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Down-regulation of Pregnane X Receptor Contributes to Cell Growth Inhibition and Apoptosis by Anti-cancer Agents in Endometrial Cancer Cells

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Running title: Pregnane X Receptor Down-regulation on Endometrial Cancer

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Abbreviations

PXR, pregnane X receptor; PXRE, PXR-responsive element; CYP3A, cytochrome P-450 3A; MDR1, multiple drug resistance 1; SRC-1, steroid receptor coactivator-1; MTS, 3-(4,5-dimethylthiazol-2-yl)-5-(3-carboxymethoxyphenyl)-2-(4-sulfophenyl)-2H-tetrazolium, inner salt; MPA, medroxyprogesterone acetate; estradiol, 17β-estradiol; D-MEM, Dulbecco's modified eagle's medium; ELISA, enzyme-linked immunosorbant assay; RT-PCR, reverse transcription-polymerase chain reaction; CAT, chloramphenicol acetyl transferase; AIB1, amplified in breast cancer 1

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Recent studies have revealed that pregnane X receptor (PXR) can function as a master regulator to control the expression of drug-metabolizing enzymes, cytochrome P-450 3A (CYP3A) family, as well as members of the drug transporter family, including multiple drug resistance 1 (MDR1). Previously, we demonstrated that steroid/xenobiotic metabolism by tumor tissue through the PXR-CYP3A pathway might play an important role in endometrial cancer, and that PXR ligands enhance PXR-mediated transcription in a ligand- and promoter-dependent fashion, leading to differential regulation of individual PXR targets, especially CYP3A4 and MDR1. In this study, we investigated the potential contribution of PXR down-regulation by RNA interference toward the augmentation of drug sensitivity and the overcoming of drug resistance. We observed the protein levels of both CYP3A4 and MDR1 in PXR siRNA-transfected cells were not increased in the presence of PXR ligands, paclitaxel, cisplatin, estradiol or medroxyprogesterone acetate (MPA), compared with control siRNA-transfected cells. There was no PXR-mediated transactivation or augmentation of transcription by coactivators in the presence of these ligands. We then found that PXR down-regulation caused a significant increase in cell growth inhibition and enhancement of apoptosis in the presence of the anti-cancer agents, paclitaxel, cisplatin and MPA. Finally, we demonstrated that PXR overexpression caused a significant decrease in cell growth inhibition and inhibited apoptosis in the presence of paclitaxel or cisplatin. These data suggest that PXR down-regulation could be a novel therapeutic approach for the augmentation of sensitivity to anticancer agents, or to overcome resistance to them, in the treatment of endometrial cancer.

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Pregnane X receptor (PXR), a new member of the steroid receptor superfamily, has been shown to mediate the genomic effects of several steroid hormones, including progesterone, pregnenolone and estrogen, and those of xenobiotics, and to bind to specific DNA sequences, PXR-responsive elements (PXREs) in the mouse, rat, and human (Kliewer et al., 1998; Lehmann et al., 1998; Bertilsson et al., 1998; Zhang et al., 1999; Blumberg et al., 1998; Pascussi et al., 1999; Schuetz et al., 1998). These elements are found in the upstream regions of genes in the cytochrome P-450 3A (CYP3A) family (Kliewer et al., 1998; Lehmann et al., 1998; Bertilsson et al., 1998; Pascussi et al., 1999), which are monooxygenases responsible for the oxidative metabolism of certain endogenous substrates and xenobiotics (De Wildt et al., 1999; Ketter et al., 1995) and in the upstream region of the multiple drug resistance 1 (MDR1) gene (Synold et al., 2001; Geick A et al., 2001), which encodes P-glycoprotein, a multidrug transporter that has a major role in drug resistance (Ambudkar et al., 2003). Because the PXR pathway is activated by a large number of prescription drugs designed to treat infection, cancer, convulsion, and hypertension (Kliewer et al., 2002), PXR is thought to play roles in drug metabolism/efflux and drug-drug interactions. Recent research demonstrated that PXR regulates the metabolism of bile acid, which is essential for the elimination of excess cholesterol from the body and the transport of dietary lipids in the intestine (Staudinger et al, 2001). These data suggest that PXR regulates an entire program of genes in the liver and intestine that are involved in the metabolism of potentially toxic substrates and their elimination from the body (Kliewer et al., 2002). Previously, we demonstrated the expression of PXR in mouse reproductive tissues, uterine and ovarian, as well as in the liver and intestine, and we showed that the expression levels of PXR and CYP3A1 in the liver and ovary were significantly increased in parallel with the progression of hypersteroidemia evaluated toward term during pregnancy, suggesting that PXR may play a role in the regulation of steroid hormone metabolism during reproduction (Masuyama et al., 2001). In addition, our recent data suggested that steroid/xenobiotic metabolism by tumor tissue through the PXR-CYP3A pathway might play an important role in endometrial cancer, especially as an alternative pathway for gonadal hormone and EDC effects on endometrial cancers expressing low levels of estrogen receptor (ER) α (Masuyama et al., 2003). Moreover, we have reported that PXR ligands enhance PXR-mediated transcription in a ligand- and promoter-dependent fashion, leading to the differential regulation of the expression of individual PXR targets, especially CYP3A4 and MDR1, in endometrial cancer cells (Masuyama et al., 2005).

Endometrial cancer is a highly curable malignancy when it presents as uterine-confined disease, but the

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prognosis for metastatic or recurrent endometrial cancer is poor. Cytotoxic chemotherapy is indicated as the frontline treatment for the majority of women with metastatic or recurrent disease. Paclitaxel in combination with cisplatin and/or doxorubicin chemotherapy improves both the response rate and the median survival (Carey et al., 2006). Moreover, hormonal therapy may be a therapeutic option in a select population of patients with well differentiated and progesterone receptor-positive tumors, minimal symptoms or non-life threatening advanced or recurrent endometrial cancer (Carey et al., 2006).

The effectiveness of the chemotherapy is often limited by the drug resistance of tumors, and much effort has been expended to improve our understanding of the mechanisms of the drug resistance and determine an approach to overcome this resistance (Tsuruo et al., 2003). In this study, to investigate the potential contribution of PXR down-regulation toward the augmentation of drug sensitivity and the overcoming of drug resistance, we examined whether the down-regulation of PXR affected the expression of PXR targets in the presence of PXR ligands, anticancer agents and steroids, in endometrial cancer cells. We also analyzed whether the down-regulation of PXR affected PXR-mediated transcription and checked the effect of PXR knockdown on cell growth and apoptosis in the presence of PXR ligands. We then checked the effect of PXR overexpression on cell growth and apoptosis in the presence of PXR ligands. These data suggest that the down-regulation of PXR could be a novel therapeutic approach for the augmentation of sensitivity to anticancer drugs, or to overcome resistance to them, in the treatment of endometrial cancer.

MATERIALS AND METHODS

Materials

Medroxyprogesterone acetate (MPA), and 17β-estradiol (estradiol) were purchased from Sigma Co., Ltd. (St. Louis, MO, USA). Carboplatin, cisplatin, docetaxel, and paclitaxel were purchased from Calbiochem-Novabiochem Corp. (San Diego, CA, USA). HEC-1 cells were obtained from the Health Science Research Resources Bank (Osaka, Japan).

Cell Culture and RNA Interference

HEC-1 cells were cultured in Dulbecco's modified eagle's medium (D-MEM) without phenol red, supplemented with 10% charcoal-striped fetal bovine serum. The medium and serum were purchased from Invitrogen Corp.

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(Carlsbad, CA, USA). The siRNA cocktail targeting human PXR was purchased from B-Bridge International Inc. (Mountain View, CA), which contains 3 siRNAs: first sequence ggacaaggccacuggcuau (sense), auagccaguggccuugucc (antisense), second sequence agccgacaguggcgggaaa (sense), uuucccgccacugucggcu (antisense), and third sequence gggccaagacagauggaca (sense), uguccaucugucuuggccc (antisense). Negative control cocktail (Cat# C6A-0126), which consist of non-complementary sequence of human, mouse and rat, and liposome for siRNA transfection (siFECTOR) were also purchased from B-Bridge International Inc. Cells were transfected with PXR siRNA or control siRNA using siFECTOR according to the manufacturer's protocol.

Western Blot Analysis

Whole cell extracts were obtained from cells transfected with PXR siRNA or control siRNA using M-PER Mammalian Protein Extraction Reagents (Pierce Chemical Co., Rockford, IL, USA), according to the manufacturer's protocol, and stored at –80 C until analysis. Protein content was determined using a bicinchoninic acid protein assay (Pierce Chemical Co.), and equivalent amounts of nuclear protein (25 μg/sample) from each extract were solubilized in SDS buffer (0.05M Tris-HCl, 2% SDS, 6% mercaptoethanol, 10% glycerol, pH 6.8) and analyzed by Western blot analysis as previously described (Masuyama et al., 1998). We employed a goat polyclonal antibody for PXR (1:1000 dilution), and rabbit polyclonal antibodies for MDR-1 (1:500 dilution) and β-actin (1:1000 dilution) (Santa Cruz Biotechnology, Inc., Santa Cruz, CA, USA), and CYP3A4 (1:1000) (PanVera Corp. Madison, WI, USA). The amount of each band was quantitated densitometrically using Image Scanner GT-9500 (Epson, Suwa, Japan) and Bio Image BQ 2.0 software (Ann Arbor, MI, USA).

Reverse Transcription-Polymerase Chain Reaction (RT-PCR)

Total RNA was extracted from endometrial cancer cells using Trizol reagent (Life Technology, Inc., Grand Island, NY, USA). Each sample was treated with DNase I to remove genomic DNA contamination. To generate first-strand DNA, 0.1 μg of total RNA was reverse transcribed at 42 C for 20 min in 20 μl of reaction solution containing 1xPCR buffer, 5 mM MgCl2, 1 mM dNTPs, 2.5 μM random 9-mer primer, 10 U RNase inhibitor and 5 U AMV reverse transcriptase, using an RNA PCR kit (TAKARA Co., Ltd., Kyoto, Japan), according to the manufacturer's protocol. The primers used to amplify human PXR and GAPDH have been described previously

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(Masuyama et al., 2003; Masuyama et al., 2005). Amplification of PXR and GAPDH was carried out on a GeneAmp PCR system 9700 (Applied Biosystems, Foster City, CA, USA) as described previously (Masuyama et al., 2003; Masuyama et al., 2005). The number of PCR cycles resulting in PCR products in the linear logarithmic phase of the amplification curve was determined. PCR samples were electrophoresed on 3% Nu-Sieve agarose gels and visualized by staining with ethidium bromide. The housekeeping gene GAPDH was used to control for variations in RNA recoveries from each specimen.

Transient Transfection Studies

The pSG5-PXR expression plasmid containing full-length human PXR cDNA was kindly provided by Dr. S. A. Kliewer (Kliewer et al., 1998). The $(CYP3A4)^3$-tk-chloramphenicol acetyl transferase (CAT) vector was generated by insertion of three copies of a double-strand oligonucleotides containing the DR-3/CYP3A4 (5'-gggtcagcaagttca-3'), and the $(MDR1)^3$-tk-CAT vector was generated by insertion of three copies of a double-strand oligonucleotides containing the DR-4/MDR1 (5'-aggtcaagttagttca-3') as described previously (Geick et al., 2001, Goodwin et al., 1999). The AIB1 cDNA, which was generated by reverse transcriptase-polymerase chain reaction (RT-PCR), and the SRC-1 cDNA, which was a gift from Dr. M. J. Tsai (Baylor College, Houston, TX, USA), were subcloned into pcDNA3 expression vectors (Invitrogen, San Diego, CA, USA). Ishikawa cells and HEC-1 cells were cotransfected with 1 μg of a reporter gene construct ($(CYP3A4)^3$-tk-CAT or $(MDR1)^3$-tk-CAT) or tk-CAT vector. For coactivator expression, 1 μg of pcDNA3-steroid hormone receptor-1 (SRC-1) vector, pcDNA3-amplified in breast cancer 1 (AIB1) vector, or pcDNA3 vector alone, was also transfected into the cells. In all transfections, liposome-mediated transfections were accomplished using Lipofectamine (Life Technologies Inc., Gaithersburg, MD, USA) according to the manufacturer's instructions. Transfected cells were treated either with vehicle alone or with the indicated concentrations of steroid hormones or anticancer agents for 24 h. Cell extracts were prepared and assayed for CAT activity. The amount of CAT was determined using a CAT enzyme-linked immunosorbant assay (ELISA) kit (Roche Diagnostics Co., Tokyo, Japan) according to the manufacturer's instructions.

Cell Growth and Apoptosis Assay

Transfected cells ($5x10^3$ cells/well) were seeded and incubated in a 96-well culture plate for 0, 24, 48, 72 or 96 h.

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Cell proliferation was measured using a CellTiter 96 aqueous One Solution Cell Proliferation Assay (MTS assay) according to the manufacturer's protocol (Promega Corp. Madison, WI, USA). For the detection of apoptosis, the Cell Death Detection ELISA kit (Roche Diagnostics Co.) was used according to the manufacturer's protocol.

Statistical Analysis

Statistical analysis was performed using one-way ANOVA followed by Dunnett's test, as shown in Figures 1, 4, 5, 6 and 7. Data are the means± S.D. $P<0.05$ denotes the presence of a statistically significant difference.

RESULTS

The Effect of PXR siRNA on the Expression of PXR, CYP3A and MDR1 in the Presence of PXR Ligands

We used HEC-1 cells as an endometrial cancer cell line for this study because PXR is abundant in this cell line (Masuyama et al., 2003). To investigate the effect of PXR siRNA on the expression of PXR, CYP3A and MDR1 in the presence of PXR ligands, we qualitatively examined the protein levels of CYP3A4, MDR1, and PXR in HEC-1 cells that had been exposed to steroids and anticancer drugs. In this study, we used known PXR ligands, estradiol, MPA, paclitaxel and cisplatin, and other anticancer agents, docetaxel and carboplatin, which are not ligands for PXR (Masuyama et al., 2005), as control. First, we confirmed the efficacy of PXR siRNA for the knockdown of PXR mRNA in HEC-1 cells, using RT-PCR and Western blotting. Neither PXR mRNA nor PXR protein was detected in HEC-1 cells transfected with PXR siRNA (Fig. 1A). In cells transfected with PXR siRNA, no significant increases were seen in CYP3A4 and MDR1 protein levels in the presence of the PXR ligands, paclitaxel and cisplatin, compared with cells treated with control siRNA (Fig. 1B). The normally positive effects of steroids, estradiol and MPA on CYP3A4 or MDR1 expression were not observed in PXR siRNA-transfected cells (Fig. 1C). And the effects of paclitaxel on CYP3A4 or MDR1 expression were not observed in PXR siRNA-transfected cells for the incubation of 72 h as well as 36 h (Fig. 1D). We observed no non-specific effect by siRNA because there were no differences of the PXR expression and cell growth between the control-siRNA treated cells and no siRNA-treated cells. Moreover, we observed the same results of these experiments using other endometrial cancer cell line, Ishikawa cells, in which PXR is moderately expressed (Masuyama et al., 2003) (data not shown).

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The Effect of PXR siRNA on PXR-mediated Transcription through the PXR Responsive Elements, CYP3A or MDR1

Next, we examined the effect of PXR siRNA on PXR-mediated transcription through PXREs, CYP3A or MDR1. Three different reporter gene constructs, $(CYP3A4)^3$-tk-CAT, $(MDR1)^3$-tk-CAT and tk-CAT, were introduced into HEC-1 cells. In control siRNA transfected cells or untransfected cells using $(CYP3A4)^3$-tk-CAT, the steroids 17β-estradiol and MPA significantly activated native PXR-mediated transcription. The antitumor agents cisplatin and paclitaxel also significantly activated native PXR-mediated transcription, but the fold increases were lower compared with those in the presence of steroids in these HEC-1 cells. By contrast, cisplatin and paclitaxel had a stronger effect on native PXR-mediated transcription through the MDR1-responsive element, compared with steroids. The other drugs we tested, carboplatin and docetaxel, had no effect on this transcription. In cells transfected with PXR siRNA, we observed no PXR-mediated transactivation in the presence of PXR ligands. No non-specific effects by siRNA on the transcription were observed because there were no differences of the PXR-mediated transcription between in the control siRNA-transfected cells and in untransfected cells and no differences of basal transcription using the tk-CAT vector among PXR siRNA-, control siRNA-transfected cells and untransfected cells (Fig. 2).

PXR siRNA Abolished the Effect of Overexpressed Coactivator on PXR-mediated Transcription

We used a transient reporter expression assay in HEC-1 cells to examine whether PXR siRNA abolished the effect of an overexpressed coactivator on PXR-mediated transcription. As shown in Fig. 3, the coactivators tested here enhanced PXR-mediated transcription in the presence of PXR ligands, estradiol and paclitaxel, through both PXREs (CYP3A4 and MDR1). The effect of steroid receptor coactivator-1 (SRC-1) on PXR-mediated transcription in the presence of estradiol was more efficient than that in the presence of paclitaxel through the CYP3A4-responsive element. By contrast, the effect of amplified in breast cancer 1 (AIB1) on PXR-mediated transcription in the presence of paclitaxel was significantly increased compared with that in the presence of estradiol through the MDR1-responsive element. In cells transfected with PXR siRNA, there was no augmentation of PXR-mediated transcription due to an overexpressed coactivator in the presence of these PXR ligands, through either PXRE. We observed no non-specific effects by siRNA on the augmentation of the

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transcription by an overexpressed coactivator because there were no differences of the PXR-mediated transcription between in the control-siRNA transfected cells and in untransfected cells and no differences of basal transcription using the tk-CAT vector among PXR siRNA-, control siRNA-transfected cells and untransfected cells.

The Effect of PXR siRNA on Cell Proliferation in the Presence of Anti-Cancer Agents

We then examined the effect of PXR down-regulation on cell proliferation in the presence of anti-cancer agents. Cell viability was determined by an 3-(4,5-dimethylthiazol-2-yl)-5-(3- carboxymethoxyphenyl)-2-(4-sulfophenyl)-2H-tetrazolium, inner salt (MTS) assay and the effect of PXR siRNA on cell growth is shown in Figure 4. We found that the down-regulation of PXR expression significantly enhanced cell growth inhibition in the presence of the anti-cancer agents, paclitaxel and cisplatin, which are PXR ligands (Fig. 4A, C). On the other hand, there was no difference in cell growth inhibition by other anticancer agents, docetaxel and carboplatin, between PXR siRNA- and control siRNA-tranfected cells (Fig. 4B, D). There was no difference in cell growth between control siRNA-transfected cells and untransfected cells.

The Effect of PXR siRNA on Apoptosis in the Presence of Anti-Cancer Agents

To investigate whether the effect of cell growth inhibition by PXR siRNA in the presence of anti-cancer agents is related to the induction of apoptosis, the effect of PXR siRNA on apoptic cell death was examined. We observed that the down-regulation of PXR significantly enhanced apoptosis in PXR siRNA-transfected cells compared with cells transfected with control siRNA or without siRNA in the presence of paclitaxel or cisplatin (Fig. 5A, C). On the other hand, there was no difference in apoptosis induced by other anticancer agents, docetaxel and carboplatin, between PXR siRNA- and control siRNA-tranfected cells (Fig. 5B, D). There was no difference in apoptosis between control siRNA-transfected cells and untransfected cells.

The Effect of PXR siRNA on Cell Proliferation and Apoptosis in the Presence of Steroids, Estradiol or MPA

We also examined the effect of PXR down-regulation on cell proliferation and apoptosis in the presence of steroids, MPA and estradiol. We found that the down-regulation of PXR expression significantly enhanced cell

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growth inhibition in the presence of MPA as well as the anti-cancer agents, paclitaxel and cisplatin (Fig. 6A). On the other hand, estradiol induced a significant increase in cell growth in PXR siRNA-transfected cells compared with control siRNA-tranfected cells (Fig. 6B). We also observed that the down-regulation of PXR significantly enhanced apoptosis in PXR siRNA-transfected cells compared with cells transfected with control siRNA or untransfected cells in the presence of MPA as well as paclitaxel and cisplatin (Fig. 6C). However, there was no difference in apoptosis induced by estradiol between PXR siRNA- and control siRNA-tranfected cells (Fig. 6D). There was no difference in cell growth and apoptosis between control siRNA-transfected cells and untransfected cells.

The Effect of Overexpressed PXR on Cell Proliferation and Apoptosis in the Presence of Anticancer Agents

Finally, we examined the effect of overexpressed PXR on cell proliferation and apoptosis in the presence of anticancer agents. We confirmed the overexpression of PXR in cells transfected with pSG5-PXR expression vector (Fig. 7A). We found that the overexpression of PXR significantly suppressed cell growth inhibition in the presence of paclitaxel or cisplatin after incubation for 72 h and 96 h (Fig. 7B, C). Moreover, we also observed that PXR overexpression significantly inhibited apoptosis in the presence of paclitaxel or cisplatin after incubation for 72 h and 96 h (Fig. 7D, E).

DISCUSSION

Previously, we demonstrated that steroid/xenobiotic metabolism by tumor tissue through the PXR-CYP3A pathway might play an important role in endometrial cancer (Masuyama et al., 2003) and that PXR ligands enhance PXR-mediated transcription in a ligand- and promoter-dependent fashion, leading to the differential regulation of the expression of individual PXR targets, especially CYP3A4 and MDR1 (Masuyama et al., 2005). The CYP3A subfamily is involved in the metabolism of endogenous substrates such as steroid hormones and bile acids (De Wildt et al., 1999; Ketter et al., 1995). This subfamily also plays important roles in the metabolism of procarcinogens and pharmaceutical agents, including innumerable drugs, chemical carcinogens, mutagens, and other environmental contaminants (De Wildt et al., 1999; Ketter et al., 1995; Masuyama et al., 2000). MDR1 was originally identified because of its overexpression in cultured cancer cells associated with an

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acquired cross-resistance to multiple anticancer drugs, and has been shown to be an ATP-dependent efflux pump of hydrophobic anticancer drugs (Ambudkar et al., 2003). Recently, it was reported that MDR1 is also regulated by PXR (Synold et al., 2001; Geick et al., 2001). Some endometrial carcinomas, as well as normal endometrial controls from both proliferative and secretory phases of the menstrual cycle, overexpress P-glycoprotein, which is encoded by the MDR1 gene (Schneider et al., 1993). Here, we show that the protein levels of neither CYP3A4 nor MDR1 were increased in cells transfected with PXR siRNA, in the presence of PXR ligands, paclitaxel, carboplatin, estradiol and MPA, compared with cells treated with control siRNA. In addition, we observed no PXR-mediated transactivation or augmentation of transcription by coactivators in the presence of any PXR ligands. These data suggest that PXR ligands affect the expression of CYP3A4 and MDR1 genes through a PXR-mediated pathway, and that the PXR-CYP3A4 and PXR–MDR1 pathways are blocked by PXR down-regulation in endometrial cancer cells.

A number of tumor cells, including endometrial cancer cells, have been reported to undergo apoptotic cell death when treated with chemotherapic agents such as adriamycin, vincristine, etoposide, cisplatin and paclitaxel (Tsuruo et al., 2003, Bhalla, 2003). Apoptosis and anti-apoptosis pathways are related to drug sensitivity and resistance (Tsuruo et al., 2003). Next, we checked the effects of PXR knockdown on cell growth and apoptosis in the presence of PXR ligands. We found that down-regulation of PXR expression significantly enhanced cell growth inhibition and apoptosis in the presence of the anti-cancer agents, paclitaxel and cisplatin, indicating that down regulation of PXR in cancer cells might alter the effects of anticancer agents in the treatment of endometrial cancer. Contrarily, PXR overexpression caused a significant decrease in cell growth inhibition and inhibited apoptosis in the presence of paclitaxel or cisplatin. Because paclitaxel has been identified as a substrate of CYP3A4 and P-glycoprotein (Harris et al., 1994; Sparreboom et al., 1997), and the role of P-glycoprotein in mediating paclitaxel resistance in tumors has also been shown (Wu et al., 2003, Penson et al., 2004), PXR down-regulation might play a novel therapeutic role in the sensitivity of endometrial cancer cells to paclitaxel, and their resistance to it, through the inhibition of drug metabolism and/or transport/efflux of this drug. However, it is unclear whether MDR1-dependent protection is activated under cytotoxic conditions induced by cisplatin, which is not a substrate for MDR1 (Takara et al., 2002). Recent review indicated that cisplatin is a substrate for CYP3A4/5 (Harmsen et al., 2007), suggesting that PXR down-regulation might inhibit the drug metabolism of cisplatin through PXR-CYP3A4 pathway and the cells might become sensitive to

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cisplatin. Further analysis including functional experiments tying the block in MDR1 protein induction to a loss in cell surface efflux function or in drug metabolism will be required to clarify the mechanism underlying the enhancement of cell growth inhibition and apoptosis by PXR down-regulation in the presence of paclitaxel or cisplatin. A recent report showing that PXR levels are directly related to drug resistance in osteosarcoma cell lines also supports our data (Mensah-Osman et al., 2007). But, although a number of clinical trials have attempted to alter P-glycoprotein activity and thus improve clinical outcomes, the majority of these studies showed no clear-cut success (Dalton et al., 1995, Sonneveld et al., 2001, Leonard et al., 2003). Further analysis including *in vivo* experiments will be required to show the potential of this PXR down-regulation for clinical use.

Hormonal therapy using MPA might be effective for the treatment of endometrial cancer patients with well differentiated and progesterone receptor-positive tumors, minimal symptoms or non-life threatening advanced or recurrent endometrial cancer; however, trials to date have not been adequately powered to determine significant differences in survival (Carey et al., 2006). We demonstrated that down-regulation of PXR also enhances cell growth inhibition and apoptosis in the presence of MPA, suggesting that the down-regulation of PXR might enhance the effect of MPA on endometrial cancer cells. Because MPA is a substrate for CYP3A4 (Kobayashi et al., 2000), the PXR pathway might play an important role in mediating the metabolism/efflux of MPA in endometrial cancer cells. In addition, we observed that the down-regulation of PXR enhanced cell proliferation, but didn't affect apoptosis in the presence of estradiol, suggesting that endometrial cancer cells respond more effectively to estrogen under conditions of PXR down-regulation. Moreover, we have also demonstrated a significant inverse correlation between PXR and ER in cases of endometrial cancer (Masuyama et al., 2003). Because estradiol is also a substrate for CYP3A4 (Tsuchiya et al., 2005) and relatively high concentration of estradiol is required to enhance PXR-mediated transcription (Masuyama et al., 2003), PXR-mediated pathways might play an important role in the steroidogenesis of endometrial cancer cells under a local high steroid hormone condition and the PXR level in tumors might affect the response to estrogen.

In summary, we examined whether the down-regulation of PXR affected the expression of PXR targets and PXR-mediated transcription in endometrial cancer cells. In cells transfected with PXR siRNA, neither CYP3A4 nor MDR1 protein levels were increased in the presence of the PXR ligands, paclitaxel, cisplatin, estradiol and MPA, compared with cells treated with control siRNA. Moreover, we observed no PXR-mediated

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transactivation or augmentation of transcription by coactivators in the presence of PXR ligands. We also checked the effect of PXR knockdown on cell growth and apoptosis. We found that down-regulation of PXR expression caused a significant increase in cell growth inhibition and an enhancement of apoptosis in the presence of the anti-cancer agents, paclitaxel and cisplatin. We also investigated the effects of PXR overexpression on cell growth and apoptosis. Overexpression of PXR caused a significant decrease in cell growth inhibition and inhibited apoptosis in the presence of paclitaxel or cisplatin. These data suggest that down-regulation of PXR could be a novel therapeutic approach for the augmentation of sensitivity to anticancer agents, or to overcome resistance to them, in the treatment of endometrial cancer.

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Footnotes

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Figure Legends

Fig. 1. The Effect of PXR siRNA on the Expression of PXR, CYP3A and MDR1 in the Presence of PXR Ligands.

A, HEC-1 cells were transfected with PXR or control siRNA. Whole cell extracts were prepared as described in the materials and methods section. PXR and β-actin protein levels were determined by Western blotting using anti-PXR and -β-actin antibodies. Total RNA was also obtained from HEC-1 cells and analyzed for the expression of PXR and GAPDH mRNAs using RT-PCR. PCR products were separated on 3% Nu-Sieve agarose gels and visualized by ethidium bromide staining. B, HEC-1 cells were transfected with PXR or control siRNAs and treated with DMSO or various anticancer agents for 36 h. Whole cell extracts were prepared and CYP3A4, MDR1, and PXR protein levels were determined by Western blotting using antibodies against CYP3A4, MDR1 and PXR. As a loading control, β-actin protein levels were also examined using anti-β-actin antibody. Each bar represents the mean ± SD from three independent experiments (*p<0.01 compared with control siRNA-treated control). C, PXR or control siRNA-transfected HEC-1 cells were treated with DMSO or 10^{-6} M concentrations of various steroids for 36 h. Whole cell extracts were prepared and CYP3A4, MDR1, PXR, and β-actin protein levels were determined by Western blotting using the same antibodies. Each bar represents the mean ± SD from three independent experiments (*p<0.01 compared with control siRNA-treated control). D, PXR or control siRNA-transfected HEC-1 cells were treated with DMSO or 10^{-6} M paclitaxel for 36 or 72 h. Whole cell extracts were prepared and CYP3A4, MDR1, PXR and β-actin protein levels were determined by Western blotting using the same antibodies. Each bar represents the mean ± SD from three independent experiments (*p<0.01 compared with control siRNA-treated control).

Fig. 2. Effect of PXR siRNA on PXR-mediated Transcription through the PXR-Responsive Elements, CYP3A or MDR1

HEC-1 cells were transfected with PXR siRNA or control siRNA, or without siRNA, and then transiently transfected with 1 μg of the $(CYP3A4)^3$-tk-CAT, $(MDR1)^3$-tk-CAT or tk-CAT vector. The cells were treated with ethanol vehicle, 10^{-6} M steroids, or anticancer agents for 24 h. The amount of CAT was determined using a CAT ELISA kit (Roche Diagnostics Co., Tokyo, Japan) according to the manufacturer's instruction. The results represent the means ± SD of three independent experiments.

Fig. 3. PXR siRNA Abolished the Effect of an Overexpressed Coactivator on PXR-mediated Transcription

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HEC-1 cells were transfected with PXR siRNA or control siRNA, or without siRNA, and then transiently cotransfected with 1 μg of the $(CYP3A4)^3$-tk-CAT, $(MDR1)^3$-tk-CAT or tk-CAT reporter gene constructs in addition to 1 μg of pcDNA3-AIB1, -SRC-1, or pcDNA3 expression vectors. Cells were treated with ethanol vehicle or 10^{-6} M estradiol or paclitaxel for 24 h. The amount of CAT was determined using a CAT ELISA kit. The results represent the means ± SD of three independent experiments.

Fig. 4. The Effect of PXR siRNA on Cell Proliferation in the Presence of Anti-Cancer Agents

HEC-1 cells were transfected with PXR siRNA or control siRNA, or without siRNA, and were seeded and incubated with paclitaxel (A), docetaxel (B), cisplatin (C) or carboplatin (D) in 96-well culture plates for 0, 24, 48, or 72 h. Then, cell proliferation was measured using a CellTiter 96 aqueous One Solution Cell Proliferation Assay (MTS assay) according to the manufacturer's protocol (Promega Corp. Madison, WI, USA). The results represent the means ± SD of three independent experiments.

Fig. 5. The Effect of PXR siRNA on Apoptosis in the Presence of Anti-Cancer Agents

HEC-1 cells were transfected with PXR siRNA or control siRNA, or without siRNA, and were seeded and incubated with paclitaxel (A), docetaxel (B), cisplatin (C) or carboplatin (D) in 96-well culture plates for 0, 24, 48, or 72 h. Then, for the detection of apoptosis, a Cell Death Detection ELISA kit (Roche Diagnostics Co.) was used according to the manufacturer's protocol. The results represent the means ± SD of three independent experiments.

Fig. 6. The Effect of PXR siRNA on Cell Proliferation and Apoptosis in the Presence of Steroids, Estradiol or MPA

HEC-1 cells were transfected with PXR siRNA or control siRNA, or without siRNA, and were seeded and incubated with estradiol (A, C) or MPA (B, D) in 96-well culture plates for 0, 24, 48, or 72 h. Then, cell proliferation was measured using a CellTiter 96 aqueous One Solution Cell Proliferation Assay (MTS assay) according to the manufacturer's protocol (Promega Corp. Madison, WI, USA). For the detection of apoptosis, a Cell Death Detection ELISA kit (Roche Diagnostics Co.) was used according to the manufacturer's protocol. The results represent the means ± SD of three independent experiments.

Fig. 7. The Effect of Overexpressed PXR on Cell Proliferation and Apoptosis in the Presence of Anticancer Agents

HEC-1 cells were transfected with pSG5-PXR vector or pSG5 expression vector alone, or without vector.

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Nuclear extracts were prepared as described in the materials and methods section. PXR protein level was determined by Western blotting using an anti-PXR antibody (A). Cells were incubated with paclitaxel (B, D) or cisplatin (C, E) in 96-well culture plates for 0, 24, 48, 72 or 96 h. Then, cell proliferation was measured using a CellTiter 96 aqueous One Solution Cell Proliferation Assay (MTS assay) according to the manufacturer's protocol (B, C). For the detection of apoptosis, a Cell Death Detection ELISA kit was used according to the manufacturer's protocol (D, E). The results represent the means ± SD of three independent experiments.

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Figure 1

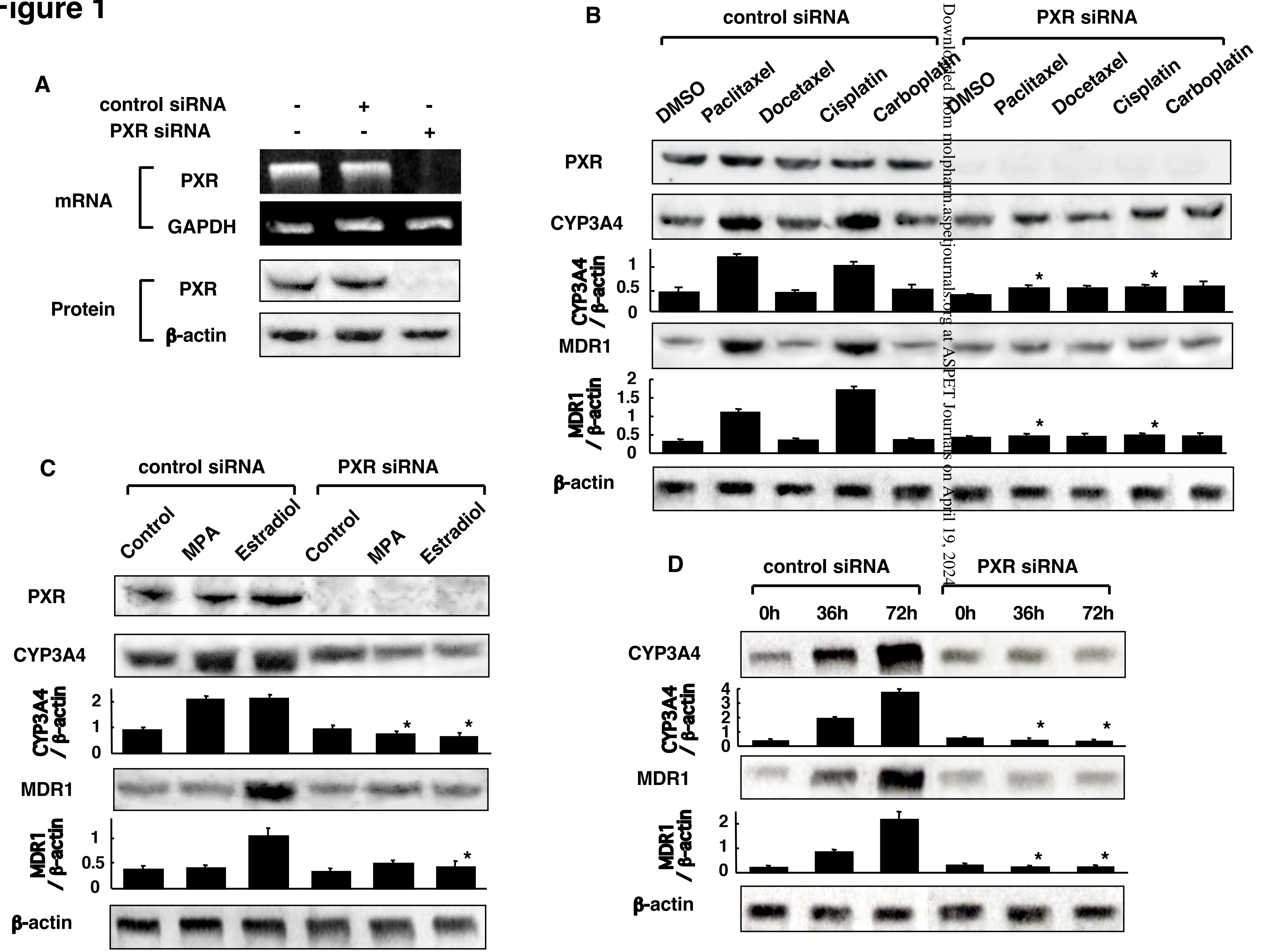

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Figure 2

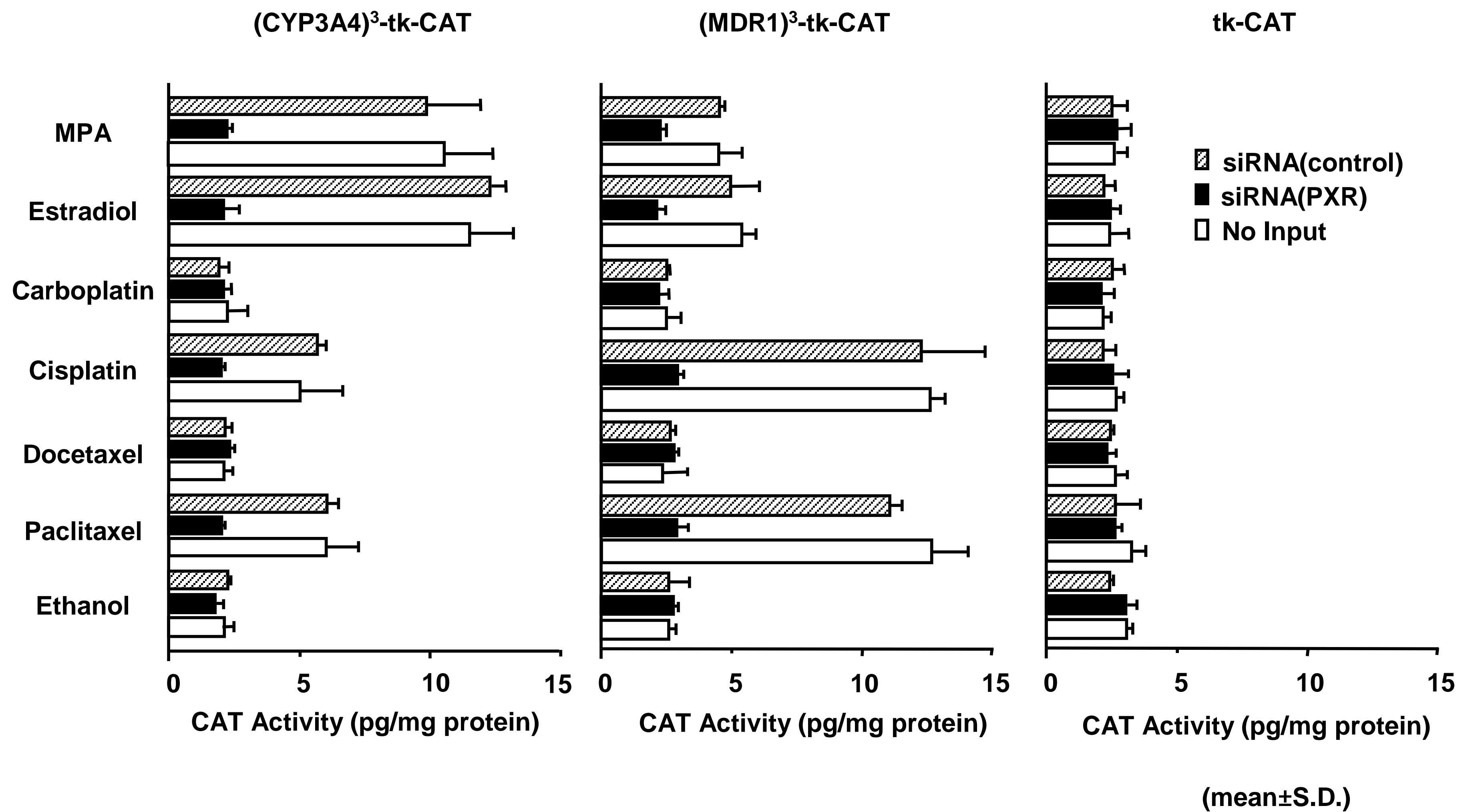

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Figure 3

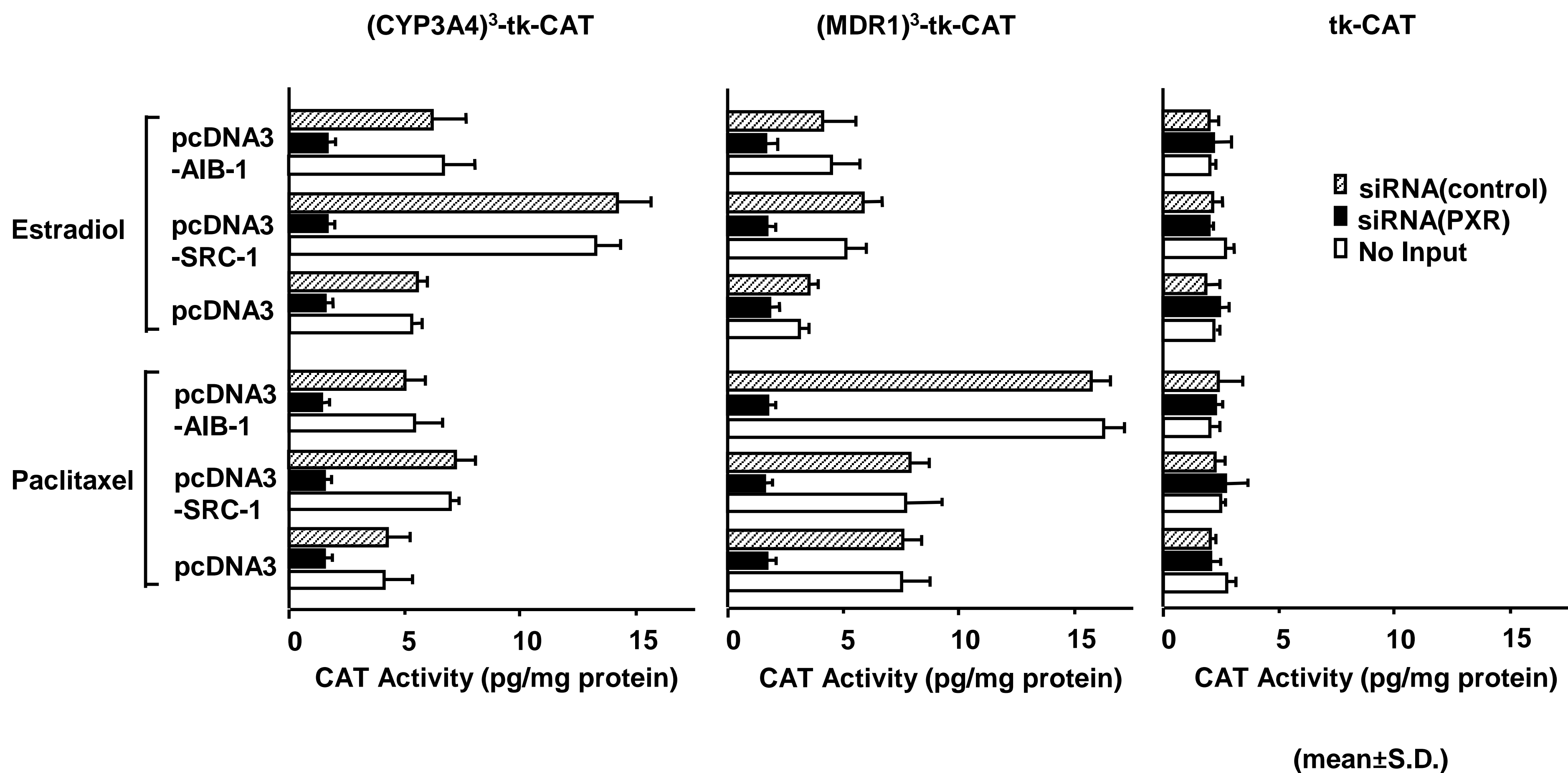

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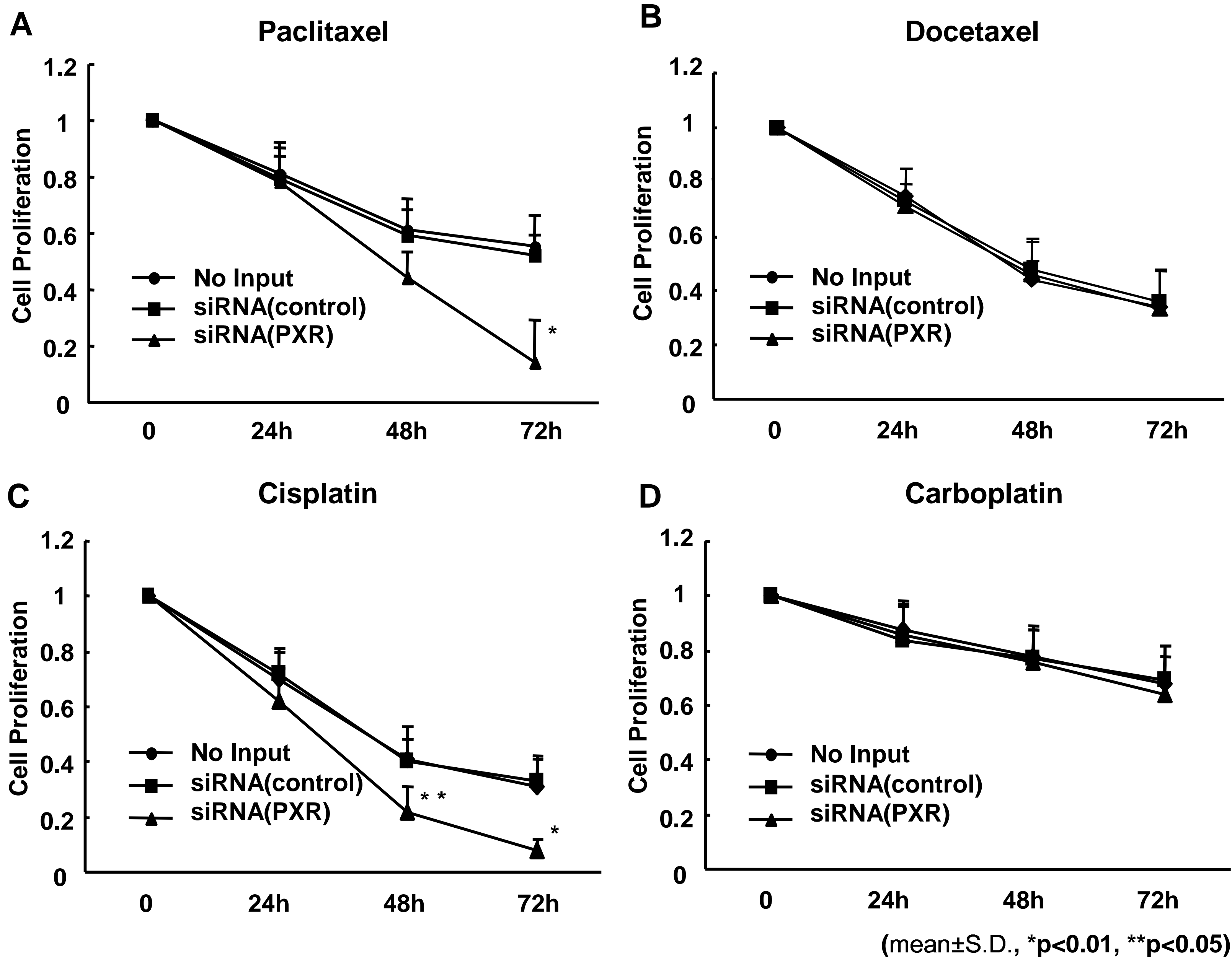
Figure 4



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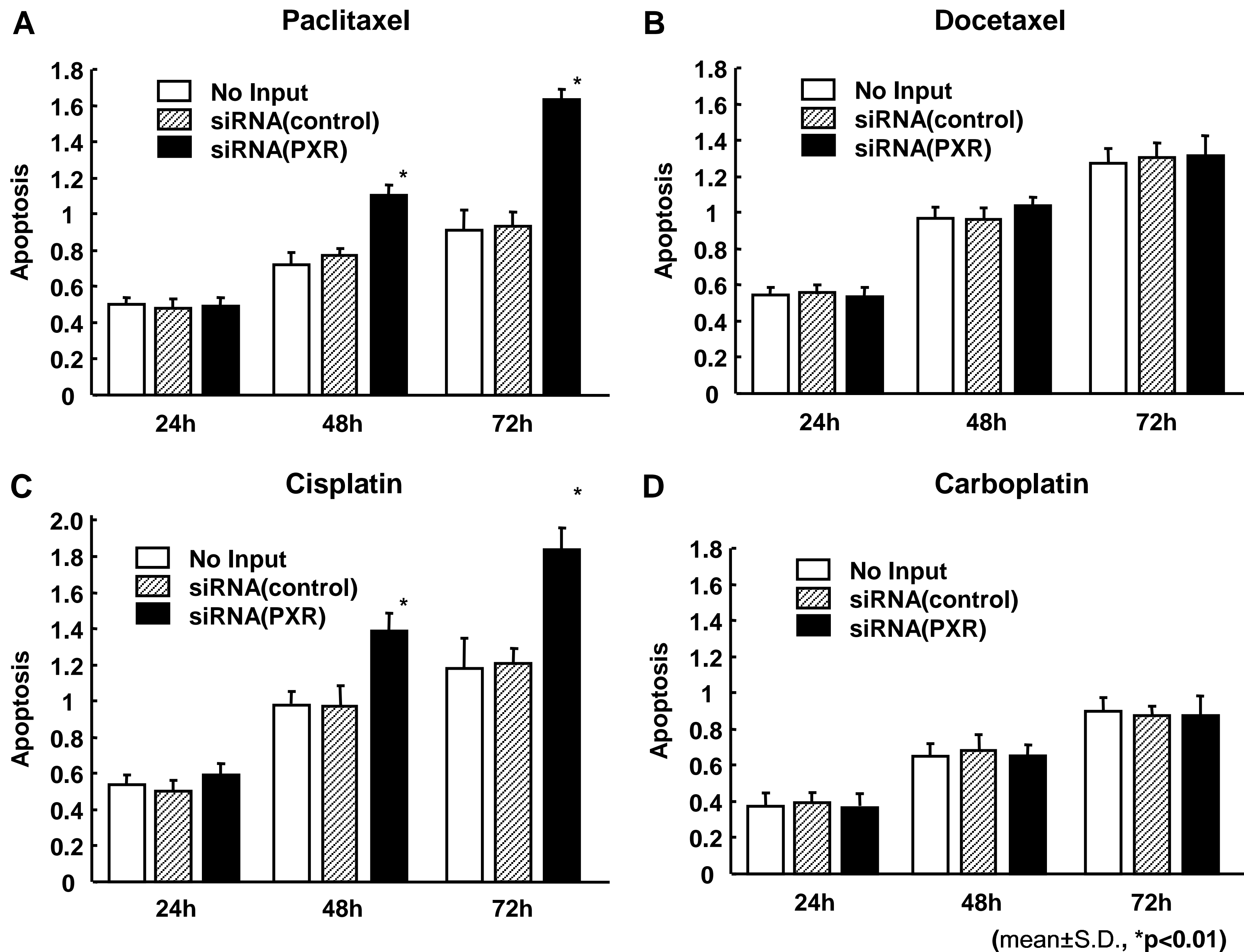

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Figure 6

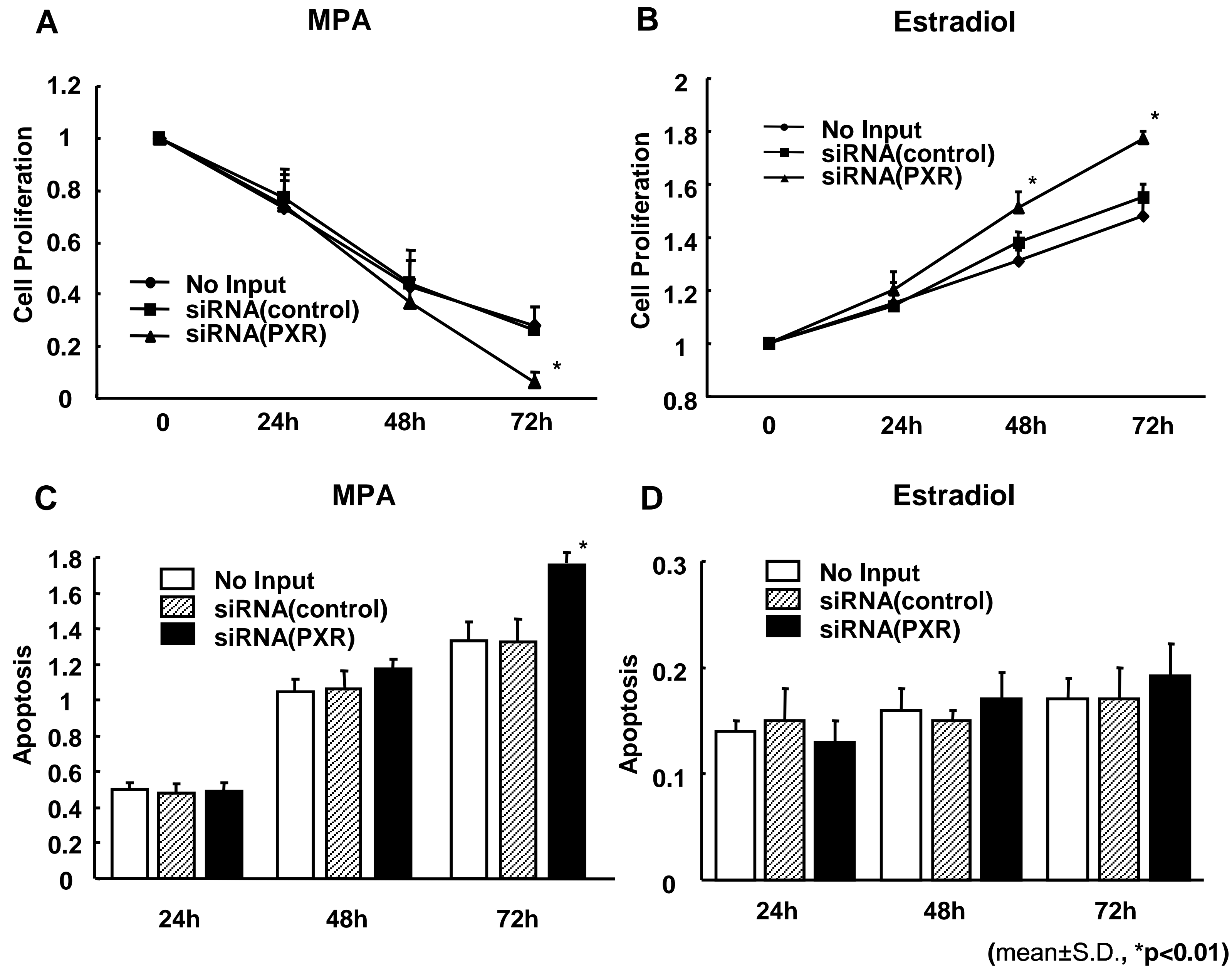

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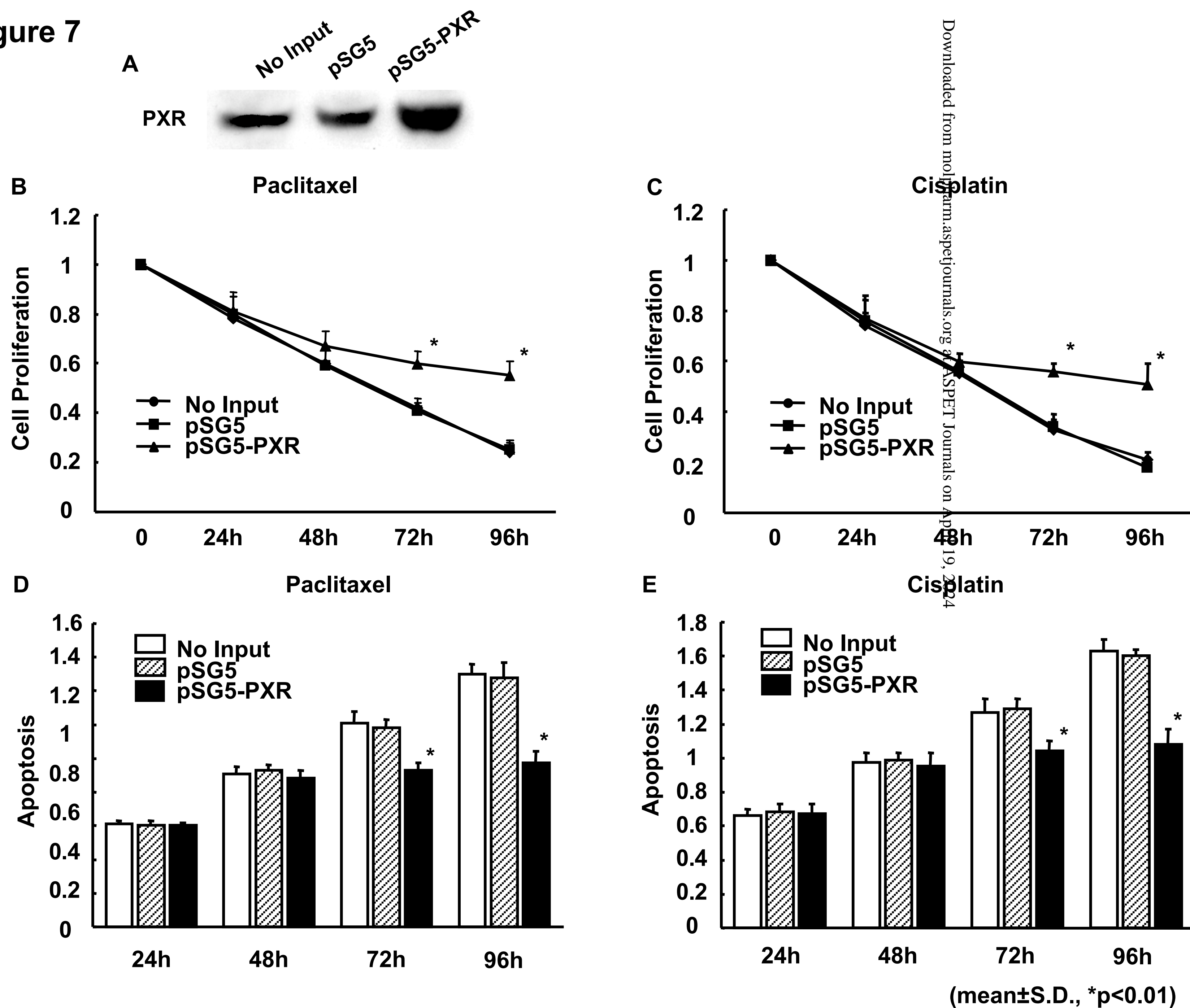
Figure 7



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