**Hepsin inhibits the cell growth of endometrial cancer**

KEICHIRO NAKAMURA1, NORIO TAKAMOTO1, FERNANDO ABARZUA2, ATSUSHI HONGO1, JUNICHI KODAMA1, YASUTOMO NASU2, HIROMI KUMON2 and YUJI HIRAMATSU1

1Department of Obstetrics and Gynecology, 2Department of Urology, Okayama University Graduate School of Medicine, Dentistry and Pharmaceutical Sciences, Okayama, Japan

Received March 21, 2008; Accepted May 19, 2008

DOI: 10.3892/ijmm_00000035

**Abstract.** Currently, several therapeutic approaches including surgery, chemotherapy, and radiation therapy are available for the treatment of endometrial cancer. However, endometrial cancer cells may survive, resulting in relapse of the disease, and ultimately causing demise of the patient. Hepsin is a cell surface-expressed chymotrypsin-like serine protease and a member of the family of type II transmembrane serine proteases. To date, little is known about its precise mechanisms of action. We investigated the biological functions and effects of Akt and in vitro of Hepsin, using endometrial cancer cell lines transfected with Hepsin. In stably transfected Ishikawa/Hepsin cell lines (Hepsin-10 and -12), we observed a significant inhibitory effect on cell growth in monolayer culture, anchorage-independent cell growth in soft agar in vitro, and tumorigenicity in vivo through the p53-dependent pathway in BG-1 ovarian cancer cell lines transfected with Hepsin (4). However, little is known about its mechanisms of action.

p53 is a transcription factor that activates genes involved in growth arrest, apoptosis, DNA repair and angiogenesis (5). The apoptotic cell death and cell proliferation in stressed conditions are regulated at cell cycle checkpoints by p21WAF1/CIP1 and 14-3-3σ, as well as p53 family members which are responsible for DNA damage (6).

DNA damage checkpoints operate throughout the cell cycle to maintain genetic integrity. DNA damage checkpoints delay cell cycle progression by the inhibition of the cyclin-dependent kinase (Cdk)-cyclin complexes. Cyclin-Cdk complexes are key regulators of the cell cycle: cyclin D-Cdk 4/6 for G1 progression, cyclin E-Cdk 2 for the G1-S transition, cyclin A/Cdk 2 for S phase progression, and cyclin A/B-Cdc-2 for G2/M phase (7). Damaged cells maintain a 4N DNA content and a high level of cyclin B. Damaged cells sustained in the G2 state contain a 4N DNA content, with stabilized cyclin A and cyclin B binding to Thr14/Tyr15-phosphorylated Cdc-2 (8).

A number of pro-apoptotic genes such as Bax (9) and Bak (10) are direct p53 target genes whose expression levels are up-regulated by p53. p53 is also involved in down-regulation of the anti-apoptotic genes Bcl-2 (11) and Bcl-xL (12). Functions of the p53-dependent pathway in cell cycle arrest and DNA damage repair are thought to prevent replication of damaged DNA and to protect cells from damage-induced apoptosis.

The purpose of the current study was to explore the role of Hepsin in endometrial cancer biology. Our results indicate that Hepsin overexpression inhibits the cell growth of endometrial cancer in vitro and in vivo.

**Materials and methods**

**Endometrial cancer biology.** The Ishikawa, HEC-1A, EN cancer cell lines were derived from human endometrial carcinomas expressed chymotrypsin-like serine protease and a member of the family of type II transmembrane serine proteases (2). Previous studies demonstrated that Hepsin is active during the G2-M phase of the cell cycle, and also found an increase in the cell population undergoing apoptosis in LNCaP and PC-3 prostate cancer cells (3). Studies also showed inhibitory effects on cell growth in a monolayer culture, anchorage-independent cell growth in soft agar in vitro, and tumorigenicity in vivo through the p53-dependent pathway in BG-1 ovarian cancer cell lines transfected with Hepsin (4). However, little is known about its mechanisms of action.

**Key words:** Hepsin, endometrial cancer, cell cycle

**Correspondence to:** Dr Keiichiro Nakamura, Department of Obstetrics and Gynecology, Okayama University Graduate School of Medicine, Dentistry and Pharmaceutical Sciences, 2-5-1 Shikata-cho, Okayama 700-8558, Japan
E-mail: k-nakamu@cc.okayama-u.ac.jp

**Cells and media.** The Ishikawa, HEC-1A, EN cancer cell lines were derived from human endometrial carcinomas.
20 μl of reaction solution containing 1X PCR buffer, 5 mM total RNA was reverse-transcribed at 42˚C for 30 min in RNA PCR kit (Takara Co. Ltd., Kyoto, Japan), 2.5 μg of manufacturer's instructions. According to the protocol of the (Isogen, Nippon Gene, Tokyo, Japan) according to the lines using the acid guanidium-phenol-chloroform method.

Western blot analysis. Cell lysates were collected and estimated using a Protein Assay system (Bio-Rad, Hercules, CA) according to the manufacturer's protocol. Proteins from each cell line were subjected to SDS-PAGE and were transferred onto a nitrocellulose membrane. Polyclonal and monoclonal antibodies used for immunoblotting were as follows: Hepsin (Cayman Chemical, Ann Arbor, MI), p53, 14-3-3-α, Bak, Bax, Bcl-XL, Bcl-2 (Santa Cruz Biotechnology, Santa Cruz, CA), Cdc-2, cyclin B, cyclin A (BD Biosciences, Franklin Lakes, NJ), p63, p73 (Oncogene Research Products, Darmstadt, Germany), caspase-3 and β-actin (Sigma Chemical, St. Louis, MO). The working dilution of all of these primary antibodies was 1:1000. Membranes were then incubated with appropriate secondary antibodies. Expression of antigen-antibody complexes was detected with an enhanced chemiluminescence kit (Amersham Biosciences, Piscataway, NJ).

Real-time PCR assay. Total RNA was extracted from cell lines using the acid guanidium-phenol-chloroform method (Isogen, Nippon Gene, Tokyo, Japan) according to the manufacturer's instructions. According to the protocol of the RNA PCR kit (Takara Co. Ltd., Kyoto, Japan), 2.5 μg of total RNA was reverse-transcribed at 42˚C for 30 min in 20 μl of reaction solution containing 1X PCR buffer, 5 mM MgCl₂, 1 mM deoxynucleoside triphosphate, 2.5 μM random 9 mers primer, 10 units of ribonuclease inhibitor and 5 units AMV reverse transcriptase. Real-time quantitative RT-PCR was performed using a rapid Lightcycler thermal cycler instrument (Roche Diagnostics, Light Cycler, Mannheim, Germany) under conditions recommended by the manufacturer. Primers for real-time PCR were 5'-CCAAGGACACCCTC CCTC-3' (Hepsin-F), 5'-AAAGAGCATCCCTCATCAGG-3' (Hepsin-R), 5'-CAACTACATGGTTTACATGTTC-3' (GAPDH-F) and 5'-GCCAGTGGACTCCACCG-3' (GAPDH-R), as described previously (16). The products were checked by melting point analysis and electrophoretic mobility. Standard curves for the calculation of the number of transcripts were plotted using plasmids containing the respective amplified fragment as an insert, and were corrected by using GAPDH as the reference gene.

Generation of transient and stable transfectants. For transient transfectants, a full-length Hepsin cDNA expression construct encoding Hepsin protein (cloned in Genetron expression vector, pcDNA3.1/GS; Research Genetics) was transfected into the Ishikawa, EN and HEC-1A endometrial cancer cell lines using TransFast transfection reagent (Promega, Madison, WI) during a 48-h treatment. Hepsin stable transfectants in the Ishikawa cancer cell lines were generated using the TransFast transfection reagent. Zeocin (0.6 mg/ml) (Invitrogen, Carlsbad, CA)-resistant colonies were selected after 4 weeks. Two of these clones, designated Hepsin-10 and -12, were expanded for the experiments. Mock transfectants served as the control.

MTS assay. In order to evaluate the cell proliferation effects of Hepsin, we used the MTS assay (Promega, Madison, WI) with Endo, prostitution cells and empty vector-transfected Ishikawa endometrial cancer cells were added in situ to 10 μg/ml of DiI (Invitrogen, Carlsbad, CA) in DMEM containing 10% FBS for 1 h. Cells (5x10⁴) of each genotype were added to the inserts, and 0.75 ml of medium was added to the bottom of each well. After 48 h of incubation, membranes were removed from the inserts and mounted on slides, and the invading cells were counted using a microscope. MTS assays were performed in triplicate.

Cell growth in monolayer culture. Hepsin-10, Hepsin-12, and empty vector-transfected Ishikawa endometrial cancer cells were plated at a density of 2.5x10⁴ cells/well in 6-well plates containing DMEM without phenol red, supplemented with 10% charcoal-stripped FBS. Cell growth was assessed by counting the cell numbers by using a hemocytometer after 1, 3, 5 and 7 days of culture. All data points represent triplicate experiments.

Cell growth in soft agar. A cell suspension (1x10⁴ cells/well) in 1 ml 0.2% Noble agar with DMEM without phenol red supplemented with 10% charcoal-stripped FBS was overlaid onto a 35-mm dish containing a 0.5% agar base. Colonies >0.2 mm in diameter were counted on day 21 after culture. Soft agar assays were performed in triplicate.

Cell cycle analysis. Hepsin-10, Hepsin-12, and empty vector-transfected cancer cells were trypsinized, washed twice with phosphate-buffered saline (PBS), incubated with trypsin for 10 min at room temperature, incubated with trypsin inhibitor and RNase buffer for 10 min at room temperature, and stained with 200 μl propidium iodide staining solution for 10 min in the dark at room temperature (Becton Dickinson, San Jose, CA). Finally, cells were analyzed with the FACS cytometer (Calibur™, Becton Dickinson). The cell cycle phase
Tumorigenesis in nude mice. Hepsin-12 and empty vector-transfected cancer cells were washed three times with Hank’s solution and incubated with serum-free medium (SFM) at 37°C for 24 h. Then cells were trypsinized and washed twice with PBS. As a xenograft, 2.5x10⁷ cells suspended in 200 μl of sterile PBS were injected s.c. above the hind leg of 5-week male BALB/c nude mice (Charles River Japan, Yokohama, Japan). The volume of the developed tumors (cm³) was measured weekly as a spheroid from three-dimensional diameters. Each tumor volume represents the mean ± SD from five different mice.

Statistical analysis. Statistical analyses were performed using the Mann-Whitney U-test for comparison with the control and one-factor ANOVA followed by Fisher’s protected least significant difference test for all pairwise comparisons. The analyses were performed with the software package StatView version 5.0 (Abacus Concepts, Berkeley, CA). Differences were considered significant at P<0.05.

Results

Evaluation of Hepsin expression in endometrial cancer cell lines. Extracellular and cell surface proteases play an important role in embryonic development and normal tissue homeostasis. Among these, serine proteases have been implicated in the degradation of the extracellular matrix and in the modulation of cell-substratum adhesion in tumor cells associated with metastasis. Levels of Hepsin mRNA and protein were determined using real-time PCR analysis and Western blotting in various endometrial cancer cell lines. As shown in Fig. 1A, Hepsin mRNA level was almost absent in the Ishikawa endometrial cancer cell line, low in the EN endometrial cancer cell line, and abundantly expressed in the HEC-1A endometrial cancer and LNCaP (our positive control) prostate cancer cell lines. Hepsin protein was detected by Western blotting as a single band in EN, HEC-1A and LNCaP cancer cell lines, but undetectable in the Ishikawa cancer cell line (Fig. 1B).

Transient transfection of Hepsin into cancer cell lines reduced cell growth in an MTS assay. We used MTS assays to examine the cell proliferation in Ishikawa, EN and HEC-1A endometrial cancer cell lines caused by Hepsin. The transient transfection of Hepsin into these three endometrial cancer cell lines caused reduced cell growth in an MTS assay, and the inhibitory effect was most prominent in the Ishikawa cancer cell line. For this reason, the Ishikawa endometrial cancer cell line was chosen for further experiments (Fig. 1C).
expressed Hepsin were generated as described in Materials and methods. After the selection, both mRNA and protein levels of Hepsin were highly expressed in the Hepsin-10 and -12 cancer cells as expected (Fig. 2A and B).

Matrigel invasion of Hepsin-10 and -12 cells. We assessed motility and invasiveness of cells overexpressing Hepsin by using a BioCoat Matrigel Invasion Chamber. The Matrigel matrix serves as a reconstituted basement membrane in vitro,
and invasive cells are able to invade through the Matrigel matrix and the 8-μm membrane pores. Cells were plated on the upper surface of the membrane, and after 48 h, cells on the bottom side of the membrane were stained and counted (Fig. 2C). Hepsin-10 and -12 cells had significantly lower invasiveness through the Matrigel compared with the control.

Inhibition of cell growth in a monolayer culture and inhibition of anchorage-independent cell growth in soft agar in vitro of Hepsin-10 and -12 cells. Effects of Hepsin expression on cell proliferation were analyzed using Hepsin-10 and -12 cells. We found a significant inhibitory effect of Hepsin on cell growth in Hepsin-10 and -12 cells (~70% inhibition) (p<0.05) compared to the empty vector-transfected Ishikawa cells as a control (Fig. 2D and E). Therefore, the inhibitory effects on colony formation in Hepsin-transfected cells were ~90%. Furthermore, in Hepsin-10 and -12 cells, the number of colonies in the colony formation assay was significantly reduced as compared with that in the control (P<0.01) (Fig. 2F).

Increased expression of p53 by Hepsin-10 and -12 cells. The targets of p53-regulated genes or p53-interacting proteins have provided critical information for understanding the biochemical and biological functions of the p53 tumor suppressor gene. Depending on cellular contexts, p53 activation can cause cell cycle arrest or apoptosis, contributing to tumor suppression. Previously, two genes encoding similar proteins to p53 have been identified, namely p63 and p73 (17-19). They act mostly as regulators in programmed cell death, embryonic development and cell differentiation (20). To determine whether expression of members of the p53 family (p53, p63, p73) of tumor suppressor genes correlates with Hepsin expression in endometrial cancer cells, the expression levels of p53, p63 and p73 protein were analyzed in Hepsin-10 and -12 cells. Western blot analysis revealed an increased expression of p53 in both Hepsin-10 and -12 cells as compared to control cells. However, no significant changes in p63 expression were observed in Hepsin-10 and -12 cells.

Increased expression of 14-3-3σ by Hepsin-10 and -12 cells. Having observed the up-regulation of p53 by Hepsin overexpression, we investigated the possibility that downstream of p53 might be altered in these cells. The p53 protein is a transcriptional activator of several genes, including the p21WAF1/Cip1 and 14-3-3σ genes (6), which are involved in the regulation of cell cycle progression. Therefore, we analyzed 14-3-3σ and p21WAF1/Cip1 protein expression in Hepsin-10 and -12 cells. Western blot analysis revealed that expression of
14-3-3σ was increased in Hepsin-10 and -12 cells as compared with the control. However, no significant changes in p21WAF/Cip1 expression were observed in Hepsin-10 and -12 cells (Fig. 3B).

Accumulation of Hepsin-10 and -12 cells in the G2/M phase of the cell cycle. To investigate the mechanisms involved in the reduction of cell proliferation in Hepsin-transfected cells, the cell cycle profile of Hepsin-10, Hepsin-12, and empty vector-transfected cells was investigated. The cell cycle profile of the control was as follows: G0-G1 phase, 53.55%; G2-M phase, 15.56%; and S phase, 30.89%. In Hepsin-10 cells, 28.26, 48.89 and 22.85% of cells were in the G0-G1, G2-M and S phases, respectively. In Hepsin-12 cells, 20.53% of cells were in the G0-G1 phase, while 64.02% of cells were in the G2-M phase and 15.45% of cells were in the S phase. Thus, cell cycle arrest was mainly observed at G2-M in Hepsin-10 and -12 cells. These data indicate that Hepsin might act to cause cell cycle arrest at the G2-M phase, supporting the idea that Hepsin is inhibitory to cell growth. In addition to cell cycle of pre-G1 and aneuploid peak alteration, a significant proportion of cells were found to be apoptotic. The pre-G1 and aneuploidy in Hepsin-10 and -12 cells were significantly increased as compared to empty vector-transfected cells (Fig. 4A).

It is well known that the entry of cells into the M phase is regulated by Cdc-2 kinase. Activation of Cdc-2 is a complex process that requires multiple steps. The DNA damage checkpoint prevents the activation of cyclin B, cyclin A and thereby prevents cells from entering potentially deleterious mitosis when their DNA is damaged (21). It has been reported that 14-3-3σ sequesters Cdc-2/cyclin B complexes in the cytoplasm to cause G2 arrest in response to DNA damage (22,23). To determine whether overexpression of Hepsin alters the expression of Cdc-2, cyclin B and cyclin A complex in endometrial cancer cells, cyclin B, cyclin A, and Cdc-2 protein expression levels were analyzed in Hepsin-10 and -12 cells. As shown in Fig. 4B, expression of cyclin A and cyclin B was decreased in Hepsin-10 and Hepsin-12 cells as compared with the control. However, no significant changes in Cdc-2 expression were observed in Hepsin-10 and -12 cells. Thus, these results are consistent with the finding that Hepsin overexpression causes cell cycle arrest at the G2-M phase.

Activation of the p53-dependent pathway in Hepsin-10 and Hepsin-12 cells. In addition, we also investigated the effect of Hepsin on several apoptotic molecules such as anti-apoptotic Bcl-2, Bcl-xL, and pro-apoptotic Bax and Bak, which are known to take part in the activation of the caspase pathway (24-28). As shown in Fig. 5, Bak was up-regulated,
while Bcl-xL and Bcl-2 were down-regulated in Hepsin-10 and -12 cells. No significant change of Bax was observed in Hepsin-10 and -12 cells.

These results confirmed that a decrease in Bcl-2 and Bcl-xL, which are known as death antagonists due to their ability to suppress caspase-dependent pathways of apoptosis, play important roles in the p53-dependent pathway in Hepsin-overexpressing cells. To further investigate the specific apoptotic pathway regulated by Hepsin, we examined the effects of Hepsin on the caspase family by Western blotting. Analysis of protein levels in Hepsin-10 and -12 cells showed a significant increase in caspase-3 protein levels (Fig. 5).

Inhibition of tumor growth in vivo by overexpression of Hepsin. In a xenograft nude mouse model, we investigated the tumorigenic potential of Hepsin-12 cells. Tumor growth was followed for 5 weeks. Notably, there was a significant reduction in tumor growth in the Hepsin-12 group compared to the empty vector group. The extent of reduction in tumor volume compared to that of the control was >95% (P<0.01). Wet weight of tumors in mice inoculated with Hepsin-12 cells was significantly lower than control (P=0.0005) (Fig. 6A-C).

Discussion

The basement membrane is a specialized extracellular matrix structure that separates the epithelial and stromal cell compartments. To accomplish local invasion, tumor cells use extracellular and cell surface proteolytic enzymes to degrade the basement membrane proteins (29,30). Serine proteases have been implicated in the degradation of the extracellular matrix and modulation of cell-substratum adhesion in tumor cells (30). Hepsin was found to be significantly overexpressed in cancer samples compared with matched normal tissues in prostate, ovary and kidney (31-33) cancer. To date, previous studies have shown that neutralizing antibodies against Hepsin inhibited cell growth and reduced the invasiveness of both DU145 prostate and CAOV-3 ovarian cancer cells (34). On the other hand, other studies have demonstrated that Hepsin overexpression caused G2-M arrest, and there was also an increase in the cell population undergoing apoptosis in LNCaP and PC-3 prostate cancer cells (3). Our previous study using ovarian cancer cell lines transfected with Hepsin showed inhibitory effects of Hepsin on cell growth in a monolayer culture, anchorage-independent cell growth in soft agar in vitro, and tumorigenicity in vivo through the p53-dependent apoptotic pathway in BG-1 ovarian cancer cells (4). It is still unknown what mechanisms might be involved. Therefore, we decided to study the effect of Hepsin overexpression in endometrial cancer.

It has been proposed that G2-M phase arrest caused by DNA-damaging agents or by stress stimuli, could provide an opportunity for DNA repair. One of the modes of non-apoptotic cell death after G2-M phase arrest has been described as ‘mitotic death’ or ‘mitotic catastrophe’ (35,36). Mitotic death often occurs in G2-M phase-arrested cells after incomplete or defective mitosis (37). Therefore, DNA damage checkpoints delay cell cycle progression by inhibition of the Cdk-cyclin complexes. Cyclin-Cdk complexes are key regulators of the cell cycle: cyclin A/B-Cdc-2 for G2/M phase (7). In this study, we examined the effects of Hepsin overexpression on cell cycle and the Cdk-cyclin complex, using
the Ishikawa endometrial cancer cell line. Hepsin overexpression resulted in significant cell accumulation at the G2/M phase through cyclin B and cyclin A. Moreover, 14-3-3σ and p53 expression was activated by Hepsin overexpression. 14-3-3σ is known to be induced by DNA damage and is required for a stable G2 cell cycle arrest in epithelial cells expressing wild-type p53 (38,39). Loss of 14-3-3σ results in malignant transformation in vitro and supports tumor formation in vivo, which suggests that this gene has tumor-suppressive properties (40). Thus, it could be speculated, as shown in Fig. 6D that Hepsin shows potential inhibitory effects mediated by the induction of 14-3-3σ expression which leads to both cell cycle arrest at the G2/M phase through cyclin B and cyclin A and the p53-dependent pathway in Ishikawa endometrial cancer. Similar effects of Hepsin overexpression were found in LNCaP and PC-3 prostate cancer cells (3).

In summary, our studies have revealed a critical role for Hepsin in the functional activity and effects in vitro and in vivo on endometrial cancer. We demonstrated that Hepsin induces cell cycle arrest at the G2/M phase through cyclin B and cyclin A and the p53-dependent pathway, and thus we propose that Hepsin is a possible tumor suppressor gene of endometrial cancer.

Acknowledgements

We are grateful to Dr M. Nishida for providing the Ishikawa cells; to Dr H. Kuramoto for providing the HEC-1A cells; to
H. Nishi for providing the EN cells; and to the Center for Prostate Disease Research (Dr John S. Rhim) for providing the full-length Hepsin cDNA construct encoding Hepsin fusion proteins.

References