

# Proteomic approaches to study epigallocatechin gallate-provoked apoptosis of TSGH-8301 human urinary bladder carcinoma cells: Roles of AKT and heat shock protein 27-modulated intrinsic apoptotic pathways

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**Abstract.** Epigallocatechin-3-gallate (EGCG), a polyphenol constituent present in green tea, has been shown to inhibit the growth of cancer cells *in vitro* and *in vivo*. However, studies regarding human bladder carcinoma cells are limited and not well investigated. Hence, our study focused on the evaluation of EGCG-triggered apoptosis in TSGH-8301 human urinary bladder carcinoma cells *in vivo* and *in vitro* as well as its related molecular mechanisms. In an *in vivo* study, EGCG inhibited xenograft tumor size of TSGH-8301 cells in a nude mouse model. Based on an *in vitro* study, EGCG resulted in morphological changes and increased growth inhibition in a dose- and time-dependent manner in TSGH-8301 cells. Furthermore, sub-G1 populations were shown and caspase-9 and -3 activities were stimulated in EGCG-treated TSGH-8301 cells. Moreover, a caspase-9 inhibitor (Z-LEHD-FMK) and a caspase-3 inhibitor (Z-DEVD-FMK) were able to reduce EGCG-stimulated caspase-9 and -3 activities, respectively. Loss of mitochondrial membrane potential ( $\Delta\Psi_m$ ) resulted in an increase of protein levels of cytochrome c, Apaf-1, caspase-9 and -3 in TSGH-8301 cells following exposure to EGCG. Proteomic analysis revealed that EGCG affected the

expression levels of various proteins, including HSP27, porin, tropomyosin 3 isoform 2, prohibitin and keratin 5, 14, 17 in TSGH-8301 cells. EGCG also suppressed AKT kinase activity and protein levels and also altered the expression levels of Bcl-2 family-related proteins such as Bcl-2, Bax, BAD and p-BAD. Based on the above findings, this study suggests that EGCG-provoked apoptotic death in TSGH-8301 cells is mediated through targeting AKT and HSP27 and modulating p-BAD, leading to activation of the intrinsic apoptotic pathway.

## Introduction

Bladder cancer is one of the most common types of malignancies in human beings (1). Approximately 3.3 of 100 thousand people die from bladder cancer, and it is the 14th most common malignancy in Taiwan based on the report from the Department of Health, R.O.C. (Taiwan) in 2009 (2). In pathological analysis, >90% of bladder cancers are transitional cell carcinomas (TCC) (3). For the clinical therapy of bladder cancer patients, surgery, radiotherapy and chemotherapy may be used (4-6). However, these current therapies modalities are insufficient because the median survival time is about one year and it is unsatisfactory since distant metastasis may occur (7). Therefore, discovering a new more effective anti-bladder cancer agent is necessary.

Polyphenols are a group of chemical substances in human diets (8). The major sources of dietary polyphenol are fruits, vegetables and green tea (9,10). Many studies demonstrate that green tea can prevent chronic diseases and cancer in human bodies (11,12). The most important polyphenols in green tea include epicatechin (EC), epigallocatechin (EGC), epicatechin gallate (ECG), and epigallocatechin gallate (EGCG) (13-15). EGCG has been reported to have biological functions (16-19) including anti-cancer activity (20). *In vitro* and *in vivo* studies have indicated that EGCG has chemopreventive and chemotherapeutic potential for many types of cancer cell lines (21-25). EGCG is thought to repress the growth of cancer cells

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1 directly through cell-cycle arrest (26), induction of apoptosis  
2 (22,25), inhibition of metastasis (27), anti-angiogenesis (28)  
3 and activation of the immune function (29). These findings  
4 suggest that is EGCG is an attractive potential agent for  
5 chemotherapy.

6 Several studies have demonstrated that induction of  
7 apoptosis in cancer cells could be a potential target for cancer  
8 treatment (10,13). Apoptosis is a regulated mechanism leading  
9 cells to death through the extrinsic and the intrinsic pathways.  
10 The extrinsic pathway is triggered by Fas ligand (FasL),  
11 tumor necrosis factor (TNF) and tumor necrosis factor-related  
12 apoptosis-inducing ligand (TRAIL) binding to their respective  
13 receptors such as Fas, TNF receptor (TNFR), death receptor  
14 4 (DR4; TRAIL-R1) and DR5 (TRAIL-R2) (30). Interaction  
15 of specific ligands with their receptors leads to activation of  
16 Fas-associated death domain (FADD) and caspases-8 and  
17 -3 that is finally responsible for apoptosis (31). The intrinsic  
18 pathway is triggered by various stimuli such as DNA damage  
19 and chemotherapy agents. The intrinsic pathway involves  
20 disruption of the mitochondrial membrane environment  
21 and release of cytochrome c, Apaf-1, AIF, Endo G and pro-  
22 caspase-9 into the cytosol followed by activation of caspases-9  
23 and -3 (32). Accumulating evidence indicates that heat shock  
24 protein 27 (HSP27) can regulate apoptosis through regulation  
25 of caspase activation (33,34). HSP27 is induced by stress and  
26 its function includes protection from heat shock, hypertonic  
27 stress and oxidative stress (33). Recent studies have shown that  
28 HSP27 has been closely associated with AKT activity which  
29 contributes to inhibition of cell apoptosis (34).

30 A study of Rieger-Christ *et al* reported that EGCG exhib-  
31 ited growth inhibitory activity in human bladder carcinoma  
32 cell lines including the J82, UM-UC-3, EJ, KK47, T24 and  
33 TCCSUP cells (35). Also, Qin *et al* demonstrated that EGCG  
34 promoted apoptosis of T24 human bladder cancer cells  
35 through modulation of the PI3K/AKT pathway and Bcl-2  
36 family proteins (36). However, the mechanism by which  
37 EGCG affects human urinary bladder carcinoma cells specific  
38 for Taiwanese patients has not yet been clarified. In the present  
39 study, we focused on the anti-cancer effects and molecular  
40 mechanisms of EGCG in the human bladder cancer TSGH-  
41 8301 cells, a cell line derived from Taiwanese patients with  
42 urinary transitional cell carcinoma, *in vivo* and *in vitro*. We  
43 demonstrated that EGCG-induced apoptosis was carried out  
44 through AKT and the HSP27-modulated intrinsic apoptotic  
45 cascade pathways in TSGH-8301 cells.

## 46 **Materials and methods**

47 *Chemicals and reagents.* Epigallocatechin gallate (EGCG),  
48 dimethyl sulfoxide (DMSO), propidium iodide (PI), Triton X-100  
49 and Trypan blue were obtained from Sigma-Aldrich Corp.  
50 (St. Louis, MO). RPMI-1640 medium, L-glutamine, fetal bovine  
51 serum (FBS), penicillin-streptomycin and trypsin-EDTA  
52 were obtained from Invitrogen Life Technologies (Carlsbad,  
53 CA). Caspase-9 and -3 activity colorimetric assay kits, and a  
54 caspase-9 inhibitor (Z-LEHD-FMK) and a caspase-3 inhibitor  
55 (Z-DEVD-FMK) were obtained from R&D Systems Inc.  
56 (Minneapolis, MN). The following primary antibodies were  
57 obtained: anti-caspase-9 and -3 (Cell Signaling Technology,  
58 Beverly, MA); anti-HSP27, cytochrome c, Apaf-1, p-AKT, AKT,

Bcl-2, Bax, BAD, p-BAD, actin and horseradish peroxidase 61  
(HRP)-linked goat anti-mouse IgG and goat anti-rabbit IgG, 62  
(Santa Cruz Biotechnology, Santa Cruz, CA, USA). 63

64  
65 *Cell culture.* The human urinary bladder carcinoma cell line  
66 (TSGH-8301) specific for patients in Taiwan, was obtained  
67 from the Food Industry Research and Development Institute  
68 (Hsinchu, Taiwan). Cells were plated onto 75 cm<sup>2</sup> tissue culture  
69 flasks with RPMI-1640 medium with 2 mM L-glutamine  
70 containing 10% FBS, 100 U/ml penicillin and 100 µg/ml  
71 streptomycin and grown at 37°C under a humidified 5% CO<sub>2</sub>  
72 atmosphere (37). 73

74 *Mouse xenograft model in vivo.* The BALB/c nu/nu athymic  
75 mice (5-week-old) were purchased (National Laboratory  
76 Animal Center, Taipei, Taiwan) and randomly divided into 4  
77 groups of 10 mice each. At 6 weeks of age, mice were subcu-  
78 taneously injected with TSGH-8301 cells (1x10<sup>7</sup>) in Matrigel  
79 (BD Biosciences, San Jose, CA, USA) into the flanks of mice.  
80 After the tumor volume reached 200 mm<sup>3</sup>, mice were gavage  
81 fed with 100 µl PBS (control) or 12.5, 25 and 50 mg/kg/day  
82 EGCG in 100 µl PBS in each group. Tumor volume was moni-  
83 tored weekly based on the following formula: tumor volume  
84 (mm<sup>3</sup>) = LxW<sup>2</sup>/2 (L: length and W: width). At the end of 6 weeks  
85 of gavage treatment, mice were euthanized via CO<sub>2</sub> asphyxia-  
86 tion. Cancer tissues from each animal were removed, measured  
87 and weighed individually as previously described (38,39). All  
88 animal studies were conducted according to institutional guide-  
89 lines (Affidavit of Approval of Animal Use Protocol) approved  
90 by the Institutional Animal Care and Use Committee (IACUC)  
91 of China Medical University (Taichung, Taiwan). 92

93 *Cell morphology and viability determinations.* TSGH-8301  
94 cells (~2.5x10<sup>5</sup> cells/well) grown in 24-well plates were  
95 treated with EGCG at 0 and 75 µM and incubated at 37°C,  
96 5% CO<sub>2</sub> and 95% air for 72 h. Then cells were examined and  
97 photographed under a phase-contrast microscope as described  
98 previously (40,41). Cells (1x10<sup>4</sup> cells/well) seeded onto 96-well  
99 plates in 100 µl were exposed to 0, 25, 50, 75 and 100 µM  
100 of EGCG for 24, 48 and 72 h. After EGCG incubation, MTT  
101 (5 mg/ml, 10 µl) was added to each well and then cells were  
102 incubated at 37°C for 4 h. The medium was carefully moved  
103 before ~100 µl 0.04 N HCl/isopropanol were added and the  
104 absorbance at OD 570 nm was measured for each well. All  
105 results were performed from three independent experiments.  
106 The cell survival was shown as % of control (42,43). 107

108 *DNA content and analysis of the sub-G1 population by flow*  
109 *cytometry.* Approximately 2.5x10<sup>5</sup> cells per well were seeded  
110 in 24-well plates and exposed to 75 µM of EGCG for 24, 48 and  
111 72 h. Cells were washed with PBS and fixed with 70% ethanol  
112 at -20°C overnight. After being washed, cells were stained  
113 with 40 µg/ml PI, 0.1% Triton X-100 and 100 µg/ml RNase A  
114 in a PBS solution for 30 min. Each sample was analyzed and  
115 the fluorescence intensity of the DNA content was determined  
116 using a flow cytometer (FACSCalibur, Becton-Dickinson,  
117 Franklin Lakes, NJ, USA) as described elsewhere (38,44). 118

119 *Caspase-3/-9 activities and their specific inhibitors.* The  
120 activities of caspase-3 and -9 were measured by using caspase

1 colorimetric assay kits according to the manufacturer's protocol  
2 (R&D Systems Inc.). Briefly, cells ( $5 \times 10^6$  cells) were seeded in  
3 6-well plates and exposed to  $75 \mu\text{M}$  of EGCG for 0, 12, 24, 48  
4 and 72 h or control-treated before pretreatment without and with  
5 a caspase-9 inhibitor (Z-LEHD-FMK) or a caspase-3 inhibitor  
6 (Z-DEVD-FMK), respectively. Cells were harvested and lysed  
7 in 50 ml lysis buffer. The supernatant containing the protein  
8 was incubated with the caspase-3 substrate (Ac-DEVD-pNA),  
9 caspase-8 substrate (Ac-IETD-pNA) and caspase-9 substrate  
10 (Ac-LEHD-pNA), respectively in reaction buffer. All samples  
11 were incubated in 96-well flat-bottom plates at  $37^\circ\text{C}$  for 1 h.  
12 The amounts of released pNA were measured at a wavelength  
13 of 405 nm with ELISA reader (13,42).

14  
15 *Assay for mitochondrial membrane potential ( $\Delta\Psi\text{m}$ ).* Cells at  
16 a density of  $2.5 \times 10^5$  cells were plated onto 24-well plates and  
17 exposed to  $75 \mu\text{M}$  of EGCG for various periods of time (0, 6, 12  
18 and 24 h). Cells were then harvested, washed, and re-suspended  
19 in  $500 \mu\text{l}$  PBS with 50 nmole/l of 3,3'-dihexyloxocarbocyanine  
20 iodide (DiOC6, Invitrogen) at  $37^\circ\text{C}$  for 30 min to determine  
21 the level of  $\Delta\Psi\text{m}$ . Cells were immediately measured by flow  
22 cytometry as previously described (45).

23  
24 *Western blotting analysis.* TSGH-8301 cells ( $\sim 1 \times 10^7$ ) were  
25 treated with  $75 \mu\text{M}$  of EGCG for 0, 24 and 48 h as well as exposed  
26 to various concentrations of EGCG (0, 25, 50, 75 and  $100 \mu\text{M}$ )  
27 for 6 h of incubation. Cells were collected by centrifugation and  
28 the total proteins were collected by using the PRO-PREP<sup>TM</sup>  
29 protein extraction solution (iNtRON Biotechnology, Seongnam,  
30 Gyeonggi-Do, Korea). Equal amounts of protein lysate after  
31 determining the concentrations by the BCA assay (Pierce,  
32 Rockford, IL, USA) were run on a 10% SDS-PAGE gel and  
33 electrophoretically transferred to an Immobilon-P membrane  
34 (Millipore, Billerica, MA, USA) and probed with HSP27, cyto-  
35 chrome c, Apaf-1, caspase-9, caspase-3, p-AKT, AKT, Bcl-2,  
36 Bax, BAD, and p-BAD plus actin as an internal control. Bands  
37 were visualized via chemiluminescence (ECL detection kit,  
38 Millipore) using HRP-conjugated secondary antibodies. The  
39 image is the outcome of protein as described elsewhere (46-48).

40  
41 *AKT kinase assay.* Instructions in the non-radioactive AKT  
42 kinase assay kit (Cell Signaling Technology) were followed to  
43 determine the *in vitro* AKT kinase activity in EGCG-treated  
44 TSGH-8301 cells. Briefly, TSGH-8301 cells were grown up  
45 to 70% confluency in a 10-cm culture dish, and then treated  
46 for 6 h in the presence or absence of EGCG at 25, 50, 75 or  
47  $100 \mu\text{M}$ . Cells were harvested, washed with PBS and lysed in  
48 1X cell lysis buffer. Immobilized AKT primary antibody bead  
49 slurry ( $20 \mu\text{l}$ ) was added to  $200 \mu\text{l}$  of whole-cell extract ( $200 \mu\text{g}$   
50 of protein) overnight at  $4^\circ\text{C}$ . Immunoprecipitates were washed  
51 three times with lysis buffer and twice with AKT kinase buffer.  
52 Kinase assays were performed in immuno-complexes (pellets)  
53 for 30 min at  $30^\circ\text{C}$  under continuous agitation in kinase buffer  
54 containing  $200 \mu\text{M}$  ATP,  $1 \mu\text{g}$  of glycogen synthase kinase-3  
55 (GSK-3) of fusion protein. The kinase reaction was terminated  
56 by adding  $20 \mu\text{l}$  of 3X SDS sample buffer. The supernatant was  
57 saved for actin detection by immunoblotting to confirm that  
58 the same amount of whole cell extract was used and subjected  
59 to the monoclonal anti-AKT antibody. The protein level was  
60 quantified using the NIH ImageJ software and the activity was

61 expressed as % of control. Each experiment was performed in  
62 duplicate, and the assays were repeated three times.

63  
64 *Proteomic analysis.* At a density of  $1 \times 10^7$  TSGH-8301 cells  
65 in  $75 \text{ cm}^2$ -flask were incubated with or without  $75 \mu\text{M}$  of  
66 EGCG for 6 h and then harvested for preparation as previously  
67 described (49). In the first dimension, isoelectric focusing (IEF)  
68 was performed with commercially available preformed immo-  
69 bilized pH gradients (IPGs) (linear pH gradient 3-10, 13 cm) by  
70 using an IPGphor IEF System (GE Healthcare Life Sciences,  
71 Piscataway, NJ, USA) with a three-phase program as previously  
72 described (49). Before second dimensional electrophoresis, the  
73 IPG gel strips were incubated at room temperature for 15 min  
74 and the gels were then submitted to a second dimension run  
75 on a Hoefer SE 600 (GE Healthcare Life Sciences) on running  
76 12% SDS-PAGE gels ( $16 \times 15 \text{ cm}$ ), without stacking gels. The  
77 2-D polyacrylamide gels were stained with Coomassie Brilliant  
78 Blue (CBB) to assign the protein pI and MW, respectively. Data  
79 were considered significant when alterations were observed  
80 in at least two independent experiments (over five-fold up- or  
81 down-regulation) and the protein spots were consistently  
82 altered. Protein spots were quantified using the ImageMaster  
83 2D Elite software (GE Healthcare Biosciences) as previously  
84 described (49). The procedures were modified as described by  
85 Kaji *et al* (50). Protein spots excised from the CBB-stained gel  
86 were destained and dried completely. The dried gels were rehy-  
87 drated on ice for 45 min with a digestion buffer as previously  
88 described (49). Proteins were further digested at  $37^\circ\text{C}$  for 15  
89 h after removing excess solution. The resultant peptides were  
90 extracted, desalted and concentrated using in-tip reverse phase  
91 resin as previously described (49). Peptides were isolated from  
92 each gel slice after in-gel digestion, desalted, and concentrated  
93 and peptide mixtures were eluted, applied to the sample target  
94 and air dried as previously described (49) and then the sample  
95 was analyzed in a nano-LC-MS/MS system. This analysis was  
96 performed on an integrated nano-LC-MS/MS system comprised  
97 of an LC Packings NanoLC system with an autosampler, and  
98 a QSTAR XL Q-ToF mass spectrometer (Applied Biosystems)  
99 fitted with nano-LC sprayer. Samples were first trapped and  
100 desalted on a LC Packings PepMap C18  $\mu$ -Precolumn Cartidge  
101 after the peptides were eluted off from the precolumn and  
102 separated on an analytical LC Packings PepMap C18 column  
103 connected inline to the mass spectrometer as previously  
104 described (49,51). The MS data were searched against the world  
105 wide web (WWW) search programs MS-Fit provided by [http://](http://www.matrixscience.com/search_form_select.html)  
106 [www.matrixscience.com/search\\_form\\_select.html](http://www.matrixscience.com/search_form_select.html) with the  
107 NCBI database.

108  
109 *Statistical analysis.* Differences between untreated controls  
110 and treated-groups were calculated by one-way analysis of  
111 variance (ANOVA) followed by the Dunnett's test. Results are  
112 presented as mean  $\pm$  standard deviation (SD) and are represen-  
113 tative of three independent experiments. A p-value  $< 0.05$  was  
114 considered significant.

## 115 Results

116  
117  
118 *Anti-tumor activity in vivo.* We investigated the effects of  
119 EGCG on *in vivo* transplantation cancer growth for 42 days in  
120 a xenograft model. EGCG inhibited TSGH-8301 tumor growth

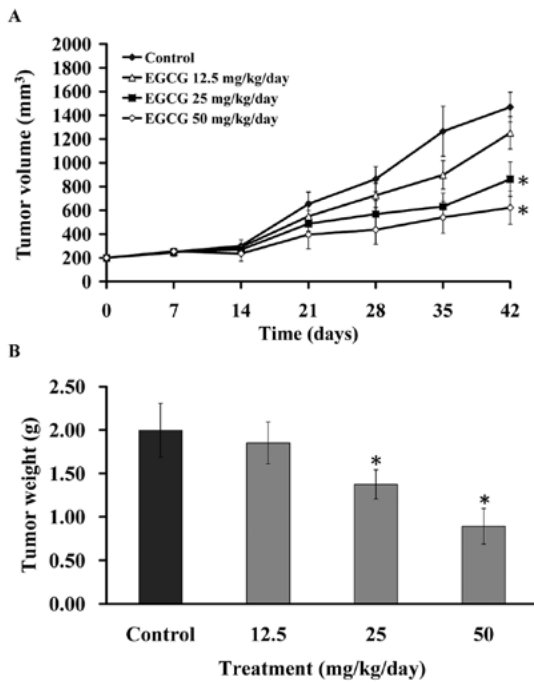


Figure 1. EGCG inhibits xenograft tumor growth in athymic mice. Human urinary bladder carcinoma TSGH-8301 cells ( $1 \times 10^7$ ) were injected subcutaneously into the flanks of male nude mice. Representative bearing xenograft solid tumor volume (A) and the effects of EGCG at 0, 12.5, 25 and 50 mg/kg/kg on tumor weight (B). Data are presented the mean  $\pm$  SD ( $n=10$ ) at 0-42 days post-cancer implantation and \* $p < 0.05$  was considered significant when compared with the control mice group.

in nude mice. EGCG was orally administered once every day at three different concentrations (12.5, 25 and 50 mg/kg). EGCG significantly reduced the tumor volume (Fig. 1A) and weight (Fig. 1B), respectively, in comparison of the control and EGCG-treated groups and these effects were dose-dependent responses.

**EGCG causes morphological changes and growth inhibition in TSGH-8301 cells.** The effects of treatment without and with EGCG on the morphological influences are shown in Fig. 2A. Our results indicate that TSGH-8301 cells exhibited clumping surface blebs and morphological shrinkage and rounding after exposure to  $75 \mu\text{M}$  for 72 h. We then determined the cell growth inhibition effects and cell viability of EGCG in TSGH-8301 cells after treatment with 0, 25, 50, 75 and  $100 \mu\text{M}$  for 24, 48, 72 h exposure by using the MTT assay. As can be seen in Fig. 2B, the cell viability was significant decreased in a dose- and time-dependent manner in EGCG-treated TSGH-8301 cells. The half maximal inhibitory concentration ( $\text{IC}_{50}$ ) in TSGH-8301 cells for 48 h exposure is close to  $75 \mu\text{M}$  which was used for further experiments and assays in this study.

**EGCG induces apoptosis in TSGH-8301 cells.** Cells were treated with  $75 \mu\text{M}$  of EGCG for 0, 24 and 72 h, and the DNA content for cell cycle distribution was analyzed by flow cytometry. EGCG-triggered cytotoxicity in TSGH-8301 cells may be mediated through induction of apoptosis and regulation of its signaling cascades. Flow cytometric profiles demonstrated that EGCG at  $75 \mu\text{M}$  is able to increase the sub-G1 group in treated TSGH-8301 cells after 48 and 72 h of treatment (Fig. 3A). In

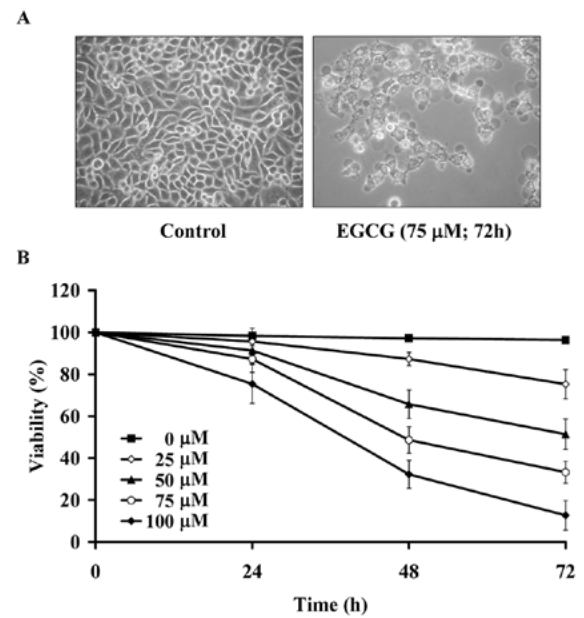


Figure 2. EGCG causes the morphological changes and inhibits cell viability in the human urinary bladder carcinoma TSGH-8301 cells. Cells after treatment with or without  $75 \mu\text{M}$  of EGCG for 72 h were examined and photographed by a phase-contrast microscope at a magnification of  $\times 200$  (A). Cells were exposed to 0, 25, 50, 75 and  $100 \mu\text{M}$  of EGCG for 24, 48, 72 h and then harvested for determination the percentage of viable cells using the MTT assay as described in Materials and methods.

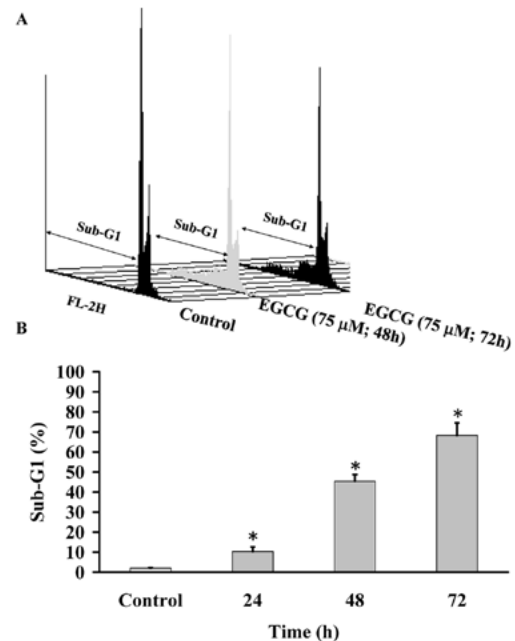


Figure 3. EGCG-induced apoptosis (sub-G1 population) examined by flow cytometry in TSGH-8301 cells. Cells exposed to  $75 \mu\text{M}$  of EGCG for 0, 24, 48 and 74 h were harvested for examining DNA content for cell cycle distribution by using a flow cytometer. Respective profile analyzed from BD CellQuest Pro software was indicated for determining sub-G1 groups (A), which is quantified and shown in panel (B) as described in Materials and methods. Each point is the mean  $\pm$  SD of three independent experiments. \* $p < 0.05$ , is significantly different compared with the untreated control.

addition, the sub-G1 populations showed significant increases in EGCG-treated TSGH-8301 cells after 24, 48 and 72 h of incubation and these effects were time-dependent (Fig. 3B).

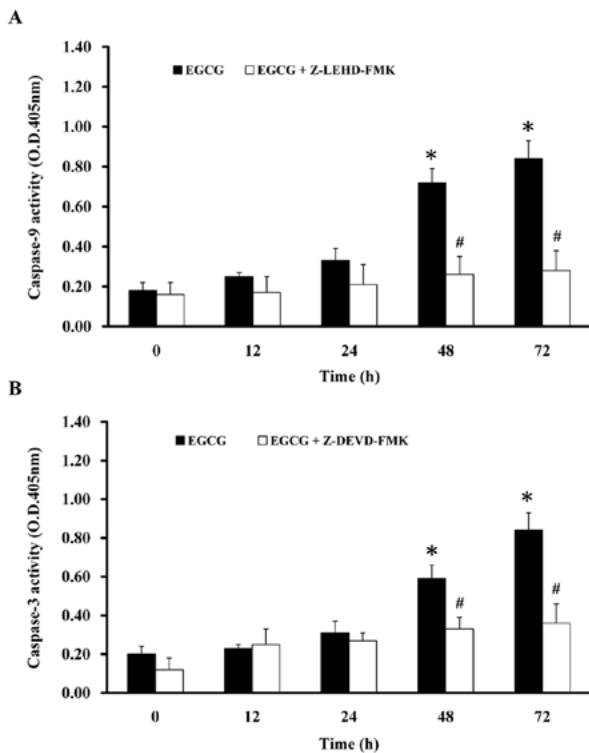


Figure 4. EGCG stimulation of the caspase-9 and -3 activities and effects of their specific inhibitors in TSGH-8301 cells. Cells were treated with 75  $\mu$ M of EGCG for 12, 24, 48 and 72 h and then the whole-cell lysate was subjected to caspase-9 (A) and -3 (B) activity assays, respectively. The caspase-9 inhibitor (Z-LEHD-FMK) and the caspase-3 inhibitor (Z-DEVD-FMK) were used to decrease the caspase activities. Data are expressed as the mean  $\pm$  SD of three independent experiments. \* $p$ <0.05, significantly different compared with the untreated group (0 h). # $p$ <0.05, significantly different compared to the EGCG 48 or 72 h treatment groups.

**EGCG stimulates caspase-9 and -3 activities in TSGH-8301 cells.** To investigate the EGCG-induced apoptotic effects in TSGH-8301 cells, cells were incubated with 75  $\mu$ M EGCG for 12, 24, 48 and 72 h and the activities of caspase-9 and -3 were determined by caspase-9 and -3 colorimetric assay kits, respectively. Treatment of TSGH-8301 cells with EGCG caused an increase of caspase-9 and -3 activities after 48 and 72 h of treatment (Fig. 4). To confirm the mechanisms of EGCG-induced apoptosis, cells were pretreated with a caspase-9 inhibitor (Z-LEHD-FMK) and a caspase-3 inhibitor (Z-DEVD-FMK) for 1 h and exposed to 75  $\mu$ M of EGCG for 12-72 h in TSGH-8301 cells. Results demonstrated that Z-LEHD-FMK and Z-DEVD-FMK are able to attenuate the EGCG-stimulated caspase-9 and -3 activities, respectively, in TSGH-8301 cells (Fig. 4). Therefore, our results suggest that caspase-9 and -3 activation-mediated mitochondrial dysfunctions may be involved in the EGCG-provoked apoptotic death in TSGH-8301 cells.

**EGCG increases the loss of  $\Delta\Psi_m$  and its associated protein levels.** We next investigated whether or not EGCG-induced apoptosis is based on the mitochondria-dependent intrinsic cascade pathway. Cells were harvested for examining the level of  $\Delta\Psi_m$  after exposure to EGCG for various intervals of time. EGCG increased the loss of  $\Delta\Psi_m$  in TSGH-8301 cells (Fig. 5A). Therefore, we further investigated whether EGCG

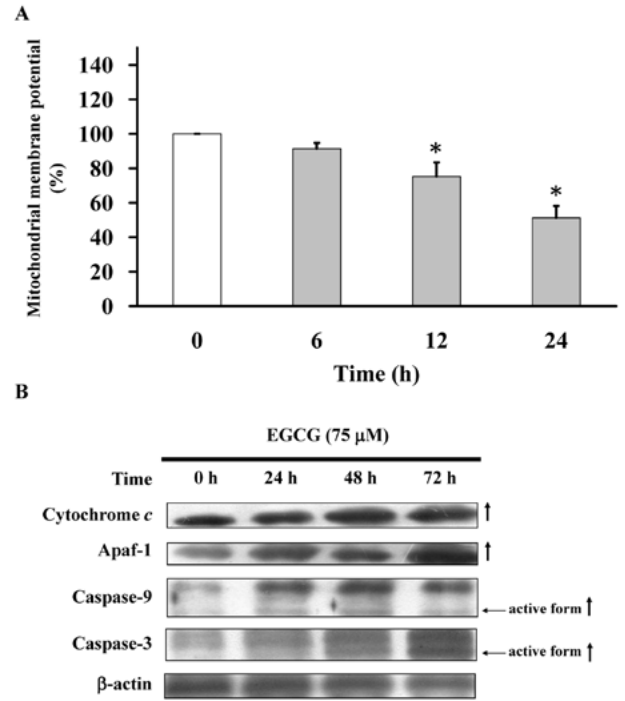


Figure 5. EGCG decreases the level of mitochondrial membrane potential ( $\Delta\Psi_m$ ) and alters apoptosis-associated protein levels in TSGH-8301 cells. Cells were incubated with 75  $\mu$ M of EGCG for 0, 6, 12 and 24 h and then stained with DiOC6 for measuring the level of  $\Delta\Psi_m$  by flow cytometry (A). EGCG affected mitochondria-dependent apoptotic relative protein levels in TSGH-8301 cells for 0, 24, 48 and 72-h exposures for determining cytochrome c, Apaf-1, caspase-9 and -3 by Western blotting (B) as described in Materials and methods.

induced apoptosis of TSGH-8301 cells through the mitochondrial and intrinsic signaling pathways. Cells were treated with 75  $\mu$ M of EGCG for 24, 48 and 72 h before analysis of protein levels by Western blotting. EGCG increased the protein levels of cytochrome c, Apaf-1, caspase-9 and -3 (Fig. 5B) in TSGH-8301 cells. Hence, this study suggests that EGCG-induced apoptotic death of TSGH-8301 cells is mediated through the mitochondrial and intrinsic cascade pathways.

**Proteomics analysis for EGCG-induced apoptosis in TSGH-8301 cells.** To explore the upstream molecular mechanisms of EGCG-induced apoptosis, the treatment condition with EGCG for 6 h was selected for the proteomic analysis. A pair of representative 2-D gel images for whole cell proteins extracted from TSGH-8301 cells with EGCG treatments for 6 h and control cells is shown in Fig. 6. Proteins were separated in the 2-D gels in the ranges of MW 14-100 kDa and pI 3-10. Image analysis revealed that a number of protein spots were significantly altered in terms of volume intensity. Highlighted in circles are the locations where protein alterations were detected. Table I lists the spot number, protein name, accession number, molecular weights, pIs, and sequence coverage from the programs MS-Fit. These altered proteins include the significant down-regulation of HSP27, porin (mitochondrial protein), tropomyosin 3 isoform 2, prohibitin (mitochondrial protein) and up-regulation of keratin 5, 14 and 17. Our data suggest that HSP27 and mitochondria may be involved in the major target of EGCG cytotoxicity in TSGH-8301 cells.

Table I. Summary of protein-database search results.

Sample no.	Protein name	Accession no.	pI	MW (Da)	Seq. coverage
1	Porin	gil190200	6.32	38069	28%
2	Tropomyosin 3 isoform 2	gil24119203	4.75	29015	32%
3	Prohibitin	gil4505773	5.57	29786	7%
4	Heat shock protein 27	gil662841	7.83	22313	41%
5	Keratin 5	gil18999435	7.59	62340	27%
6	Keratin 14	gil12803709	5.09	51619	44%
7	Keratin 17	gil4557701	4.97	48076	40%

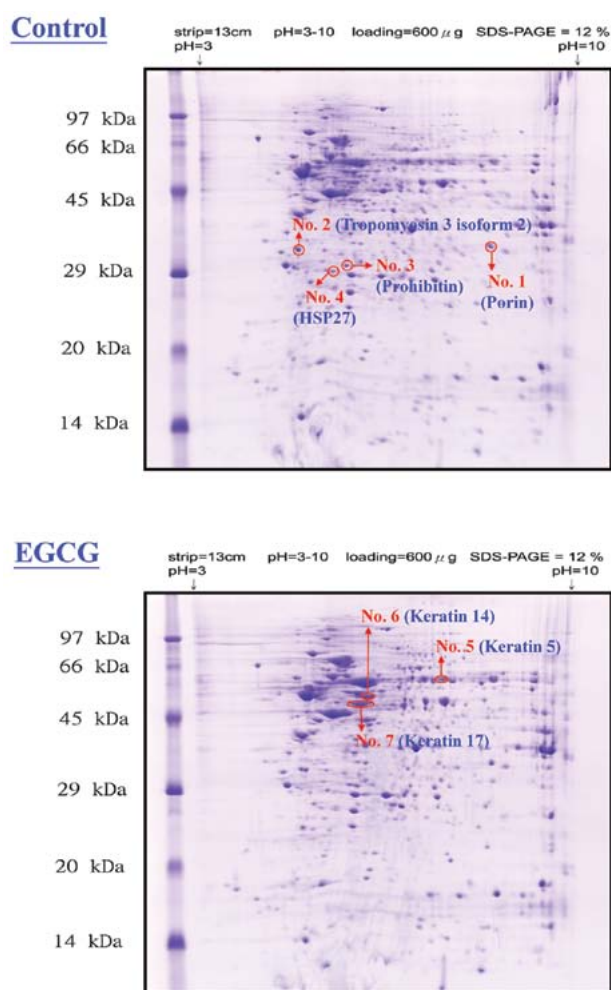


Figure 6. Overview of the 2-D gel images from extracts of TSGH-8301 cells. Spots highlighted in circles are the areas where significant and consistent differences were expressed in the protein expression levels in EGCG-untreated (Control, top) and treated (bottom) TSGH-8301 cells.

EGCG alters HSP27, p-AKT, Bcl-2, Bax, BAD and p-BAD protein levels as well as reduces AKT kinase activity in TSGH-8301 cells. To explore the upstream molecular mechanisms of EGCG-induced apoptosis, we evaluated the effect of EGCG on the HSP27, p-AKT, Bcl-2, Bax, BAD and p-BAD protein levels and AKT kinase activity in cell system. Western blot analysis identified reduction of HSP27 and phospho-AKT as molecular determinants of EGCG-induced apoptosis in TSGH-8301 cells

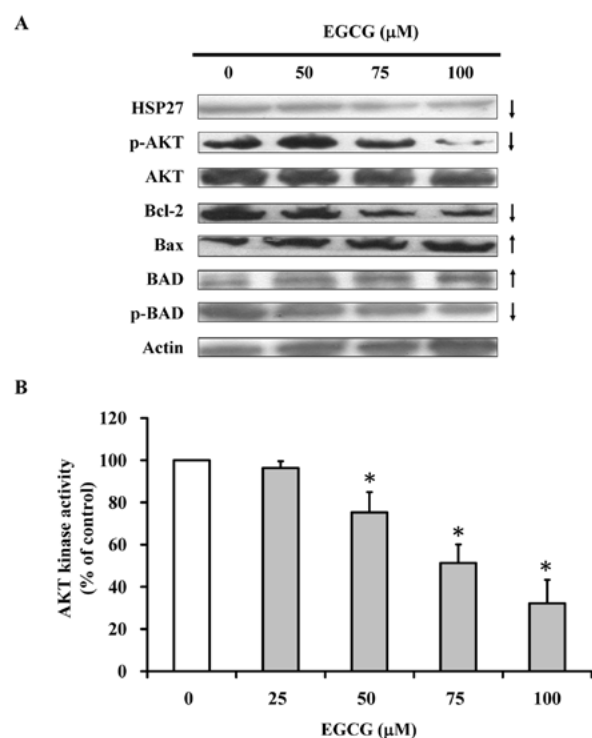


Figure 7. EGCG decreases AKT kinase activity and affects AKT and Bcl-2 family related protein levels in TSGH-8301 cells. Cells were treated with different concentrations of EGCG for 6 h and then harvested for examination of the AKT activity following the manufacturer's protocol. Results are shown as means  $\pm$  SD of three independent experiments. \* $p < 0.05$  indicates a significant difference when compared with the 0 h-treated group. Cells were exposed to 50, 75 and 100  $\mu$ M of EGCG for 6 h and then total protein lysates were used for the detections of HSP27, p-AKT, AKT, Bcl-2, Bax, BAD and p-BAD protein levels by Western blotting (B) as described in Materials and methods.

in a dose-dependent manner (Fig. 7A). Thus, these results suggest that EGCG-triggered apoptosis is involved in the decrease of the protein levels in HSP27 and p-AKT in TSGH-8301 cells. It has been reported that the pro-apoptotic protein BAD, a member of the Bcl-2 family, is rendered inactive when the phosphorylated serine/threonine protein kinase p-AKT converts p-BAD and BAD (52,53). To investigate the downstream effectors, we traced the phosphorylation status of BAD and also assessed the protein levels of Bcl-2 family, including Bcl-2, Bax and BAD in EGCG-treated TSGH-8301 cells with 0, 50, 75 and 100  $\mu$ M for 24-h exposure. Western blotting illustrated that EGCG decreased the levels of p-AKT, AKT, Bcl-2

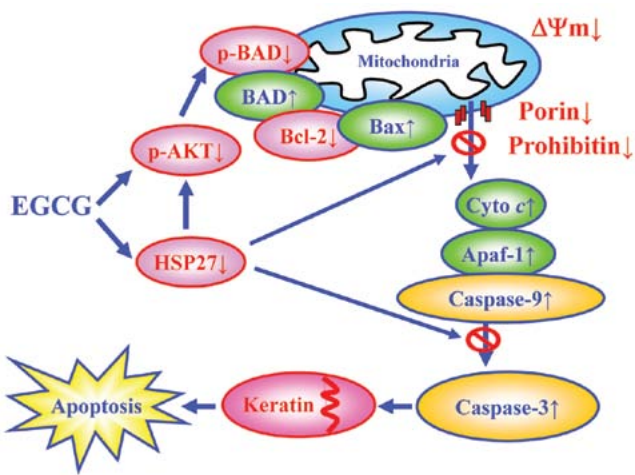


Figure 8. Illustration of the proposed signaling pathways of the EGCG-triggered apoptotic death and its modulated upstream HSP27/AKT signal in human urinary bladder carcinoma TSGH-8301 cells.

and p-BAD rather than increased the protein levels of Bax and BAD proteins in TSGH-8301 cells (Fig. 7A). Based on these results, apoptosis of TSGH-8301 cells appears to be mediated through increasing the ratio of Bax/BAD/Bcl-2 level after EGCG exposure. Moreover, TSGH-8301 cells were harvested after treatment with 0, 25, 50, 75 and 100  $\mu$ M of EGCG for 6 h to measure AKT activity. Our results reveal that EGCG down-regulated the AKT activity after 50-100  $\mu$ M EGCG for 6 h of treatment and this inhibition was time-dependent (Fig. 7B). We suggest that these responses are involved in the suppression of AKT activity, which may be regulated by p-BAD. These results signify the involvement of the HSP27/AKT/BAD survival pathway in the EGCG-induced apoptotic death of TSGH-8301 cells.

## Discussion

Many studies have reported that EGCG has growth inhibitory effects in human cancer cell lines (21-27,54,55), but few have addressed its inhibitory effects on Taiwan-specific human urinary bladder carcinoma cells. In this study, we examined the cytotoxicity of EGCG in TSGH-8301 cells *in vitro* and examined EGCG-affected TSGH-8301 cells *in vivo*. Our data indicate that EGCG inhibited xenograft tumor size of TSGH-8301 cells in a nude mouse model *in vivo* (Fig. 1). On the other hand, EGCG at 25-100  $\mu$ M could have significant cytotoxicity effects on TSGH-8301 cells *in vitro* (Fig. 2). Our previous study revealed that EGCG exerts low cytotoxicity on normal cells such as Detroit 551 normal human cell line (13). Our data suggest that EGCG represents a promising candidate as an anti-urinary bladder carcinoma agent with low toxicity to normal cells.

In this study, we have shown that EGCG triggered morphological changes (Fig. 2) and reduced the cell viability in TSGH-8301 cells in a dose- and time-dependent manner. EGCG induced accumulation of the sub-G1 population (apoptosis, Fig. 3). Moreover, our results demonstrate that EGCG significantly promoted activities of caspase-9 (Fig. 4A) and caspase-3 (Fig. 4B) after 24-72 h treatment, but there was

no significant effect in caspase-8 activity (data not shown). EGCG increased the protein levels of Bax and BAD, and inhibited the level of Bcl-2 (Fig. 7A) which led to the disruption of  $\Delta\Psi_m$  (Fig. 5A) and the release of cytochrome c, AIF and pro-caspase-9 (Fig. 5B). Furthermore, EGCG reduced the levels of porin (the voltage-dependent anion channel, regulating the mitochondrial response to certain cell death stimuli) and prohibitin (stabilization of mitochondrial function) by proteomic analysis (Fig. 6 and Table I). EGCG increased caspase-9 and -3 activities (Fig. 4), and pretreatment with caspase-9, -3 inhibitors led to decreased caspase-9 and -3 activities, resulting in keratin cleavage (Figs. 4 and 6). Qin *et al* demonstrated that EGCG promotes apoptosis in T24 human bladder cancer cells through modulation of the PI3K/AKT pathway and Bcl-2 family proteins (36). It has been reported that AKT is involved in the survival signaling pathway by phosphorylating BAD (56,57). In the present study, EGCG inhibited the activity of AKT in TSGH-8301 cells (Fig. 7B), leading to that BAD was dephosphorylated and then induced apoptosis in EGCG-treated TSGH-301 cells. Our results suggest that the intrinsic pathway is the major pathway of EGCG-induced apoptosis in TSGH-8301 cells. Several studies have reported that EGCG induces cell apoptosis through the extrinsic apoptotic pathway in HepG2 and U937 cells (58,59). In our previously studies, we also demonstrated that EGCG-induced apoptosis is mainly mediated by induction of the extrinsic and intrinsic pathways in human adrenal cancer NCI-H295 cells (13). Of note, EGCG-provoked cell death occurs through various apoptotic signaling pathways in different types of tumor cell lines *in vitro*.

EGCG could be developed as a new class of chemopreventive or chemotherapeutic agent for cancer because it targets multiple pathways and resulted in inhibition of cancer cell growth (13,58-60). Recent studies suggest that EGCG may affect many important signaling pathways, including epidermal growth factor receptor (EGFR), insulin-like growth factor receptor (IGFR), vascular endothelial growth factor receptor (VEGFR), mitogen-activated protein kinase (MAPK), nuclear factor- $\kappa$ B (NF- $\kappa$ B), phosphatidylinositol 3-kinase (PI3K)/AKT and heat shock protein 27 (33,34,61). In this study, we initially demonstrated that EGCG significantly suppressed HSP27 protein level in TSGH-8301 cells by Western blotting and proteomic analyses (Figs. 6 and 7). HSP27 (an actin-binding protein) is a stress-inducible protein that prevents apoptosis induced by anticancer agents (33,34). HSP27 is associated with the regulation of F-actin assembly and is a known regulator of AKT (33,34). Konishi *et al* have shown that in COS-7 cells treated with  $H_2O_2$ , AKT is activated and the association of HSP27 with AKT increases concurrently with the enhancement of AKT activity (62). Natsume *et al* have reported that EGCG induced suppression of the AKT cascade in osteoblasts contributes to the modulation of osteoblastic cell function toward bone formation via specifically down-regulating HSP27 induction (63). This evidence suggests that HSP27 could regulate AKT activity. However, another report has demonstrated that HSP27 directly inhibits caspase-9 and -3 activation and reduces apoptosome formation (64). Our results showed that when expressed to EGCG in TSGH-8301 cells, HSP27, markedly decreased protein levels (Fig. 7A), induced the leakage of cytochrome c, Apaf-1 and

1 pro-caspase-9 (Fig. 2A), exhibited caspase-9 and -3 activation  
 2 (Fig. 4), and significantly improved cell apoptosis (Figs. 2A  
 3 and 3). Our results suggest that HSP27 could either directly  
 4 or indirectly induce apoptosis in EGCG-treated TSGH-8301  
 5 cells. The direct effect is that HSP27 inhibits caspase-9 and  
 6 -3 activation and reduces apoptosome formation. The indi-  
 7 rect effect is that HSP27 regulates BAD phosphorylation by  
 8 altering the AKT kinases activity.

9 In conclusion, *in vivo* results indicate that the EGCG  
 10 effects in the TSGH-8301 xenograft tumor model of human  
 11 urinary bladder carcinoma was due to its anti-tumor activity.  
 12 The proposed model of EGCG mechanism of action for apop-  
 13 tosis in TSGH-8301 cells is shown in Fig. 8. EGCG induced  
 14 apoptosis in TSGH-8301 cells is mediated through the HSP27  
 15 and AKT pathways, which involve BAD phosphorylation and  
 16 activation of caspase-9 and -3. Proteomic results and mito-  
 17 chondrial functional studies confirm that the intrinsic pathway  
 18 is the major apoptotic pathway of EGCG in TSGH-8301 cells.  
 19 EGCG deserves further investigation in preclinical studies or  
 20 in a clinical trial as a potential anti-urinary bladder carcinoma  
 21 agent.

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