase-3/9 activities measured using biochemical analysis were
consistent with the results of the flow cytometric analysis (Figure 2B and C). Flow cytometric analysis indicated that low expression of miR-937 could arrest MCF7 cells at the G1/S phase (Figure 3D and E). The apoptotic cells were detected by flow cytometry to detect labeled Annexin V-FITC/PI. miR-937 inhibitors could significantly promote cell apoptosis (Figure 3F and G, \( p < 0.05 \)). Cell proliferation ability was measured by colony forming assay. The results showed that colony forming efficiency significantly decreased (Figure 3H and I, \( p < 0.05 \)).
Figure 3 Effect of down-regulated miR-937 on apoptosis and proliferation. (A) The cell viability was detected by CCK8 assay in MCF7 cells transfection with inhibitors and their negative control; (B and C) the caspase-3/9 activities measured using biochemical analysis in MCF7 cells transfection with inhibitors/negative control; (D and E) cell cycle was estimated by flow cytometry assay in MCF7 cells transfection with inhibitors/negative control; (F and G) cell apoptosis was detected by flow cytometry assay in MCF7 cells transfection with inhibitors/negative control; (H and I) colony formation was used to detect the ability of cell proliferation in MCF7 cells transfection with inhibitors/negative control. Data are presented as the mean ± standard deviation. *p<0.05 versus blank group, †p<0.05 versus inhibitors group.
APAF1 is a miR-937 target gene and is negatively regulated by miR-937

miR-937 was identified using miRNAs that overlapped 200 target genes, including APAF1, across different databases (miRDB, http://mirdb.org and TargetScan, http://www.targetscan.org/) (Figure 4A). miR-937 functions were predicted using GO analysis, while the authors found that APAF1 was mainly enriched in positive regulation of apoptotic process and signaling pathway terms (Figure 4B and C). APAF1’s mRNA and protein expression levels were detected using RT-qPCR and Western blotting. APAF1 was lowly expressed in breast cancer cell lines (Figure 4D–F). Luciferase assay was performed to validate the target sites in the APAF1 3’UTR (Figure 4G). Luciferase reporter assay showed that the relative luciferase activity of APAF1 significantly decreased after miR-937 overexpression in MCF7 cells, but it increased after miR-937 suppression. However, no significant effect was found after mutating APAF1 (Figure 4H and I). In addition, the mRNA
and protein expression levels of APAF1 were significantly suppressed after up-regulating of miR-937 and increased after down-regulating miR-937 in MCF7 cells (Figure 5A–D).

**Up-regulation of APAF1 affected cell cycle, proliferation, and apoptosis**

First, cell transfection efficiency was detected using RT-qPCR and Western blotting after MCF7 cells transfection with APAF1 (Figure 5E and F). CCK8 assay showed that the cell viability significantly decreased after APAF1 overexpression in MCF7 cells (Figure 6A). Caspase-3/9 activities measured using biochemical analysis were consistent with the results of the flow cytometric analysis (Figure 6B and C). Flow cytometric analysis indicated that up-regulation of APAF1 could arrest MCF7 cells at the G1/S phase and promote cell apoptosis (Figure 6D–G). The cloning efficiency of MCF7 cells declined sharply in the APAF1 group (Figure 6H and I).
miR-937 regulated cell proliferation and apoptosis by targeting APAF1 in MCF7 cells

Cell viability was promoted by miR-937 overexpression in MCF7 cells, which was also decreased after MCF7 cells co-transfection with miR-937 mimics and APAF1 based on CCK8 analysis (Figure 7A). Further, the cell apoptosis rate and caspase-3/9 activity of control, control + NC, and miR-937 mimics+NC groups showed no obvious difference. The cell apoptosis rate and caspase-3/9 activity increased after MCF7 cells were co-transfected with miR-937 mimics and APAF1 based on flow cytometry results (Figure 7B and E).

Figure 6 Up-regulation of APAF1 regulated cell proliferation and apoptosis in MCF7 cells. (A) The cell viability was detected by CCK8 assay in MCF7 cells transfection with APAF1 and negative control; (B and C) the caspase-3/9 activities measured using biochemical analysis in MCF7 cells transfection with APAF1/negative control; (D and E) cell cycle was estimated by flow cytometry assay in MCF7 cells transfection with APAF1/negative control; (F and G) cell apoptosis was detected by flow cytometry assay in MCF7 cells transfection with APAF1/negative control; (H and I) colony formation was used to detect the ability of cell proliferation in MCF7 cells transfection with APAF1/negative control. Data are presented as the mean ± standard deviation. *p<0.05 versus control group, †p<0.05 versus NC group.
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cancer cell lines (Figure 1D), and the results agreed with the

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an important role in cell proliferation in gastric cancer

and lung cancer.12 According to the study results, the authors

speculated that miR-937 may be involved in breast cancer

cell proliferation. Our results reveal that down-regulation of

miR-937 suppressed cell proliferation increased caspase-3/9

activity to induced cell apoptosis, and arrested the cells at the

G1/S phase (Figures 1–3). The balance between proliferation

and apoptosis was broken in the development of cancer, the

ability of proliferation much higher than the ability of apo-

ptosis in the malignant tumor cell.18,19 The current study found

that the role of miR-937 in proliferation was higher than that

of apoptosis. This is consistent with the previous results.12,17

Accordingly, these results demonstrate a correlation between

cellular biological function and miR-937. Next, the miR-937

target genes were predicted using the miRDB and TargetScan

databases, and 200 genes were identified (Figure 4A). To

identify the enrichment of target genes, 3 GO terms, namely

molecular function, cellular component, and biological pro-

duction was measured using biochemical analysis in MCF7
cells co-transfection with miR-937 mimics and APAF1; (D

and

E) cell apoptosis was detected by flow cytometry assay in MCF7
cells transfected with inhibitors/negative control. Data are

presented as the mean ± standard deviation. *p<0.05 versus

control group, †p<0.05 versus control+NC group, ‡p<0.05 versus

miR-937 mimics + NC group.

Figure 7 miR-937 regulated cell proliferation and apoptosis by targeting APAF1 gene. (A) The cell viability was detected by CCK8 assay in MCF7 cells co-transfection with

miR-937 mimics and APAF1; (B and C) the caspase-3/9 activities measured using biochemical analysis in MCF7 cells co-transfection with miR-937 mimics and APAF1; (D and

E) cell apoptosis was detected by flow cytometry assay in MCF7 cells transfected with inhibitors/negative control. Data are presented as the mean ± standard deviation. *p<0.05 versus control group, †p<0.05 versus control+NC group, ‡p<0.05 versus miR-937 mimics + NC group.

Discussion

It reported that microRNA feedback loops induced apoptosis

in breast cancer and colorectal cancer.14,15 A study showed that

13 miRNAs were expressed in breast cancer tissues and

serum, but they showed variations.16 Thus, miRNAs may be

released into the blood via breast cancer cells and be involved

in different molecular mechanisms in tissues and serum.

There were 1096 patients with breast cancer and 112 controls

in the TCGA cohort (Figure 1A and B). The average

miRNAs expression level in the TCGA cohort was analyzed.

From the expression data in 86 DEGs, 8 miRNAs are closely

related to the breast cancer survival rate (Figure 1C). miR-

301b, miR-204, miR-3677, miR-105, miR-133a-2, and miR-

1258 were reported in the previous literature. Therefore,

miR-937 was studied further using RT-qPCR. The results

here showed that miR-937 was highly expressed in breast

cancer cell lines (Figure 1D), and the results agreed with the

bioinformatic analysis. Research found that miR-937 played

an important role in cell proliferation in gastric cancer17 and

lung cancer.12 According to the study results, the authors

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identify the enrichment of target genes, 3 GO terms, namely

molecular function, cellular component, and biological pro-

cession, were employed (Figure 4B and C). In addition, the

authors found that APAF1 was mainly enriched in the cell

apoptosis function. But apoptin-induced apoptosis is cas-
pase-dependent and also engages in the Apaf-1-apoptosome-

mediated mitochondrial death pathway.20 Therefore, further

study is needed to explore whether miR-937 affects cell

proliferation and apoptosis by altering APAF1 expression.

APAF1 is a critical component of the apoptosome

that could be activated by various cellular stimuli, DNA damage,

and oncogene activation.13 APAF1 inactivation suggests that it

may serve as a tumor suppressor.13 Previous studies verified

that the mitochondrial death gene APAF1 is highly expressed

in breast cancer cells after high-dose 5-FU treatment21 and

gastric cancer cell after oridonin treatment.22 APAF1 is also
closely correlated with cell apoptosis in cutaneous squamous cell carcinoma, prostate cancer, lung cancer, and colorectal cancer. According to our results, APAF1 is low expressed in breast cancer cell lines. A dual-luciferase reporter assay revealed that the relative luciferase activity decreased significantly after miR-937 mimics treatment in the WT-3′-UTR-APAF1 system, but it was not significantly changed by miR-937 mimics in the MUT-3′-UTR-APAF1 system (Figure 4). The overexpression of APAF1 significantly promoted cell apoptosis and suppressed cell proliferation (Figures 5–6). To further explore the correlation between APAF1 and miR-937, cell viability and apoptosis were assessed using the CCK8 and flow cytometry assays, and caspase-3/9 activity detection after MCF7 cells were co-transfected with miR-937 mimics and APAF1. The results showed that cell proliferation was suppressed and cell apoptosis was promoted by increasing caspase-3/9 activity after MCF7 cells were co-transfected with miR-937 mimics and APAF1 (Figure 7).

In conclusion, the frequent up-regulation of APAF1 and/or down-regulation of miR-937 in breast cancer may shift the balance of cell proliferation and apoptosis.

**Abbreviation list**

APAF1, apoptotic peptide activating factor 1; TCGA, Cancer Genome Atlas; GO, gene ontology; CCK8, Cell Counting Kit-8; UTR, untranslated region; DAVID, Database for Annotation, Visualization and Integrated Discovery; NHGRI, National Human Genome Research Institute; NCI, National Cancer Institute NCI.

**Availability of data and materials**

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

**Author contributions**

All authors contributed to data analysis, drafting and revising the article, gave final approval of the version to be published, and agree to be accountable for all aspects of the work.

**Disclosure**

The authors report no conflicts of interest in this work.

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