

LOXL1-AS1 promotes thymoma and thymic carcinoma progression by regulating miR-525-5p-*HSPA9*

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Abstract. Due to the lack of specific symptoms in early thymic epithelial tumours (TETs), patients are mostly in the advanced stage at the time of presentation. The aim of the present study was to explore the mechanism by which the long noncoding RNA (lncRNA) LOXL1-AS1 affects thymoma and thymic carcinoma progression by targeting the miR-525-5p-*HSPA9* axis. Bioinformatics was used to analyse the process of LOXL1-AS1 targeting miR-525-5p-*HSPA9* and its expression characteristics in TET. The relationships between LOXL1-AS1, miR-525-5p, *HSPA9* and prognosis were analysed. The dual luciferase reporter assay was applied to verify targeting. The gene was knocked down or overexpressed by plasmid transfection. Cell counting kit 8 (CCK-8) assay, flow cytometry and Transwell assay were used to detect cell viability, apoptosis and invasion ability, respectively. Proteins and RNAs were examined by western blot analysis and qPCR, respectively. A tumour-burdened assay was used to perform *in vivo* verification. LOXL1-AS1 and *HSPA9* were overexpressed in thymoma and thymic carcinoma; high levels of LOXL1-AS1 and *HSPA9* were associated with poor prognosis, and there was a significant positive correlation between their levels. Downregulation of miR-525-5p expression was also associated with poor prognosis of patients. Clinical trials also demonstrated the same trends. miR-525-5p inhibited the expression of *HSPA9* protein by targeting the 3'-untranslated region (UTR) of *HSPA9* mRNA. LOXL1-AS1 promoted the expression of *HSPA9* as a sponge targeting miR-525-5p. Animal experiment results also showed that knockdown of miR-525-5p promoted cancer by promoting the expression of *HSPA9*. In conclusion, LOXL1-AS1 and *HSPA9* are highly expressed in thymoma and thymic carcinoma; miR-525-5p is

expressed at low levels in thymoma and thymic carcinoma; and downregulation of miR-525-5p is associated with poor prognosis. In summary, this study demonstrates that LOXL1-AS1 acts as a sponge that targets miR-525-5p to promote *HSPA9* expression, thereby promoting the growth and invasion and inhibiting apoptosis of thymoma and thymic carcinoma cells.

Introduction

Thymic epithelial tumours (TETs) mainly refer to thymomas derived from thymic epithelial cells (1). The main feature of TETs is abnormal proliferation of epithelial cells, which occurs in 0.2 to 1.5% of all malignant tumours (2). The 2015 WHO classification criteria (3) divided TETs into seven subtypes, namely, type A, atypical type A, type AB, type B1, type B2, type B3, and thymic carcinoma. Thymic cancer can be divided into different types, such as squamous cell carcinoma, adenocarcinoma, and mucoepidermoid carcinoma. As TETs are tumours that are prone to recurrence *in situ* but rarely metastasize, complete surgical resection is the primary treatment option (4,5). However, due to the lack of specific symptoms in early TET, patients are mostly at an advanced stage at the time of presentation (6). Moreover, for patients with thymic carcinoma, there may be a possibility of high recurrence and metastasis after surgery, radiotherapy and chemotherapy (7,8). At present, the treatment plan for thymic carcinoma remains controversial. Analysis of the mechanism of TET recurrence and metastasis has great clinical significance.

MicroRNA (miRNA) is a series of small-molecule noncoding single-stranded RNAs that consist of approximately 22 nucleotides encoded by an endogenous gene (9). MiRNA is mainly involved in post-transcriptional gene expression regulation, and it can directly bind to target message RNA (mRNA) by recognizing and complementing the 3'-untranslated region (UTR) (10,11). This function of miRNAs causes RNA degradation or translation, thereby downregulating the expression of target genes. This process by which miRNA regulates gene expression is regulated by long noncoding RNA (lncRNA). LncRNAs are a class of RNAs that are more than 200 nucleotides in length and do not have protein translation capabilities (12). LncRNA can target miRNA as a sponge by competing endogenous RNA (ceRNA), thereby regulating the role of miRNAs in the degradation and translation of mRNA (13,14). The mechanism of lncRNA-miRNA-mRNA has

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been elucidated in tumours (15,16); however, there are many RNAs, and researchers are focused on finding more meaningful RNAs. Bioinformatics analysis helps to identify more important and meaningful RNAs (17).

In this study, TET was the research object. TCGA data and clinical results revealed that LOXL1-AS1 and *HSPA9* were highly expressed, miR-525-5p was expressed at low levels, and these findings were associated with the prognosis of TET patients. Moreover, LOXL1-AS1 promoted invasion and inhibited apoptosis by regulating miR-525-5p-*HSPA9* in thymoma and thymic carcinoma cells.

Materials and methods

Bioinformatics analysis. The expression characteristics of LOXL1-AS1, miR-525-5p, *HSPA9* and the prognosis in TCGA were analysed through the tool websites GEPIA (<http://gepia.cancer-pku.cn/index.html>) and Starbase (<http://starbase.sysu.edu.cn/index.php>).

Clinical research. TETs were collected (n=70), with thymoma tissues from 42 patients and thymic carcinoma from 28 patients. Thirty patients with normal thyroid tissue were used as a control group. All tissue samples were obtained from the Shanghai General Hospital from March 2011 to March 2014. None of the samples were treated with radiotherapy or chemotherapy. The levels of LOXL1-AS1, miR-525-5p and *HSPA9* mRNA in the samples were detected by quantitative polymerase chain reaction (qPCR). The *HSPA9* proteins were detected via western blot analysis. The relationships between the levels of LOXL1-AS1, miR-525-5p, *HSPA9* and the 5-year survival rate were analysed.

The patients were informed and agreed to the contents of this study; written informed consent was provided. This study was approved by the ethics committee of Shanghai General Hospital.

Cell culture and transfection. The thymoma cell line Thy0517 is derived from AB-type thymoma tissue and established by the Thoracic Surgery of the General Hospital of Tianjin Medical University (China). The Ty-82 cell line was derived from the metastatic thymic carcinoma undifferentiated cell line, purchased from the BioVector NTCC Typical Culture Collection (Beijing). Thymocytes HBT8810 cells were constructed from the thymus of an aborted 6-month-old fetus. The cells were obtained from Professor Heng Cun from the Chinese Academy of Medical Sciences. The cells were cultured in Dulbecco's modified Eagle's medium containing 10% foetal bovine serum (FBS, Thermo Fisher Scientific), 100 IU/ml penicillin, and 100 µg/ml streptomycin and maintained in a culture incubator at 37°C and 5% CO₂. The genes in the cells were overexpressed or downregulated by plasmid transfection. In brief, 2 µl Lipofectamine™ 2000 (Invitrogen), 40 pmol of miR-525-5p mimic, miR-525-5p inhibitor, sh-*HSPA9*, sh-LOXL1-AS1 or negative control (NC) (GenePharma) were mixed in 50 µl serum-free medium at room temperature for 15 min. The lipid compounds were diluted in 300 µl serum-free medium and 600 µl medium containing FBS to produce a 1-ml volume mixture and incubated with the cells at 37°C with 5% CO₂ for subsequent experiments.

Reverse transcription (RT)-qPCR. Total RNA from tissues and cells was obtained using TRIzol (Invitrogen). The concentration and purity were detected by a NanoDrop2000 spectrophotometer (Nano Drop Technologies). RNA was reverse transcribed using a reverse transcription cDNA kit (Thermo Fisher Scientific) for synthesis of cDNA (42°C for 60 min, 70°C for 5 min and then 4°C preservation). SYBR-Green PCR Master Mix (Roche) and PCR Detection System (ABI 7500, Life Technology) were applied to conduct the RT-qPCR experiments. The PCR cycle was as follows: Pretreatment at 95°C for 10 min; followed by 40 cycles of 94°C for 15 sec, 60°C for 1 min, finally at 60°C for 1 min and at 4°C for preservation. A comparative cycle threshold ($\Delta\Delta Cq$) was employed to analyse the expression of RNAs (18). *GAPDH* and *U6* expression was used for normalization. The primers were designed and synthesized by Genecopoeia (Guangzhou) and are shown in Table I.

Dual luciferase reporter assay. Wild-type (WT)/mutated (MUT) LOXL1-AS1/*HSPA9* and miR-525-5p mimic were both cloned into pMIR-REPORT Luciferase vectors (Ambion; Thermo Fisher Scientific). Thy0517 Ty-82 cells were transfected with both vectors using Lipofectamine 2000 for 24 h. The Dual Luciferase-Reporter 1000 Assay System (Promega) was used to evaluate luciferase activity.

Cell counting kit 8 (CCK-8) assay. Cells (2x10⁴ cells/ml, 100 µl per well) were seeded in 96-well plates, and 10 µl of CCK-8 (Beyotime Institute of Biotechnology) was added and cultured at 37°C for 2 h. The optical density (OD) at 450 nm was measured using a microplate reader (Tecan Infinite M200 Micro Plate Reader; LabX) to calculate relative cell viability.

Flow cytometry. Apoptosis rates were tested using flow cytometry (BD FACSCalibur) with an Annexin V-FITC/PI kit (Sanjian Biological Technology Co., Ltd.). The reagents were added according to the manufacturer's instructions. Q2+Q3 was the apoptotic rate.

Transwell assay. Cells (3x10⁴) were transferred to the upper chamber of a Transwell apparatus (8-µm; BD Biosciences). As a chemoattractant, the bottom chamber was filled with complete medium supplemented with 10% FBS. After 48 h of incubation, the cells that did not invade through the membrane were wiped. The cells were then fixed with 20% methanol and stained with 0.2% crystal violet. Cells invading the bottom chamber per field were counted under an inverted microscope (Olympus IX71).

Western blot analysis. The protein was extracted from cells and tissues using protein lysate, and the concentration was detected by a BCA kit. Then, 25 µg protein from each sample was separated using 10% SDS-PAGE at 110 V for 100 min and transferred to PVDF membranes at 90 V for 90 min. The PVDF membrane was blocked in 5% nonfat milk for 1 h at room temperature. The HSPA9 antibody (ab2799; Abcam; 74 kDa) and GAPDH antibody (ab8245; Abcam) were diluted at 1:1,000 with 5% BSA and added to the cells overnight at 4°C. Then, the secondary antibody (sc-516102/sc-2357; Santa Cruz

Table I. Primer sequences.

Primer name	Sequence (5'-3')
LOXL1-AS1: Forward	TTCCCATTTACCTGCCCCAAG
Reverse	GTCAGCAAACACATGGCAAC
miR-525-5p: Forward	GCGGTCCCTCTCCAAATGT
Reverse	AGTGCAGGGTCCGAGGTATT
HSPA9: Forward	AAGCTTCATATGATAAGTGCCAGCCGAGCTGCA
Reverse	GGATCCTTACTGTTTTCCTCCTTTTGATCTTCCTT
U6: Forward	CTCGCTTCGGCAGCACA
Reverse	AACGCTTCACGAATTTGCGT
GAPDH: Forward	GGAAGGACTCATGACCACAGTCC
Reverse	TCGCTGTTGAAGTCAGAGGAGACC

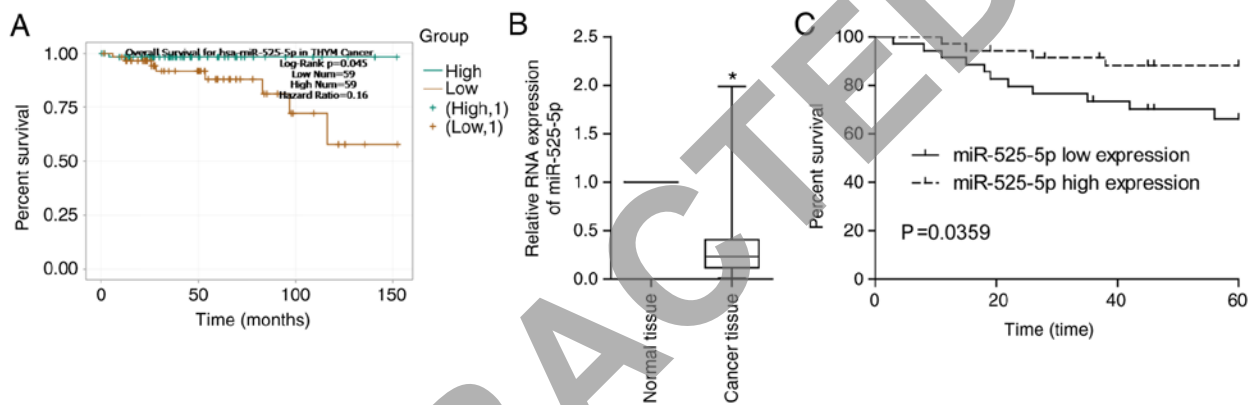


Figure 1. Low levels of miR-525-5p are associated with poor prognosis in TET. (A) The relationship between miR-525-5p and the survival rate of thymoma patients in TCGA. (B) Expression characteristics of miR-525-5p in TETs. (C) The relationship between miR-525-5p and the survival rate of TET patients. *P<0.05.

Biotechnology, Inc.) was diluted at 1:5,000 and added to the cells at room temperature for 2 h. Protein blot bands were detected by Pierce™ ECL plus Western blotting substrate (Thermo Fisher Scientific) in ChemiDoc MP (Bio-Rad).

Tumour-burdened assay. The animal experiment protocol was approved by the Animal Experimentation Ethics Committee of Shanghai General Hospital.

Specific pathogen-free (SPF) 4-week-old BALB/c nude mice were purchased from the Animal Center of Air Force Medical University (Shanghai). All mice were housed in a specific pathogen-free animal facility with free access to water and food at 22±1°C with 55±2% humidity and a 12-h light/dark cycle. After transfection, the cells were used to build the model. The mice were injected with 1×10⁶ cells. Twenty-eight days after injection, the mice were sacrificed by cervical dislocation. Mice were considered as dead when the breathing and heartbeat stopped, no reflexes occurred, and the body became cold. Then, the tumours were removed for weighing and images were captured.

Statistical analysis. Experimental data are presented as the mean ± SD. Statistical analysis was performed using one-way analysis of variance (ANOVA) and Tukey's multiple comparison test served as the post hoc test. The two-tailed t-test was used to analyze the difference between the two groups. The

log-rank test was used for survival analysis. Pearson's correlation analysis was used to analyze the correlation of continuous variables. P<0.05 was statistically significant. All statistical analyses were performed using GraphPad Prism 7.

Results

Low levels of miR-525-5p are associated with poor prognosis in TET. Through the TCGA database, we found that thymoma patients with low miR-525-5p levels had a lower 5-year survival rate (Fig. 1A). By detecting clinical thymoma and thymic carcinoma samples, it was found that miR-525-5p in TET tissues was significantly lower than that in normal tissues (Fig. 1B). Low levels of miR-525-5p predicted a worse prognosis (Fig. 1C).

miR-525-5p promotes apoptosis and inhibits invasion in thymoma and thymic carcinoma cells. Ty-82 and Thy0517 cells were divided into 4 groups: Mimic-NC, mimic-miR-525-5p, inhibitor-NC and inhibitor-miR-525-5p. The level of miR-525-5p was detected by RT-qPCR after transfection, and the results showed that the transfection experiment was successful (Fig. 2A and B). The cell viability of each group on the 1st, 2nd, 3rd, 4th and 5th day was examined by the CCK-8 assay. The results showed that the cell viability of the mimic-miR-525-5p group was significantly decreased, and the

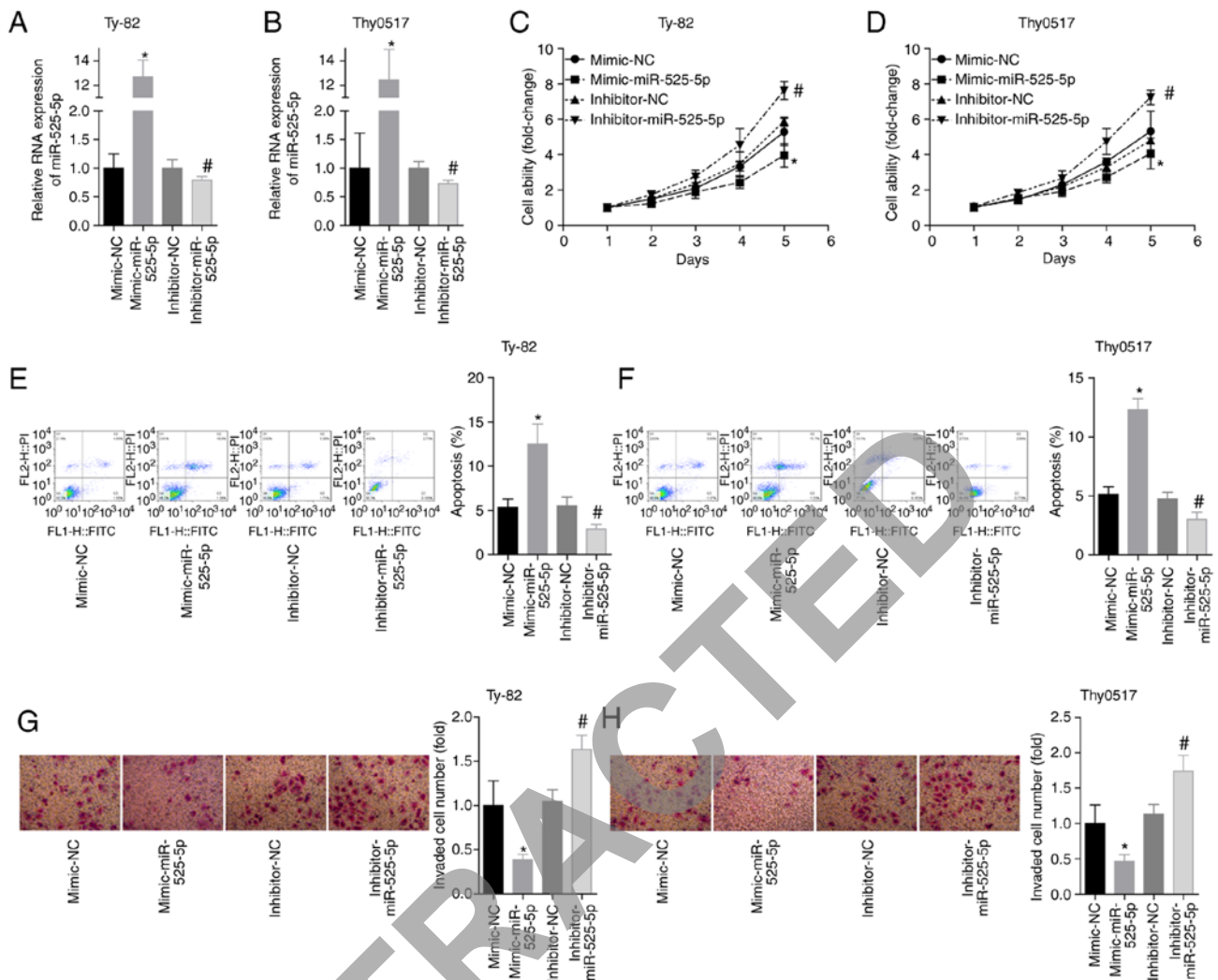


Figure 2. miR-525-5p promotes apoptosis and inhibits invasion in thymoma and thymic carcinoma cells. (A and B) Expression characteristics of miR-525-5p in each group. (C and D) Cell abilities of Thy0517 and Ty-82 cells in each group. (E and F) Apoptosis rates of Thy0517 and Ty-82 cells in each group. (G and H) Invasion abilities of Thy0517 and Ty-82 cells in each group. * $P < 0.05$ vs. mimic-NC group; # $P < 0.05$ vs. inhibitor-NC group.

cell viability of the inhibitor-miR-525-5p group was significantly increased (Fig. 2C and D). The results of flow cytometry showed that the apoptosis rate of the mimic group was higher than that of the mimic-NC group within 48 h, and the cell viability of the inhibitor group was lower than that of the inhibitor-NC group (Fig. 2E and F). In addition, the upregulation of miR-525-5p levels inhibited cell invasion, while the downregulation of miR-525-5p levels promoted cell invasion (Fig. 2G and H). These results suggested that miR-525-5p exerted a tumour suppressor effect on thymoma and thymic carcinoma.

miR-525-5p targeting inhibits the expression of HSPA9. To further analyse the mechanism by which miR-525-5p inhibited thymoma and thymic carcinoma growth and invasion and promoted apoptosis, we predicted and verified that miR-525-5p directly targeted the 3'-UTR of *HSPA9* mRNA (Fig. 3A-C). Further studies showed that the level of *HSPA9* protein in the mimic-miR-525-5p group was significantly lower than that in the mimic-NC group, while the level of *HSPA9* protein in the inhibitor-miR-525-5p group was significantly higher than that in the inhibitor-NC group (Fig. 3D and E). This indicated

that miR-525-5p could inhibit the level of *HSPA9* protein by targeting *HSPA9* mRNA.

HSPA9 promotes TET progression. To analyse the clinical significance of miR-525-5p targeting *HSPA9* in TET, we analysed the transcriptional characteristics of *HSPA9* in the TCGA database. The results showed that *HSPA9* was significantly overexpressed in thymoma (Fig. 4A and B), and a high level of *HSPA9* was closely associated with poor prognosis (Fig. 4C). Clinical studies also showed that *HSPA9* levels were upregulated in TET tissues (Fig. 4D), and high levels of *HSPA9* had a lower 5-year survival rate (Fig. 4E). In the TET tissues, the levels of miR-525-5p and *HSPA9* were negatively correlated (Fig. 4F). In addition, we detected the levels of LOXL1-AS1, miR-525-5p and *HSPA9* mRNA and protein in the human embryonic thymocyte line HBT8810 and the thymoma cell lines Thy0517 and Ty-82. The results showed that compared with HBT8810, the levels of LOXL1-AS1 and *HSPA9* mRNA and protein in Thy0517 and Ty-82 cells were increased, while the levels of miR-525-5p were decreased (Fig. 4G and H). This suggested that *HSPA9* played a cancer-promoting role in TET, and its role may be targeted regulation by miR-525-5p.

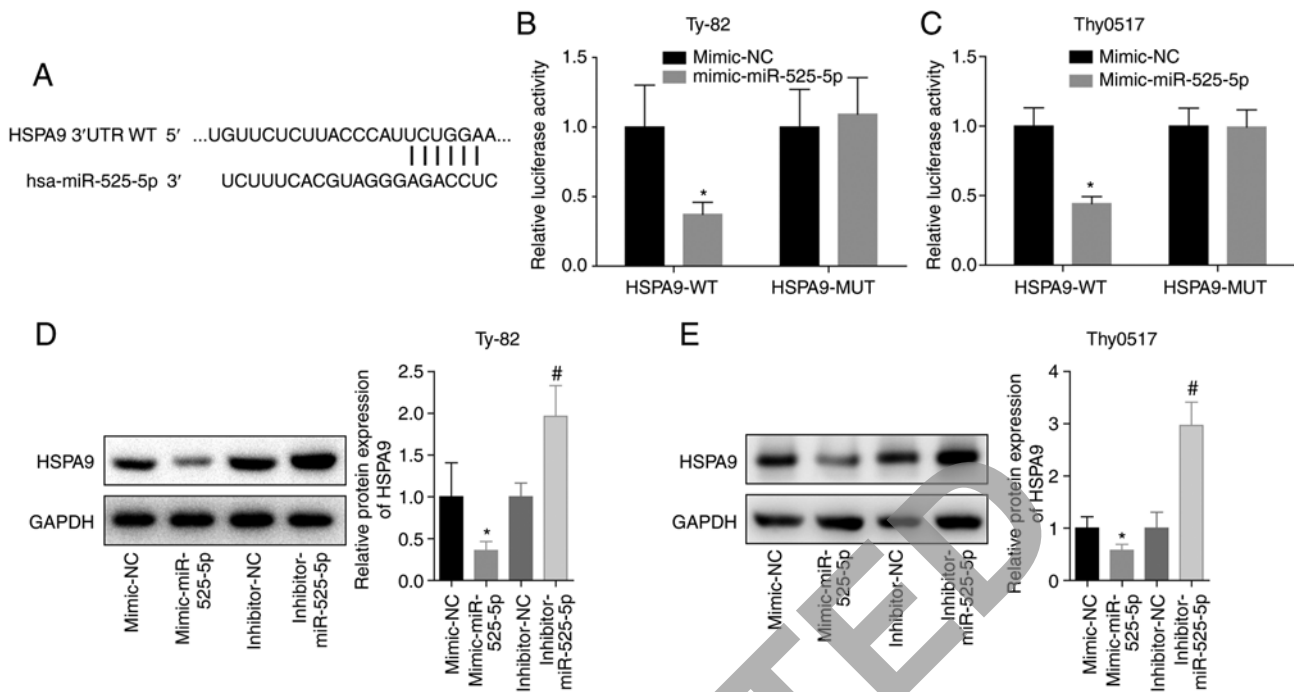


Figure 3. miR-525-5p targeting inhibits the expression of *HSPA9*. (A) Targeted binding site of miR-525-5p and *HSPA9*. (B and C) The results of the dual luciferase reporter assay. (D and E) *HSPA9* expression levels of Thy0517 and Ty-82 in each group. * $P < 0.05$ vs. mimic-NC group; # $P < 0.05$ vs. inhibitor-NC group.

miR-525-5p promotes apoptosis and inhibits invasion of thymoma and thymic carcinoma cells by targeting HSPA9. To demonstrate that miR-525-5p targeted *HSPA9* in regulating the biological behaviour of thymoma and thymic carcinoma cells, Thy0517 and Ty-82 cells were divided into 4 groups: Inhibitor-NC+sh-NC, inhibitor-miR-525-5p+sh-NC, inhibitor-miR-525-5p+sh-*HSPA9* and inhibitor-NC+sh-*HSPA9*. The result of cell transfection with sh-*HSPA9* was confirmed by RT-qPCR and western blot analysis (Fig. 5A and D). Downregulation of miR-525-5p levels increased *HSPA9* mRNA and protein levels, while transfection of sh-*HSPA9* plasmid significantly reversed the promotion of *HSPA9* by miR-525-5p inhibitor (Fig. 5E and H). By measuring cell viability, it was found that downregulation of *HSPA9* inhibited cell viability in Ty-82 and Thy0517 cells and partially reversed the downregulation of cell viability by miR-525-5p inhibitor (Fig. 5I and J). Compared with the inhibitor-NC+sh-NC group, the apoptosis rate of the inhibitor-miR-525-5p+sh-NC group decreased and the invasive ability increased, while the apoptosis rate of the inhibitor-NC+sh-*HSPA9* group increased and the invasive ability decreased. In addition, the apoptosis rate of the inhibitor-miR-525-5p+sh-*HSPA9* group was significantly higher than that of the inhibitor-miR-525-5p+sh-NC group, and the invasive ability was significantly lower than that of the inhibitor-miR-525-5p+sh-NC group (Fig. 5K and N). This suggested that downregulating *HSPA9* reversed the inhibition of apoptosis and the promotion of invasion by downregulating miR-525-5p. This suggested that *HSPA9* had a role in promoting the growth and metastasis of thymoma and thymic carcinoma, and miR-525-5p inhibited the progression of thymoma and thymic carcinoma by targeting *HSPA9*.

Inhibitory effects of miR-525-5p targeting HSPA9. To further investigate the inhibitory effects of miR-525-5p targeting

HSPA9 on tumours, we used the four groups of cells to establish a tumour-bearing nude mouse model. The two cell lines constructed 20 tumour-burdened mouse models, and a total of 40 mice were used. The mice were divided into four groups, and the number of models in each group was five. In the end, 13 Thy0517 cells were successfully modelled, with a success rate of 65.0%. There were 15 subcutaneous tumours of Ty-82 cells, and the modelling success rate was 75.0%. The results showed that downregulation of miR-525-5p levels promoted tumour growth, downregulating *HSPA9* inhibited tumour growth and reversed the effect of the miR-525-5p inhibitor (Fig. 6A and D). Moreover, the *HSPA9* protein level in the tumour tissues of the inhibitor-miR-525-5p+sh-NC group was significantly higher than that in the inhibitor-NC+sh-NC group. The level of *HSPA9* protein in the inhibitor-NC+sh-*HSPA9* group was lower than that in the inhibitor-NC+sh-NC group. The level of *HSPA9* protein in the inhibitor-miR-525-5p+sh-*HSPA9* group was lower than that in the inhibitor-miR-525-5p+sh-NC group (Fig. 6E and F). This *in vivo* experiment showed that downregulation of miR-525-5p promoted tumour growth by targeting the expression of *HSPA9* protein.

LOXL1-AS1 plays a role in cancer promotion in TET. The process by which miRNAs target mRNA is regulated by lncRNA. The data in TCGA indicated that LOXL1-AS1 was overexpressed in thymoma, and the upregulation of LOXL1-AS1 was most pronounced compared to other tumours (Fig. 7A and B). Clinical studies also showed that LOXL1-AS1 was upregulated in TET, and a high level of LOXL1-AS1 was associated with poor prognosis in TET patients (Fig. 7C and D). Correlation analysis revealed that LOXL1-AS1 was negatively correlated with miR-525-5p and positively correlated with *HSPA9* in TET tissues (Fig. 7E and F). The dual luciferase reporter results also demonstrated that LOXL1-AS1 can directly

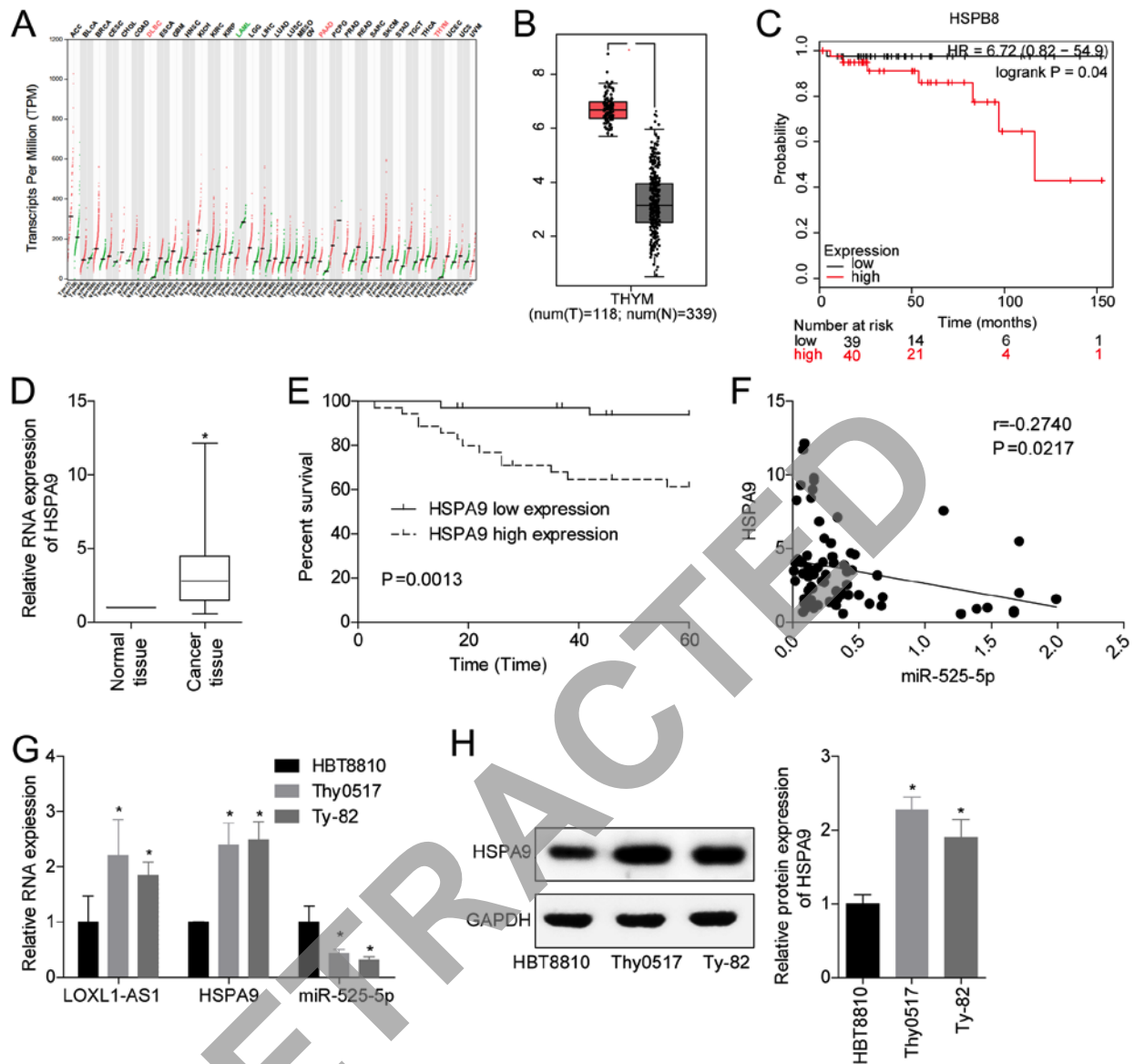


Figure 4. *HSPA9* plays a role in cancer promotion in TET. (A and B) Expression characteristics of *HSPA9* in thymoma patients in TCGA. (C) The relationship between mHSPA9 and the survival rate of thymoma patients in TCGA. (D) Expression characteristics of *HSPA9* in TETs. (E) The relationship between *HSPA9* and the survival rate of TET patients. (F) Correlation between miR-525-5p and *HSPA9* levels. (G and H) Expression levels of LOXL1-AS1, *HSPA9* and miR-525-5p in HBT8810, Thy0517 and Ty-82 cells. * $P<0.05$.

target miR-525-5p (Fig. 8A, B and C). Then, we conducted a verification experiment, and Ty-82 and Thy0517 cells were divided into vector-NC+mimic-NC, LOXL1-AS1+mimic-NC, LOXL1-AS1+mimic-miR525-5p and vector-NC+miR-525-5p groups. RT-qPCR was applied to detect LOXL1-AS1 and miR-525-5p. The results showed that LOXL1-AS1 reduced the level of miR-525-5p, and the overexpression of miR-525-5p also reduced the level of LOXL1-AS1 (Fig. 8D and E). The mRNA and protein levels of *HSPA9* were detected by qPCR and western blot analysis. Overexpression of LOXL1-AS1 significantly increased the level of *HSPA9*, while overexpression of miR-525-5p reversed the promotion of *HSPA9* by LOXL1-AS1 (Fig. 8F-I). This suggested that the process by which miR-525-5p inhibited *HSPA9* expression may be regulated by LOXL1-AS1.

LOXL1-AS1 inhibits thymoma and thymic carcinoma apoptosis and promotes invasion by targeting miR-525-5p. To

further analyse the effects of LOXL1-AS1 on thymoma and thymic carcinoma cells, Thy0517 and Ty-82 cells were divided into 4 groups: sh-NC+inhibitor-NC, sh-LOXL1-AS1+inhibitorNC, sh-LOXL1-AS1+inhibitor-miR525-5p and sh-NC+miR-525-5p. Silencing LOXL1-AS1 caused an increase in miR-525-5p and a decrease in *HSPA9* mRNA/protein. Inhibition of miR-525-5p also caused increases in LOXL1-AS1 and *HSPA9* mRNA/protein (Fig. 9A-G). The results showed that for Ty-82 cells, silencing LOXL1-AS1 inhibited cell viability and invasion and promoted apoptosis, and downregulated miR-525-5p reversed the inhibition of LOXL1-AS1 on cell growth and invasion (Fig. 9H, I and K). The same trend was observed in Thy0517 cells (Fig. 9J and L). This indicated that LOXL1-AS1 affected the inhibition of *HSPA9* by miR-525-5p by targeting miR-525-5p, thereby exerting a cancer-promoting effect in thymoma and thymic carcinoma.

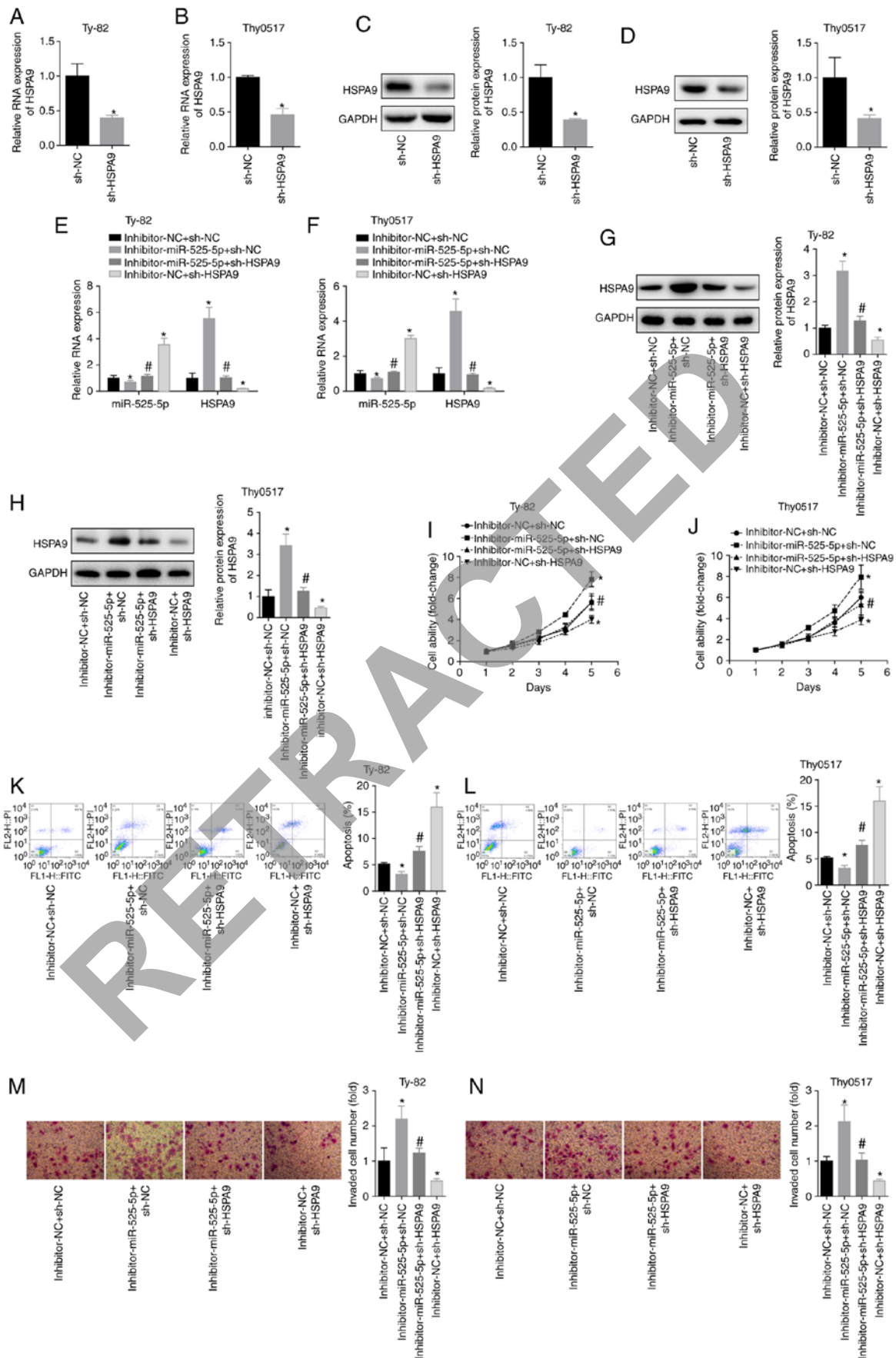


Figure 5. miR-525-5p promotes apoptosis and inhibits the invasion of thymoma and thymic carcinoma cells by targeting *HSPA9*. (A-F) After transfection with sh-*HSPA9*, the expression levels of *HSPA9* mRNA and protein in the cells. (E and F) miR-525-5p and *HSPA9* mRNA levels of Thy0517 and Ty-82 in each group. (G and H) *HSPA9* protein expression levels of Thy0517 and Ty-82 in each group. (I and J) Cell abilities of Thy0517 and Ty-82 cells in each group. (K and L) Apoptosis rates of Thy0517 and Ty-82 cells in each group. (M and N) Invasion abilities of Thy0517 and Ty-82 cells in each group. **P*<0.05 vs. inhibitor-NC+sh-NC group; #*P*<0.05 vs. inhibitor-miR-525-5p+sh-NC group.

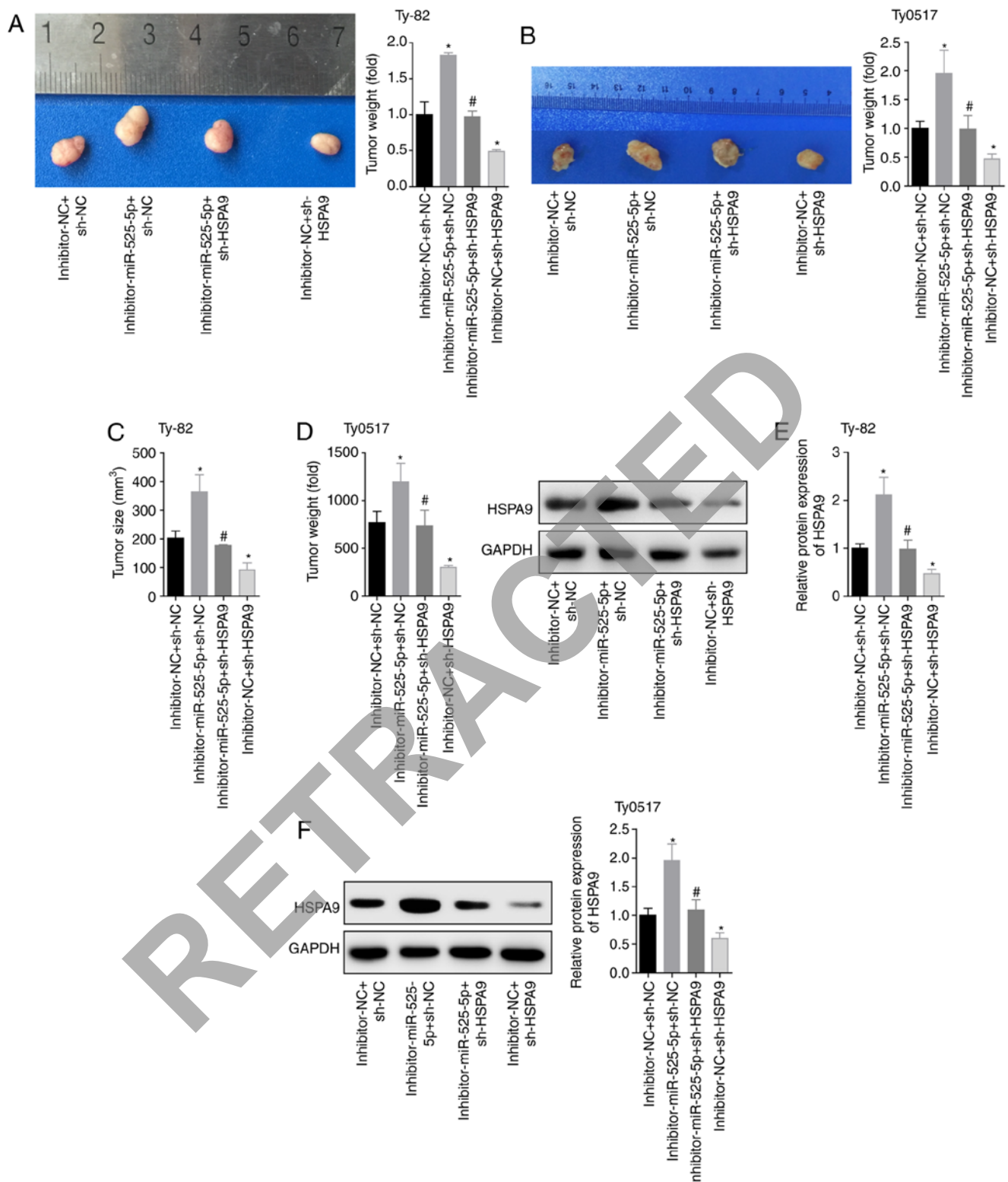


Figure 6. miR-525-5p inhibits tumour growth by targeting *HSPA9*. (A-D) Tumour weight and volume in each group. (E and F) *HSPA9* protein expression levels of tumours in each group. * $P < 0.05$ vs. inhibitor-NC+sh-NC group; # $P < 0.05$ vs. inhibitor-miR-525-5p+sh-NC group.

Discussion

In this study, LOXL1-AS1 regulated the expression of *HSPA9* by targeting miR-525-5p and regulated the cell growth, apoptosis and invasion of thymoma and thymic carcinoma cells.

TET is a complex tumour that can be divided into multiple subtypes, of which thymic carcinoma is the most

malignant. Some patients may have recurrence after surgical resection or chemoradiotherapy, and the probability of metastasis and postoperative recurrence of thymic carcinoma is higher (19,20). However, the mechanism of metastasis and recurrence of thymic carcinoma is still unclear. Analysis of the mechanisms of metastasis and recurrence of TET, especially thymic carcinoma, is important.

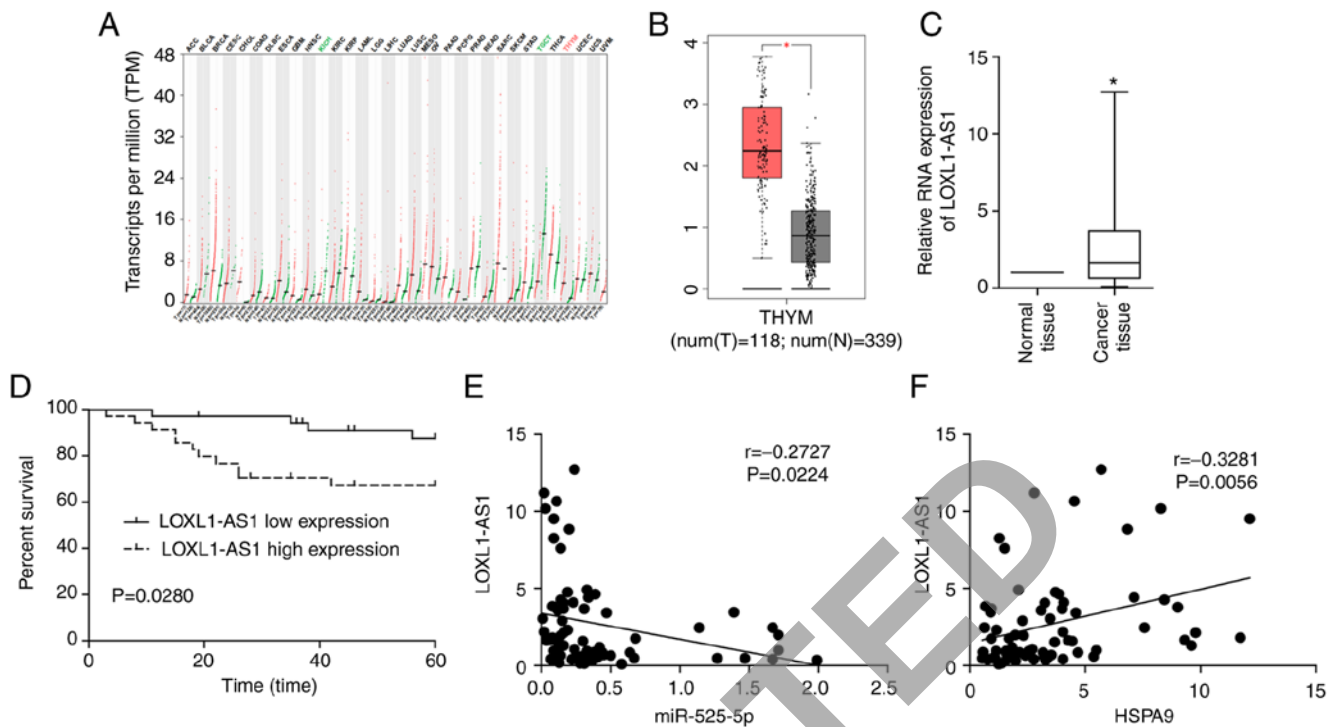


Figure 7. LOXL1-AS1 plays a role in cancer promotion in TET. (A-B) Expression characteristics of LOXL1-AS1 in thymoma patients in TCGA. (C) Expression characteristics of LOXL1-AS1 in TET. (D) The relationship between LOXL1-AS1 and the survival rate of TET. (E) Correlation between miR-525-5p and LOXL1-AS1 levels in TET tissues. (F) Correlation between *HSPA9* and LOXL1-AS1 levels in TET tissues. * $P < 0.05$

As a post-transcriptional regulator, the roles of miRNAs in tumorigenesis, development, and drug resistance have been gradually revealed (21-23). The role of miRNA in thymoma and thymic carcinoma cells was confirmed. miR-145-5p is downregulated in TET, and *in vitro* experiments showed that miR-145-5p inhibits the proliferation and invasion of thymic undifferentiated carcinoma cells, and it also plays a regulatory role in the cell's ability to obtain resistance to cisplatin and erlotinib (24). The elevation of circulating miR-21-5p and miR-148a-3p levels in patients with TET may suggest a lower risk of metastasis and may serve as biomarkers for predicting the prognosis of TET (25). An *in vitro* experiment confirmed that miR-195a-5p inhibits the proliferation of medullary thymic epithelial cells by directly targeting Smad7 (26). In addition, Enkner *et al* (27) showed that miRNA-mRNA may become a new target for the treatment of TET. miR-525-5p is a newly identified tumour-associated miRNA, and miR-525-5p can block the UBE2C/ZEB1/2 signal axis by targeting the inhibition of UBE2C expression, impairing the invasive ability of cervical cancer cells (28). miR-525-5p may also be used as a new prognostic biomarker and therapeutic target for lung squamous cell carcinoma (29). Moreover, miR-525-5p has a cancer-promoting effect in colorectal cancer (30). However, it can promote proliferation and anti-apoptosis in ovarian cancer (31). It has also been found that miR-525-5p may be carcinogenic in laryngeal squamous cell carcinoma (32). To initially analyse the expression and clinical significance of miR-525-5p in TET, it was found that patients with low miR-525-5p levels had lower survival rates in 509 thymoma patients in the TCGA database. It was also found through clinical trials that miR-525-5p was underexpressed in thymic carcinoma tissues, and high levels

of miR-525-5p predicted a better prognosis. That preliminary study suggested the anticancer effects of miR-525-5p in thymic carcinoma. Subsequently, thymoma and thymic carcinoma cells with low expression and overexpression of miR-525-5p were constructed, and the results showed that miR-525-5p inhibited cell growth and invasion and promoted apoptosis. This indicated that miR-525-5p exerted a tumour suppressor effect in thymoma and thymic carcinoma.

To further investigate the mechanism by which miR-525-5p exerted a tumour suppressor effect in thymoma and thymic carcinoma, we predicted and verified that miR-525-5p directly targeted inhibition of *HSPA9* expression. The data in TCGA also showed that *HSPA9* was overexpressed in thymoma and was associated with poor prognosis. Similar results were obtained with respect to clinical tissue samples, and *HSPA9* mRNA was found to be negatively correlated with miR-525-5p levels in thymic carcinoma tissues. *HSPA9* (Mortalin), also known as GRP75, is a member of the heat shock protein (HSP) 70 family and is located on chromosome 5q31.2, which is mainly found in mitochondria and plays an important role in regulating cell growth and survival. Studies have shown that depletion of *HSPA9* induces growth arrest and causes apoptosis and death as well as plays a role in cancer promotion in thyroid cancer (33), liver cancer (34), and breast cancer (35). In the present study, cell experiments also showed that silencing *HSPA9* inhibited thymoma and thymic carcinoma cell growth and invasion and promoted apoptosis, and silencing *HSPA9* reversed the effects of the miR-525-5p inhibitor on cell growth, invasion and apoptosis. This indicated that miR-525-5p could inhibit growth and invasion and promote apoptosis of thymoma and thymic carcinoma cells by targeting the inhibition of *HSPA9* expression.

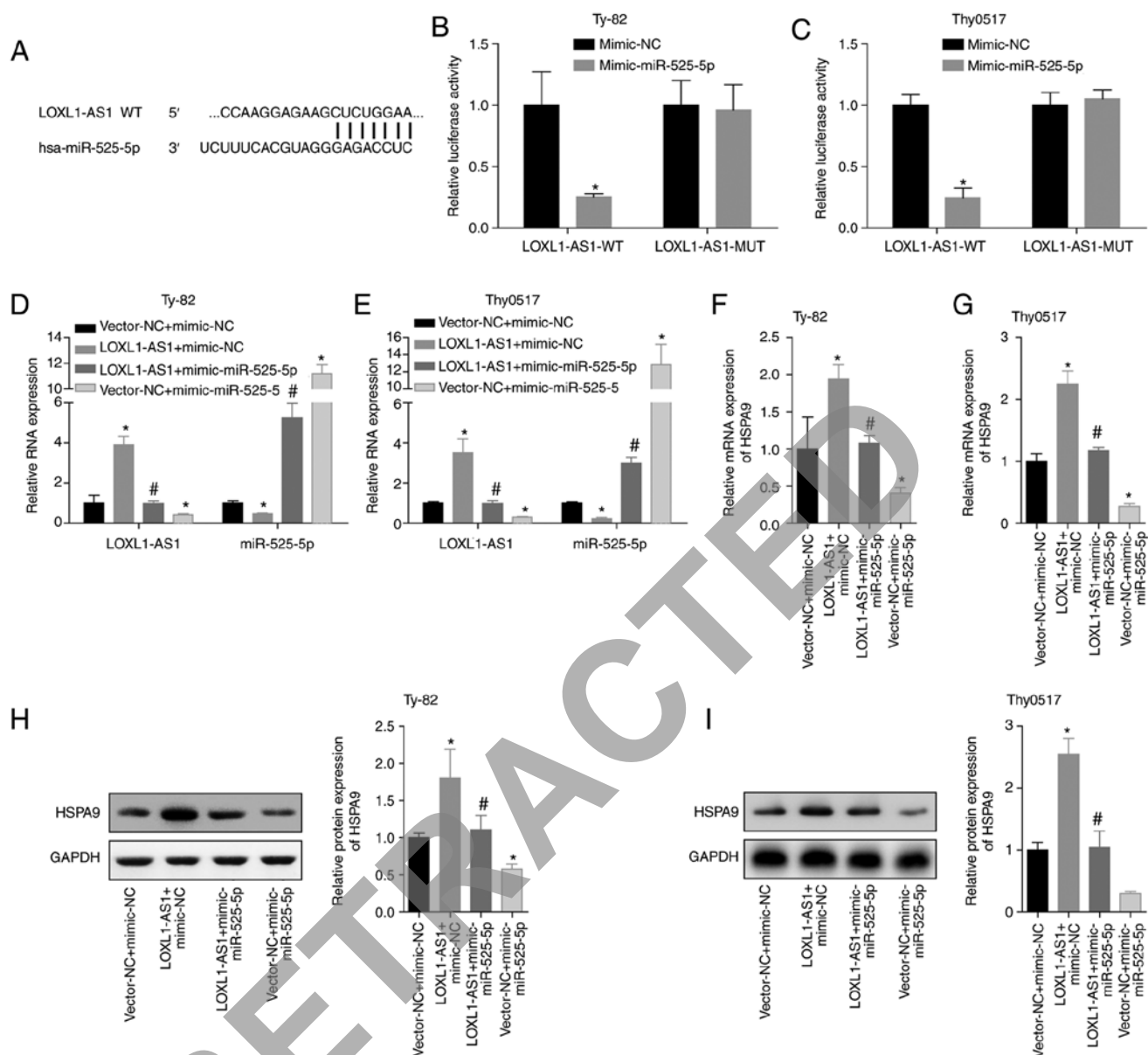


Figure 8. LOXL1-AS1 targets miR-525-5p. (A) Targeted binding site of miR-525-5p and *HSPA9*. (B-C) The results of the dual luciferase reporter assay. (D and E) LOXL1-AS1 and miR-525-5p levels in each group. (F-I) *HSPA9* mRNA and protein levels in each group. (B and C) * $P < 0.05$ vs. mimic-NC group; (D-I) * $P < 0.05$ vs. vector-NC+mimic-NC group; # $P < 0.05$ vs. LOXL1-AS1+mimic-NC group).

The targeting process of miRNA to mRNA is also regulated, and lncRNA can target miRNA by ceRNA, thereby regulating the role of miRNAs in the degradation and translation of mRNA (36,37). lncRNA functions as a miRNA sponge to regulate miRNA and is one of the main ways to regulate miRNA-mRNA. lncRNA regulates mRNA expression networks through miRNA formation and participates in the disease progression of myasthenia gravis with thymoma (38). Kong *et al* (39) found that MALAT can target miR-338-3p as a sponge and promote the expression of MSL2, which may become a new therapeutic target for myasthenia gravis with thymoma. LOXL1-AS1 promotes migration and invasion in glioblastoma (40), medulloblastoma (41) and osteosarcoma (42) cells, suggesting the promotion of LOXL1-AS1 in tumour metastasis. Moreover, LOXL1-AS1 can be used as a sponge to bind to miRNA, thereby promoting the expression of target genes and promoting the proliferation and invasion of tumour

cells (43-46). We first analysed the transcription level of LOXL1-AS1 by TCGA database, and the results showed that LOXL1-AS1 was upregulated significantly in thymoma. Similar results were obtained by testing clinical samples, and high levels of LOXL1-AS1 predicted a worse prognosis. Correlation analysis also revealed that LOXL1-AS1 was negatively correlated with miR-525-5p and positively correlated with *HSPA9*. Cellular experiments also demonstrated that in Thy0517 and Ty-82 cells, silencing LOXL1-AS1 inhibited cell growth and invasion and promoted apoptosis by targeting miR-525-5p.

In conclusion, LOXL1-AS1 and *HSPA9* are highly expressed in thymoma and thymic carcinoma, miR-525-5p is expressed at low levels in thymoma and thymic carcinoma, and these expression levels are associated with poor prognosis. In addition, LOXL1-AS1 acts as a sponge targeting miR-525-5p to promote *HSPA9* expression, thereby promoting the growth and invasion of thymoma and thymic

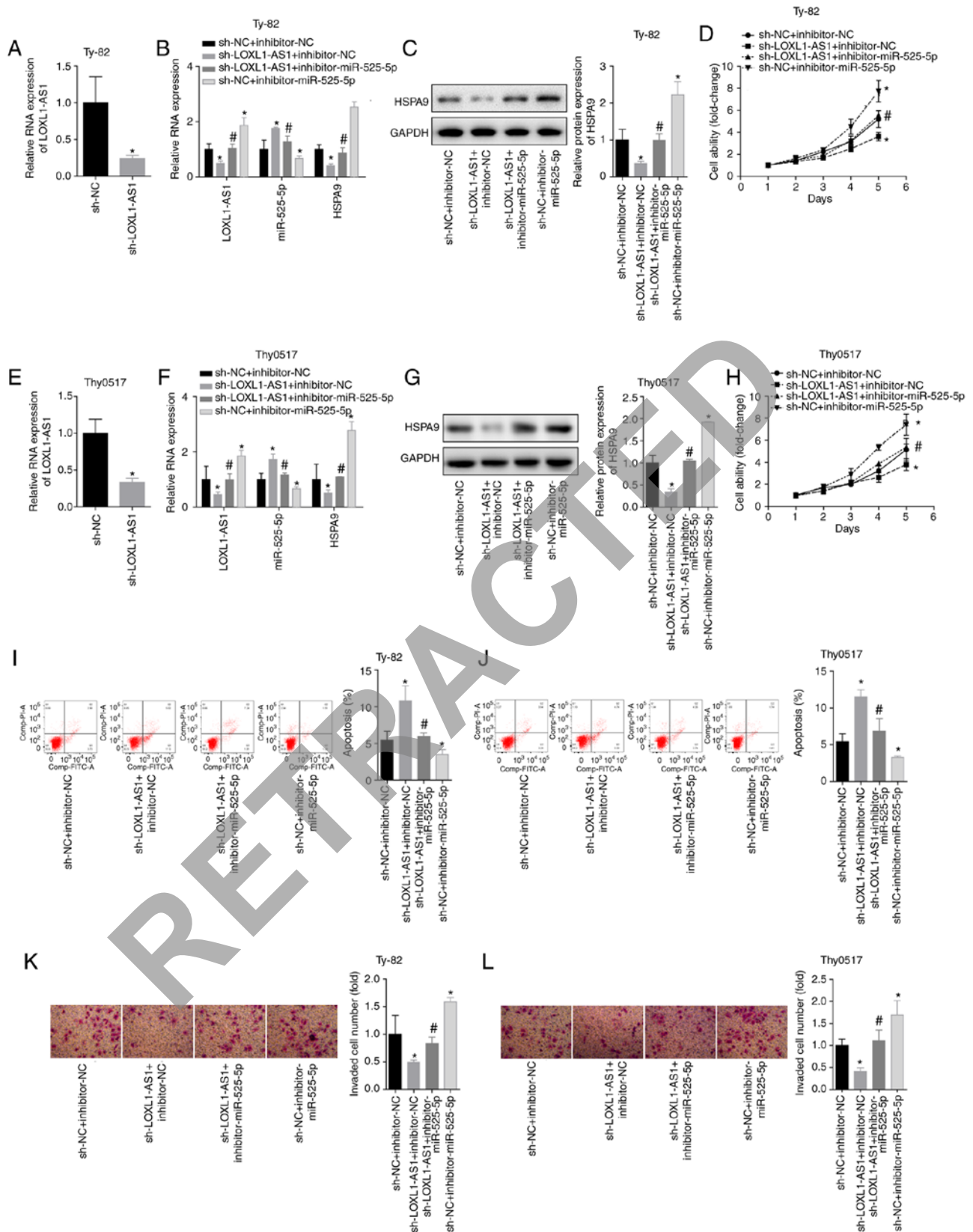


Figure 9. LOXL1-AS1 inhibits thymoma and thymic carcinoma cell apoptosis and promotes invasion by targeting miR-525-5p. (A-C and E-G) LOXL1-AS1, miR-525-5p and HSPA9 levels of Thy0517 and Ty-82 in each group. (D and H) Cell abilities of Thy0517 and Ty-82 cells in each group. (I and J) Apoptosis rates of Thy0517 and Ty-82 cells in each group. (K and L) Invasion abilities of Thy0517 and Ty-82 cells in each group. *P<0.05 vs. sh-NC+inhibitor-NC group; #P<0.05 vs. sh-LOXL1-AS1+inhibitor-NC group.

carcinoma cells and inhibiting apoptosis. This suggests that LOXL1-AS1-miR-525-5p-HSPA9 can act as a biomarker for

thymoma and thymic carcinoma and may be a new target for the treatment of thymoma and thymic carcinoma.

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Availability of data and materials

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

Authors' contributions

JW, HH, XZ and HM designed the experiments, analysed the data and interpreted the results. JW, HH analysed and interpreted the patient data. JW, XZ and HM were responsible for data acquisition. JW, HH, XZ, HM wrote the manuscript and prepared the figures. XZ and HM reviewed and edited the manuscript. HM coordinated and directed the project. All authors approved the final version of the manuscript.

Ethics approval and consent to participate

Approval for the study was obtained from the ethics committee of the Shanghai General Hospital and the Helsinki Declaration. Written informed consent was obtained from all participants before experiments. Animal experiments were carried out according to the National Institute of Health's Guidelines for the Care and Use of Laboratory Animals and was given permission by the Animal Care and Research Committee of Shanghai General Hospital.

Competing interests

The authors declare that they have no competing interests.

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