Human adiponectin inhibits cell growth and induces apoptosis in human endometrial carcinoma cells, HEC-1-A and RL95-2

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Abstract

Obesity is one of the well-established risk factors for endometrial cancer. Recent clinical studies have demonstrated that circulating adiponectin concentrations are inversely correlated with the incidence of endometrial carcinoma. Such epidemiological findings are consistent with the paradoxical observations that adiponectin levels are reduced in obesity. This study investigated the direct effects of adiponectin on two endometrial carcinoma cell lines, HEC-1-A and RL95-2. These cell lines express both variants of adiponectin receptors, adipo-R1 and adipo-R2. Adiponectin treatment leads to suppression of cell proliferation in both cell types, which is primarily due to the significant increase of cell populations at G1/G0-phase and to the induction of apoptosis. The inhibition of growth in these two cell lines appears to be mediated by different signaling pathways. Although adiponectin treatment markedly increases the phosphorylation (Thr172) of AMP-activated protein kinase \( \alpha \) in both HEC-1-A and RL95-2 within 30 min, prolonged exposure (48 h) leads to inactivation of Akt as well as reduction of cyclin D1 protein expression in HEC-1-A cells. In contrast, similar treatment of RL95-2 cells with adiponectin, while having no effects on Akt activity and cyclin D1 expression, causes a decrease in cyclin E2 expression and the activity of mitogen-activated kinase (p42/44). We conclude that adiponectin exerts direct anti-proliferative effects on HEC-1-A and RL95-2 cells by inducing cell cycle arrest and apoptosis. Depending on the genotypes of the endometrial cancer cells, the inhibitory effects of adiponectin are associated with the reduction of different pro-growth regulators of cell cycle and signaling proteins. Our study thus provides a cellular mechanism underlying the linkages between endometrial cancer and obesity.

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Introduction

Besides being a serious risk factor for type 2 diabetes and cardiovascular diseases (Kahn & Flier 2000), obesity is also found to be associated with the development and progression of several types of cancer (Calle & Thun 2004), among which endometrial carcinoma shows arguably the strongest correlation with obesity (Akhmedkhanov et al. 2001). Although genetic mutations (such as in phosphatase tensin homolog, PTEN) are well recognized for their roles in the pathogenesis of endometrial cancer (Akhmedkhanov et al. 2001, Zhu et al. 2001), other adipocytes-derived factors have also contributed to the regulation of cancer cell growth (Housa et al. 2006). For example, both insulin-like growth factor-I (IGF-I) and estrone can be synthesized in and released by adipocytes, both of which have been established for their stimulatory roles in cell growth (Dougherty & Sanders 2005, Laviola et al. 2007).

As a member of adipokine family, adiponectin is synthesized and secreted almost exclusively by the adipose tissue (Scherer et al. 1995, Kadowaki & Yamauchi 2005). It is abundantly present in the blood and participates in the regulation of glucose and lipid homeostasis (Kadowaki & Yamauchi 2005). Paradoxically, circulating levels of adiponectin are decreased, rather than increased, in obesity (Scherer et al. 1995,
The reduction of blood concentrations of adiponectin is not only closely related to disease states such as type 2 diabetes and cardiovascular diseases in human obesity (Weyer et al. 2001, Ronchi et al. 2004), but also implicated in cancer development. Recent clinical studies involving several independent cohorts have demonstrated that plasma concentrations of adiponectin are inversely correlated with the risk of several types of cancer, including breast cancer (Chen et al. 2006), colorectal cancer (Otake et al. 2005), and endometrial carcinoma (Petridou et al. 2003, Cust et al. 2007). These clinical observations raise the possibility that adiponectin itself might directly act as an inhibitory factor on tumor growth. Consistent with this hypothesis, several cellular studies find that adiponectin can elicit anti-proliferative effects in breast cancer and prostate cancer cells (Bub et al. 2006, Dieudonne et al. 2006, Korner et al. 2007, Ouchi et al. 1998, Luo et al. 2005, Wang et al. 2006).

So far, there have been two canonical signaling pathways identified for adiponectin, one of which is through the activation of AMP-activated protein kinase (AMPK), a highly conserved serine/threonine protein kinase (Yamauchi et al. 2002). The other pathway is through elevation of intracellular cAMP and activation of cAMP-dependent protein kinase A (PKA; Ouchi et al. 2000). Both of these pathways are known to exert anti-proliferative effects on various cell types (Chen et al. 1998, Luo et al. 2005). For example, activation of AMPK is known to suppress cell growth and cause apoptosis in human cancer cells such as prostate cancer cells (Luo et al. 2005) and glioma cells (Rattan et al. 2005). Similarly, the cAMP/PKA pathway has been shown to inhibit cell growth in several cell types such as vascular smooth muscle cells (Indolfi et al. 1997) and leukemia B-cells (Jiang et al. 1996). This study was designed to investigate the hypothesis that adiponectin can inhibit cell proliferation and/or induce apoptosis in two different human endometrial cancer cell lines, HEC-1-A (containing wild-type PTEN activity) and RL95-2 (deficient in PTEN activity; Zhu et al. 2001). In addition, we also explored the potential signaling mechanisms underlying such effects of adiponectin.

Materials and methods

Reagents

Recombinant human adiponectin was purchased from BioVendor Laboratory Medicine (Brno, Czech Republic) and R&D Systems (Minneapolis, MN, USA). Though not necessarily fully equivalent to the circulating forms in human blood, the full-length recombinant human adiponectin protein, after reconstituted, forms multimeric structures (described in BioVendor product data sheet).

Cell culture

Human endometrial cancer cell lines, HEC-1-A and RL95-2 cells, were obtained from American Type Culture Collection (Manassas, VA, USA). HEC-1-A and RL95-2 cells were grown in McCoy’s 5A modified medium and DMEM/F12 respectively supplemented with 10% fetal bovine serum, penicillin (100 UI/ml), and streptomycin (100 mg/ml) in a humidified atmosphere of 95% air and 5% CO2 at 37 °C.

Adiponectin receptor expression

Total RNA was isolated from HEC-1-A and RL95-2 cells with TRIZOL reagent (Invitrogen), and was subsequently treated with DNase I (Ambion, Austin, TX, USA) to remove contaminating genomic DNA. The RT-PCRs were performed using a kit from Promega Corp. The reactions were carried out with the following cycles: 48 °C, 45 min (1 cycle); 94 °C, 2 min (1 cycle); 94 °C, 30 s, 57 °C, 30 s, 68 °C, 2 min (40 cycles); and 68 °C, 7 min (1 cycle). The sequences of the primers are listed below. Human adiponectin R1: 5'-TTCTTCTCATGGCTTGATGTG-3'; 5'-AGTG-GACAAAGGGCTGCTGCCA-3'. Human adiponectin R2: 5'-ATGAACGACGCAAAGACCAATGATG-3'; 5'-CGGTGTCCCAGAAGAGGAAGTCA-3'. After amplification, the PCR mixture was separated on 2.0% agarose gel and stained with ethidium bromide.

Cell count

HEC-1-A and RL95-2 cells were plated in 12-well culture plates. Before performing the experiments, cells were serum-deprived overnight and then human recombinant adiponectin (10, 20, and 40 µg/ml) was added to the cells. Medium and the reagent were replaced once at 24 h. Cells were harvested and counted using a hemocytometer 48 h after adiponectin treatment.

Analysis of cell cycle and apoptosis

After HEC-1-A and RL95-2 cells were incubated in serum-free medium overnight, cells were treated with adiponectin (20 and 40 µg/ml) for 48 h (medium was changed and fresh adiponectin was added daily). Both floating and trypsinized adherent cells were collected and rinsed with PBS. For cell cycle analysis, the cells were fixed in 70% ethanol at 4 °C overnight. Before
performing flow cytometry assays, the cells were washed with PBS twice, and resuspended in 1 ml PBS containing 0.1 mg RNase (DNase free) for 30 min at room temperature. The cells were then resuspended with PBS containing 10 μg/ml propidium iodide (PI; Sigma) and incubated for 15 min in the darkness at room temperature. The DNA content was analyzed using a BD FACStar flow cytometer and the percentages of different phases of cell cycle were determined using a ModFit program (BD Biosciences, San Jose, CA, USA).

Detection of apoptotic cells was performed using Annexin-V-FITC kit (BD Biosciences, San Jose, CA, USA) and PI staining. In this assay, single positive populations are considered early apoptotic (annexin-V positive/PI negative) or necrotic cells (annexin-V negative/PI positive), whereas double positive (annexin-V positive/PI positive) cells are thought to be in a late stage of apoptosis. The staining was performed according to the manual of the manufacturer. Briefly, the cells were incubated in the binding buffer (2.5 mM CaCl₂, 150 mM NaCl, 10 mM HEPES, pH 7.4) containing annexin-V-FITC and PI for 15 min at 20 °C. Early and late apoptotic cells were quantified using the flow cytometer.

Western blot analysis
HEC-1-A and RL95-2 cells were seeded into 12-well plates. Before performing the experiment, the medium was changed to DMEM/F12 without phenol red and fetal bovine serum. After 2 h of serum deprivation, the cells were treated with adiponectin (20 and 40 μg/ml) for 30 min or 48 h. Whole cell extract was prepared from HEC-1-A and RL95-2 cells using cell lysis buffer (50 mM NaF, 150 mM NaCl, 10 mM sodium pyrophosphate, 2 mM EDTA, 0.1% Triton X-100, and a cocktail mixture of protease inhibitors (Roche Diagnostics)). Whole cell protein extract was separated on 12% SDS-PAGE and transferred to nitrocellulose membrane (Bio-Rad). After the incubation in 5% BSA (for the detection of phospho-specific proteins) or 5% milk solution for 1 h, the membranes were incubated with primary antibodies overnight at 4 °C according to manufacturer’s suggestions. The primary antibodies against phospho-AMPKα (Thr172), AMPK, phospho-Akt (Ser473), Akt, phospho-MAPK (p42/44; Thr202/Tyr204), MAPK (p42/44), cyclin D1, cyclin E2, and β-actin were from Cell Signaling Technology. Visualization of protein bands was achieved using a standard enhanced chemiluminescent reaction.

Statistical analysis
Data are presented as the mean ± S.D. Statistical analysis was performed using one-way ANOVA. A value of \( P < 0.05 \) was considered statistically significant.

Results
Expression of adiponectin receptors in HEC-1-A and RL95-2 cells
Previous studies have identified two types of adiponectin receptors, adipo-R1 and adipo-R2 (Yamauchi et al. 2003). Using RT-PCR assays with oligonucleotide primers specific for the human forms of two receptors, we found that both adipo-R1 and adipo-R2 were expressed in HEC-1-A and RL95-2 cells, as indicated by the appearance of the expected DNA bands in the RT-PCRs (Fig. 1).

Suppression of endometrial cancer cell proliferation by adiponectin
Due to their own ability of secreting growth factors, such as transforming growth factor \( \alpha \) (TGF-\( \alpha \)) and IGF-I, HEC-1-A and RL95-2 cells can still maintain the ability of growth in the absence of serum (Reynolds et al. 1998). Thus, we applied human adiponectin to these cultured cells in the absence of serum. The concentrations of adiponectin used in our studies were within or near the physiological ranges observed in humans (Weyer et al. 2001). Treatment of the cultured HEC-1-A or RL95-2 cells with human adiponectin resulted in dosage-dependent suppressive effects on

Figure 1 The expression of adiponectin receptors in HEC-1-A and RL95-2 cells. The mRNA expression of adiponectin-R1 (adipo-R1) and adiponectin-R2 (adipo-R2) was detected in both HEC-1-A and RL95-2 cells. The expected fragments specific to adipo-R1 and adipo-R2 were 150 and 377 bps respectively and were marked with solid arrows. M, marker; C, H₂O control; 1, HEC-1-A cells; 2, RL95-2 cells.
flow cytometry analysis. Accordingly, at 20 and 40 μg/ml, human adiponectin increased the percentage of HEC-1-A cells in G1/G0-phase from 31.7 to 35.8% (P<0.05) and 42.1% (P<0.01) respectively (Table 1); concomitant with these changes, the percentage of HEC-1-A cells in S-phase was decreased from 48.9 to 45.9% (P<0.05) and 40.3% (P<0.01) respectively (Table 1). Similar results were also observed when we treated RL95-2 cells with adiponectin (Table 1).

Thus, the suppressive effects of adiponectin on endometrial cancer cell growth were associated with significant increase of cell populations at G1/G0-phase and a concomitant decrease of the treated cells at S-phase.

**Induction of apoptosis by human adiponectin**

As an additional step to evaluate the inhibitory effects of human adiponectin on endometrial cancer cell growth, we examined the state of apoptosis of the cells after adiponectin treatment using flow cytometry assays. We found that there was a significant increase in the percentage of apoptotic cells as revealed by the annexin-V staining positive patterns (Fig. 3). This appears to be the case whether we were examining both early apoptotic events (annexin-V positive only) and late apoptotic events (both annexin-V and propidium iodide positive; Fig. 3). For instance, at 40 μg/ml, adiponectin caused more than five-fold of increase in early apoptosis (5.6 vs 1.1% control, P<0.01) and more than fourfold of increase in total (including early and late) apoptosis (7.9 vs 1.8% control, P<0.01) in HEC-1-A cells after 48 h of incubation (Fig. 3). Treatment of RL95-2 cells with the same dosage of adiponectin produced similar increases in apoptosis (Fig. 3). We need to emphasize that the inhibitory nature of adiponectin on cell growth (including the induction of apoptosis) was unlikely due to some non-specific toxicity resided in the reagent itself since a parallel treatment of a rat pancreatic β-cell line, INS-1, did not lead to suppression of cell growth (data not shown).

**The signaling pathways induced by adiponectin in HEC-1-A and RL95-2 cells**

To understand the potential molecular mechanisms underlying the anti-proliferative effects of human adiponectin on endometrial cancer cells, we evaluated some of the signaling events induced by adiponectin. We found that AMPK could be rapidly activated by

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**Table 1** Flow cytometry analysis of cell cycle in HEC-1-A and RL95-2 cells

<table>
<thead>
<tr>
<th></th>
<th>HEC-1-A (C)</th>
<th>AN (20 μg/ml)</th>
<th>AN (40 μg/ml)</th>
<th>RL95-2 (C)</th>
<th>AN (20 μg/ml)</th>
<th>AN (40 μg/ml)</th>
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<tbody>
<tr>
<td>G1/G0 (%)</td>
<td>31.7±0.6</td>
<td>35.8±1.4*</td>
<td>42.1±0.1†</td>
<td>54.5±1.4</td>
<td>59.6±1.3†</td>
<td>61.4±0.3†</td>
</tr>
<tr>
<td>S (%)</td>
<td>48.9±0.1</td>
<td>45.9±2.0*</td>
<td>40.3±0.9†</td>
<td>27.2±2.7</td>
<td>22.1±1.5†</td>
<td>19.8±0.5†</td>
</tr>
<tr>
<td>G2/M (%)</td>
<td>19.3±0.5</td>
<td>18.3±0.3</td>
<td>17.6±0.9</td>
<td>18.3±1.6</td>
<td>18.3±0.1</td>
<td>18.8±0.7</td>
</tr>
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</table>

HEC-1-A and RL95-2 cells were incubated with adiponectin (20 and 40 μg/ml) for 48 h. At the end of incubation, the cells were collected for FACS analysis (see Materials and methods). The values were shown as mean±s.d. Data were the averages of triple measurements in an experiment. The experiments were repeated thrice. AN, adiponectin. The symbols ‘*’ and ‘†’ indicate statistical significance at P<0.05, P<0.01 (compared with untreated controls) respectively based on one-way ANOVA.
adiponectin treatment within 30 min in both HEC-1-A and RL95-2 cells, which was evident by the increase of phosphorylation (at Thr172) on the α-subunit of AMPK (Fig. 4A). The activation of AMPK by adiponectin occurred only at early time points (30 min to 1 h, Supplementary Figure 1, which can be viewed online at http://erc.endocrinology-journals.org/supplemental/), a signaling event likely to be needed for triggering the subsequent anti-growth actions of adiponectin.

Interestingly, in the longer treatment (48 h) with adiponectin, the signaling events diverged in these two cell lines. Accordingly, in HEC-1-A cells, adiponectin treatment caused sharp reductions in cyclin D1 expression and in the level of activated Akt (~70% decrease for cyclin D1 and >80% decrease for activated Akt at 40 μg/ml of adiponectin; Fig. 4B). During the same time frame of adiponectin treatment, the expression of cyclin E2 and the level of activated MAPK (p42/44) were unchanged in the HEC-1-A cells. In contrast, the expression of cyclin D1 and the level of activated Akt did not change following the treatment with adiponectin in RL95-2 cells (Fig. 4B), whereas the levels of cyclin E2 as well as the activated MAPK (p42/44) were suppressed by ~50% (Fig. 4B). The protein expression levels of the total Akt and MAPK (p42/44) were not altered by adiponectin treatment in both cell types (Supplementary Figure 1). Thus, the inhibitory effects of adiponectin on endometrial cancer cell proliferation were associated with the distinct reductions of several key regulatory components of cell cycle as well as pro-growth kinases, depending on the genotypes of the cancer cell lines.

**Discussion**

In this study, we find that human adiponectin inhibits the proliferation of two different types of human endometrial cancer cells, HEC-1-A and RL95-2, and that the negative impact of adiponectin on cell growth...
is primarily due to the increase of cell populations arrested at G1/G0-phase as well as to the induction of apoptosis. Owing to their own ability to secrete growth factors, such as TGF-α and IGF-I (Reynolds et al. 1998), both HEC-1-A and RL95-2 cells can maintain aggressive proliferation even in the absence of serum in the culture. Currently, it is not yet clear which of these growth factors’ actions adiponectin can oppose. Previous studies have reported the negative influence of adiponectin on platelet-derived growth factor- and fibroblast growth factor-stimulated proliferation of vascular smooth muscle cells (Cinti et al. 2005). In addition, our recent study has also found that human adiponectin can attenuate IGF-I-stimulated growth of breast cancer cells, MCF7 (unpublished observations). However, future studies are required to reveal the potential interactions between human adiponectin and the growth factors that are stimulatory to the growth of human endometrial cancer cells.

A major genetic difference between HEC-1-A and RL95-2 cells lies in the gene of PTEN with HEC-1-A containing the wild-type, and RL95-2 completely deficient in, PTEN activity (Zhu et al. 2001). PTEN is a tumor suppressor gene whose deficiency has been linked to several types of cancer including endometrial carcinoma (Tashiro et al. 1997). The lipid phosphatase activity resided in PTEN is critical in reducing the phosphorylated forms of phosphatidylinositol (PI) and the subsequent blockade of the PI3-kinase (PI3K) signaling pathway (Cantley & Neel 1999). Null mutations in PTEN will lead to constitutive activation of PI3K and Akt (Zhu et al. 2001). Interestingly, in the two cell lines we have tested, adiponectin has drastically different inhibitory effects on the activities of Akt and MAPK, both of which are known for their potent mitogenic actions (Johnson & Lapadat 2002, Toker & Yoeli-Lerner 2006). Particularly, adiponectin was able to suppress Akt activity in HEC-1-A cells, but not in RL95-2 cells. Although, based on these initial observations, it is tempting to speculate that adiponectin acts either on upstream of PTEN or through a pathway independent of PTEN, the mechanisms by which adiponectin influences endometrial cancer growth in the presence or absence of PTEN remain to be defined. In addition, the changes in Akt or MAPK activities did not occur until 48 h after adiponectin treatment when significant suppression of cell growth already happened (Supplementary Figure 1). Thus, further studies are required to define if the changes of these two pro-growth kinases are coincidental with or required for adiponectin-induced inhibition of cell growth.

In our study, we also find that adiponectin can reduce the expression of cyclin D1 and cyclin E2 in HEC-1-A and RL95-2 cells respectively. Cell cycle progression is a tightly controlled series of events that are positively regulated by cyclin-dependent kinases and their regulatory subunits, cyclins (Murray 2004). Cyclin D1 is a key regulatory element during cell cycle progression from G1- to S-phase (Murray 2004). It has been reported that overexpression of cyclin D1, not only existed in endometrial cancer but also correlated with its poor prognosis (Nikaido et al. 1996). Similarly, one of the molecular markers of endometrial cancer cells is the elevated level of cyclin E2 (Oshita et al. 2002), which also helps to propel the progression from G1- to S-phase. Thus, adiponectin-induced reduction of cyclin D1 or cyclin E2 expression is potentially a critical step for the suppression of endometrial cancer cell growth.

AMPK cascade is considered a sensor of cellular energy status and can be activated by stress, such as glucose deprivation, oxidative stress, and hypoxia (Yamauchi et al. 2002). Activation of AMPK can inhibit cancer cells proliferation and induce apoptosis (Rattan et al. 2005). Thus, adiponectin-induced activation of AMPK is likely an important signaling mechanism underlying the increased apoptosis and suppressed growth in both HEC-1-A and RL95-2 cells. Such observation is also consistent with previous findings that adiponectin can induce apoptosis in cultured breast cancer and endothelial cells (Brakenhielm et al. 2004, Dieudonne et al. 2006). However, further studies are required to delineate the pathways leading from the activation of AMPK to the changes of expression in cell cycle machinery, particularly cyclins D1 and E2.

Obesity is a serious risk factor for endometrial carcinoma (Akhmedkhanov et al. 2001). Although estrogen is one of the well-known ‘culprits’ in the development of endometrial cancer (Akhmedkhanov et al. 2001), the roles of other adipocytes-derived factors are still being defined. Adiponectin belongs to one of the adipokine family members, and its circulating concentrations are reduced in obesity despite the fact that it is exclusively synthesized in the fat cells (Weyer et al. 2001). Although adiponectin is traditionally known for its critical functions in regulating glucose and lipid metabolism as well as in maintaining cardiovascular health (Scherer et al. 1995, Kadowaki & Yamauchi 2005), recent clinical evidence also points to a strong inverse correlation between the plasma concentrations of adiponectin and the risk of endometrial carcinoma (Petridou et al. 2003, Dal Maso et al. 2004, Cust et al. 2007). The results of our cellular
studies, though to be confirmed in tumor models in vivo, are entirely consistent with the above-mentioned clinical observations, and suggest that circulating adiponectin exerts a direct negative influence on the growth of endometrial cancer cells. To our knowledge, such cellular observations have not been reported. The deficiency in adiponectin may thus serve as one of the molecular linkages between obesity and endometrial carcinoma.

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