p73 participates in male germ cells apoptosis induced by etoposide

Verónica A. Codelia¹,², Matías Cisterna², Alejandra R. Alvarez², and Ricardo D. Moreno¹,*

¹Departamento de Ciencias Fisiológicas, Facultad de Ciencias Biológicas, Pontificia Universidad Católica de Chile, Alameda 340, Santiago, Chile ²Departamento de Biología Celular y Molecular, Facultad de Ciencias Biológicas, Pontificia Universidad Católica de Chile, Alameda 340, Santiago, Chile

*Correspondence address. Fax: +56-2-222-5515; E-mail: rmoreno@bio.puc.cl

Submitted on January 4, 2010; resubmitted on May 19, 2010; accepted on May 28, 2010

ABSTRACT: Etoposide is a commonly used drug in testicular cancer chemotherapy. However, the molecular pathways that activate germ cell apoptosis in response to etoposide are poorly understood. The aim of this study was to evaluate the participation of p73, a member of the p53 family, in apoptosis induced by etoposide in male germ cells. First, we used GC2-spc cells—a male germ cell model—to evaluate apoptotic signaling after treatment of etoposide. We found an important increase in p73 protein levels, along with the c-Abl kinase, its physiological activator, in response to etoposide. This increase was accompanied by a decrease in cell viability and activation of caspase-3. Pifithrin (PFT) treatment prevented p73 increase and apoptosis induced by etoposide. Also, the in vitro knockdown of p73 or p53 by shRNA, significantly prevented the decrease in cell viability after etoposide treatment. In an in vivo model—21-day-old rat testes—we observed an up-regulation of the protein levels of p73 and phosphorylated p73—at c-Abl site Tyr99—in response to the etoposide injection. STI571 (a pharmacological inhibitor of c-Abl) or PFT co-injection prevented etoposide-induced up-regulation of phospho-p73 and pro-apoptotic TAp73 isoform levels. Moreover, caspases-3, -8, -9 activation and germ cell death induced by etoposide were significantly decreased by these drugs. These results support the notion that the c-Abl/p73 pathway is activated in germ cells after etoposide treatment, triggering apoptosis, possibly assisting p53.

Key words: Spermatogenesis / p73 / apoptosis / germ cells / etoposide

Introduction

Testicular cancer is the most common type of cancer affecting men between 15- and 35-year-old (Bosl and Motzer, 1997). In 1975, the incidence in the USA was 3.5 cases per 100,000 (Flechon et al., 2008), although in 2004, it had increased to 5.8 cases per 100,000. Nevertheless, even in advanced stages of tumor progression, most cases of testicular cancer are curable. Treatments include surgery, radiation and chemotherapy or usually a combination of these methods. The most commonly used drugs for testicular cancer are Vepesid or VP-16 (Etoposide), Platinol (cisplatin) and Blenoxane (bleomycin sulfate). Etoposide is a podophyllotoxin semi-derivative agent that is used in a variety of chemotherapeutic treatments, including therapy for pediatric tumors. Previous reports have proposed that etoposide’s antimitotic activity is mediated by its interaction with topoisomerase II, an ATP-dependent nuclear enzyme that regulates DNA topology by transiently breaking and joining double-stranded DNA (Bromberg et al., 2003). It has been shown that etoposide induces apoptosis, dependent or independent on p53, in several cultured cancer cell lines and it is widely used in different protocols for testicular cancer (Sturgeon et al., 2008). Previous evidence has shown that spermatogonia and spermatocytes are the major cell types undergoing apoptosis induced by etoposide in both adult and pubertal rats (Sjoblom et al., 1998; Stumpp et al., 2004; Ortiz et al., 2009). The first widely used chemotherapy was a combination of cisplatin, vinblastin and bleomycin (PVB) (Einhorn and Donohue, 1977), but a later study by Lederman et al. showed the benefit of etoposide combined with cisplatin and bleomycin (BEP) with respect to treatment with PVB. This chemotherapy leads to a 95% regression in patients (Williams et al., 1987) and furthermore, BEP therapy was shown to be less toxic than PVB (Bosl and Motzer, 1997). Nowadays, etoposide is the first line drug used against testicular cancer. However, the molecular mechanisms by which etoposide induces germ cell apoptosis remain unknown.

p73 is a transcriptional factor, member of the p53 family and shares aminooacidic and structural similarity with p53, especially within its DNA binding domain (Levrero et al., 1999). In view of this, p73 can transactivate several target genes in common with p53, and induce apoptosis through Bax translocation and p53 up-regulated modulator...
of apoptosis (PUMA) activation (Melino et al., 2004; Ramadan et al., 2005; Soond et al., 2007; Ortiz et al., 2009). Nevertheless, it has been shown that p73 can also activate other genes and trigger apoptosis independently of the status of p53 (De Laurenzi et al., 2000; Schmelz et al., 2005). p73 is expressed in several isoforms by alternative use of its promoter, generating TAp73 isoforms that contain the transactivation domain, or ΔNp73 isoforms, lacking the transactivation domain. It has been shown that although the TAp73 isoforms induce apoptosis, ΔNp73 isoforms counteract this activity and function as pro-survival proteins (Belloni et al., 2006; Ramadan et al., 2005). c-Abl tyrosine kinase phosphorylates p73, thereby activating it, in response to several genotoxic stimuli such as oxidative damage or DNA breaks (Agami et al., 1999; Gong et al., 1999).

We have previously shown that etoposide induces apoptosis in meiotic spermatocytes in pubertal rat testes, accompanied by an increase of p53 protein levels, along with caspase-3,8 and -9 activation. In addition, p73 is also expressed in adult mammalian testes, where it appears to have a role in apoptosis caused by irradiation (Hamer et al., 2001), but its role in male germ apoptosis after genotoxic stimuli has never been addressed. In this context, pharmacological inhibition of c-Abl with the tyrosine kinase inhibitor STI571 (Gleevec, Imanitib) has been shown to be an excellent tool to study the role of p73 in vivo and in vitro conditions (Alvarez et al., 2008; Cancino et al., 2008). Thus, the goal of this study was to elucidate the role of p73 in apoptosis triggered by etoposide in rat germ cells, using an in vitro and in vivo model.

Materials and Methods

Cell culture and cell viability assays

GC2-spc cells were maintained in Dulbecco Modified Eagle Medium supplemented with 10% FBS plus 100 U/ml penicillin and 100 U/ml streptomycin in a humidified atmosphere containing 5% CO₂ at 37°C (Hofmann et al., 1994). To measure cell viability, GC2 cells were plated in 96-well plates at 10,000 cells/well and then assayed at different times. Cells were treated with 10–100 μM Etoposide, 100 μM Pifithrin (Sigma, St Louis, MO, USA) (PFT) or a combination of both drugs. After incubation at 37°C, MTS substrates (Cell TITER 96 Aqueous Assay, Promega, Madison, WI, USA) were added according to protocol, and absorbance at 490 nm was measured in an enzyme-linked immunosorbent assay (ELISA) reader (Boots CellTech Diagnostics Inc., Slough, UK).

Animals

Twenty-one-day-old male Sprague–Dawley rats were acquired from the Animal Facility of our Faculty. The rats were housed under a 12L:12D cycle, with water and food provided ad libitum. The rats were killed by cervical dislocation. Investigations were conducted in accordance with the rules laid down by the Consortium for Developing a Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching and by our National Research Council. All animal protocols were endorsed by the Chilean National Fund of Science and Technology (FONDECYT).

Intratesticular injections

Twenty-one-day-old male rats were anesthetized with xylazine/ketamine: (10 and 75 mg/kg) injected intracavitably into the abdomen. Both testes were exteriorized through a low midline incision and in each testis 10 μl of etoposide (Merck, Darmstadt, Germany), dissolved in PBS at a concentration of 100 μM, infused via a 30G needle, inserted through the tunica albuginea with the tip resting in the testicular interstitium. Following drug delivery, the testes were returned to the peritoneal cavity, and the incision was closed. Twenty-four hours later, both testes were removed (Ortiz et al., 2009). In each experiment one testicle was fixed for histology and the other used for protein extraction. As a control, PBS alone was injected into both testes. For c-Abl inhibition we used STI571 (Novartis Pharma, Basel, Switzerland) dissolved in NaCl 0.9% at a final concentration of 50 μg/ml. We also used PFT at a final concentration of 100 μM in PBS. Ten microliter of each drug was independently co-administered with 100 μM etoposide. After drug delivery, the testes were returned to the peritoneal cavity and the incision was closed. As a control, NaCl 0.9% or PBS alone was injected into the testes. Three different rats were used for all experiments and they were sacrificed 24 h after injection for the assessment of germ cell apoptosis.

Histology and apoptosis determination

Testes were fixed in Bouin’s solution and embedded in paraffin. Sections were counterstained with periodic acid-Schiff and hematoxylin for the assessment of germ cell apoptosis. We have previously showed that pycnotic germ cells express apoptotic markers such as active caspase-3 and stain positively for TUNEL (Moreno et al., 2006). The apoptotic index was calculated as the average number of apoptotic (pycnotic) germ cells per seminiferous tubule cross-section. Three testicular histological sections were taken per rat (three rats total) and a minimum of 100 randomly selected tubules were counted in each tissue section (a total of 900 tubules were recorded per treatment). The data represent the mean ± SE.

Immunofluorescence

GC-2 cells were plated on polylysine-coated coverslips at 30,000 cells/coverslip. After 1 day in DMEM medium, cells were treated with 100 μM Etoposide for 4 h. Cells were fixed in cold Methanol at −20°C and washed three times 10 min in PBS. Three percent BSA in PBS for 1 h was used to block. Primary antibody against active caspase-3 (Cell Signaling, Danvers, MA, USA) was applied at a concentration of 2 μg/ml and incubated overnight at 4°C in a humidified chamber. Then, slides were washed three times for 10 min in PBS containing 0.1% Tween-20. Secondary antibody anti-rabbit conjugated with Alexa Fluo-594 (1/500) (Molecular Probes, OR, USA) was applied for 2 h at room temperature. Samples were counterstained with 10 μg/ml 4′,6-diamidino-2-phenylindole (DAPI, Sigma) and washed three times for 10 min in PBS containing 0.1% Tween-20. Light and fluorescence images were captured under an Olympus BX51 microscope and analyzed with Adobe® Photoshop 7.0 (Adobe System Incorporated, USA).

Immunohistochemistry

p73 and c-Abl were localized in paraffin embedded cross-sections of rat testis fixed in 4% paraformaldehyde. The samples were treated with 3% H₂O₂ in PBS for 5 min and then blocked for 5 min with 4% BSA. Slides were washed twice for 5 min in a Tris–HCl buffer, pH 7.6 with 0.3 M NaCl and 0.1% Tween 20 and incubated overnight at 4°C in a humidified chamber with primary antibodies against p73 or c-Abl (2 μg/ml in 4% BSA–PBS. Biotinylated secondary antibody, streptavidin–biotinylated–peroxidase complex, amplification reagent (biotinyl tyramide) and peroxidase-conjugated streptavidin were applied step-by-step for 15 min each. Afterwards, incubation slides were washed twice in a buffer for 3 min each. Finally, a substrate-chromogen solution consisting of concentrated Tris–HCl and 0.8% H₂O₂ (substrate) and 3,3-diaminobenzidine tetrahydrocholoride solutions (chromogen) were applied for 5 min and washed in distilled water. Samples were observed under a phase contrast.
microscope (Optiphot-2, Nikon, Japan) and photographed with a digital camera (CoolPix 4500, Nikon, Japan).

Protein extraction and western blot assay

Seminiferous tubules were separated by continuous pipetting in 1.5 ml KHB (Krebs–Henseleit buffer plus 1% BSA) medium [2 g/l D-Glucose, 0.141 g/l Magnesium Sulfate (Anhydrous), 0.16 g/l NaH2PO4, 0.35 g/l KCl and 6.9 g/l NaCl] with 15 μl of a collagenase solution (0.5 mg/ml) added. Tubuli were decanted whereas maintaining Leydig and blood cells suspended in the medium, which was consequently discarded. Protein extraction was performed by homogenization of the isolated seminiferous tubuli obtained from 21-day-old rat testis or the GC2 cells harvested in a buffer containing 1 M NaCl, 1 mM EDTA, 10 mg/ml PMSF, 1% Triton X-100, 20 mM Tris–HCl pH 7.4 and centrifuged for 10 min at 1000 g. The samples were run on a 10% polyacrylamide gel (SDS–PAGE) under reducing and denaturing conditions, and transferred to a PDVF membrane at 400 mA for 2 h. PDVF membranes were blocked with 5% (w/v) non-fat milk, 0.1% Tween in PBS, pH 7.4 and then incubated overnight at 4°C with the following antibodies: rabbit polyclonal anti p73 (2 μg/ml, Santa Cruz Biotechnology, Santa Cruz, CA, USA), rabbit polyclonal anti p73 phosphorylated at Tyr99 (dilution 1/1000; Cell Signaling, Danvers, MA, USA), rabbit polyclonal anti c-Abl (2 μg/ml, Santa Cruz Biotechnology) or anti-β-actin (1 μg/ml; Sigma), as a loading control. Membranes were then incubated with a secondary antibody conjugated with horseradish peroxidase (KPL, Gaithersburg, MD, USA) diluted 1:3000 in blocking solution for 1 h at room temperature, and complexes were detected by ECL (Pierce Biotechnology, Rockford, IL, USA). Bands obtained were analyzed measuring the pixels with Adobe® Photoshop 7.0 (Adobe System Incorporated, USA) and normalized to β-actin. Each experiment was carried out in triplicate and performed at least three times.

Caspase activity measurements

Caspase activity assays were performed as previously described (Codelia et al., 2008). Briefly, seminiferous tubules were separated by continuous pipetting in 1.5 ml KHB (Krebs–Henseleit buffer plus 1% BSA) medium with 15 μl of a collagenase solution (0.5 mg/ml) added. Tubuli were decanted while maintaining Leydig and blood cells suspended in the medium, which was consequently discarded. Isolated seminiferous tubuli were homogenized in a buffer containing 1 M NaCl, 1 mM EDTA, 10 mg/ml PMSF, 1% Triton X-100, 20 mM Tris–HCl pH 7.4. The activity of each caspase was determined by using colorimetric substrates labeled with chromophore p-nitroaniline (pNA) for caspase-3 (Ac-DEVD-pNA), caspase-8 (AC-IETD-pNA) and caspase-9 (AC-LEHD-pNA), Calbiochem (Darmstadt, Germany). pNA is released upon caspase cleavage and produces a yellow color that was measured at 405 nm. Absorbance proportionally increases depending on the amount of caspase activity present in the sample. The amount of product generated was calculated by extrapolation of a standard curve of free pNA. One international unit (IU) was defined as the amount of caspase hydrolyzing 1 μmol of pNA/min at 25°C. Results of specific activity are expressed in units of enzyme per milligram of tissue (U/mg protein). The results are presented as the mean of three different rats. Protein concentration was measured by using the BCA method (Pierce, Rockord, IL, USA).

shRNAs and transfections

The shRNA-p53, shRNA-p73 and non-silencing control short hairpin mRNAs (shRNAs) vector were a kind gift from Dr Thorsten Stiewe (Philips-Universiteit Marburg, Marburg, Germany). The respective target sequences were as follows: shRNA-p53 GTCGTTATGTGCCGACGTAC, shRNA-p73 GGCAGAGTGTGGTTGTC GCC and TTCTCCGAACGTTCACGT for control shRNAs. Transient transfections of GC-2 were performed with LipofectAMINE 2000 reagent according to the manufacturer’s recommendations (Invitrogen, Carlsbad, CA, USA).
Statistical analysis

For mean comparisons, we used analysis of variance (ANOVA). When the ANOVA test showed statistical differences, the Tukey post hoc test was used to discriminate between groups. Statistical significance was considered as \( P < 0.05 \) (Sokal, 1995). Statistical analyses were performed using GraphPad Prism version 5.0 for Windows (GraphPad Software, San Diego, CA, USA, www.graphpad.com). Results are given as mean ± Standard Error (SE).

Results

Etoposide induces apoptosis and c-Abl/p73 activation in GC2 cells

To evaluate the effects of etoposide on the c-Abl/p73 signaling, we used—as an in vitro cell line model of germ cells—the GC-2 cell line. GC-2 cells are a good in vitro model of spermatocytes since they show meiosis markers at 37°C (Hofmann et al., 1994). First, we evaluated if etoposide-induced apoptosis in GC-2 cells. As expected, etoposide caused a significant decrease in cell viability in a concentration-dependent manner after 6 h of incubation with the drug, as evaluated by the MTS assay (Fig. 1A and B, \( *P < 0.05 \)). This drop in cell survival was accompanied by an increase in caspase-3 activation (Fig. 1C and D), suggesting GC2 cells died by apoptosis.

Then, we analyzed if there was a concomitant increase in p73 protein levels after etoposide treatment. Results showed that 100 \( \mu \)M etoposide treatment up-regulated p73 protein levels significantly after 30 min of incubation (Fig. 2A and B). Levels of the tyrosine kinase c-Abl, the physiological activator of p73, were also increased after etoposide treatment (Fig. 2A), suggesting the activation of the c-Abl/p73 module in response to etoposide. Next, we evaluated if the pharmacological inhibition of p73 could prevent etoposide-induced apoptosis in GC-2 cells. PFT is a classical pharmacological p53 inhibitor (Murphy et al., 2004), however, a recent report shows that PFT also causes a decrease in p73 levels (Davidson et al., 2008). We observed that PFT administered together with etoposide prevented up-regulation of p73 levels, as well as the decrease in cell viability induced by etoposide after six hours of treatment (Fig. 2C, D and E, \( ***P < 0.001 \)). PFT alone did not alter the levels of p73. In order to specifically reduce the levels of p73 or p53, we used shRNA. Results showed that even though shp73 treatment resulted in a modest reduction of protein levels (Fig. 3A), the cell viability of transfected cells treated with etoposide was significantly higher than those transfected with sh-ns (\( **P < 0.01 \)). shp53 treatment clearly reduced p53 protein levels, which was in accordance with an increase in cell viability after etoposide treatment, as compared with those cells transfected with a nonsense shRNA (Fig. 3A and B, \( **P < 0.01 \)). Thus, our results indicate that both p73 and p53 participate in etoposide-induced apoptosis in GC-2 cells.

Etoposide induces c-Abl/p73 in pubertal rat testis

In order to evaluate the participation of p73 in apoptosis induced by etoposide in vivo, we performed intratesticular injections of etoposide in 21-day-old rats. At this age, physiological apoptosis occurs at a low...
level, allowing for easy detection of any changes of these levels (Moreno et al., 2006; Lizama et al., 2009). Our previous studies showed that a single intratesticular injection of 10 μl of a solution containing 200 μM etoposide into 21-day-old rats, induced a significant increase in germ cell apoptosis 24 h after treatment (Ortiz et al., 2009), associated with an increase in p53 protein levels. Here, we observed that 100 μM etoposide significantly increased levels of total p73 as well as p73 phosphorylated at Tyr99—a c-Abl phosphorylation site—supporting the hypothesis of c-Abl/p73 signaling activation by drug treatment (Fig. 4A and B, *P < 0.05). In addition, STI571 prevented the increase of the phosphorylated form of p73, as well as the TAp73 and ΔNp73 isoforms induced after etoposide treatment. About 100 μM PFT prevented up-regulation of total p73 and phosphorylated p73 (Fig. 4A and B). Even more, PFT was also able to prevent the increase of TAp73 and the ΔNp73 isoform after etoposide treatment (Fig. 4 C and D). In order to define which cell type expresses p73 and c-Abl in 21-day-old rat testis, we performed immunohistochemistry. Results showed that p73 had a ubiquitous distribution, both cytoplasmic and nuclear, in vehicle-treated testes of 21-day-old rats (Fig. 5B). The immunoreaction against p73 increased after etoposide treatment in all cell types, including apoptotic (pycnotic) cells (Fig. 5A, arrow). On the contrary, c-Abl showed a cytoplasmic localization in both germ and Sertoli cells (Fig. 5C). After etoposide treatment, the c-Abl immunoreaction significantly increased in the cytoplasm of most testicular cells, but mainly in late pachytene spermatocytes (Fig. 5C, arrowhead) Controls without the primary antibody did not show any reaction (Fig. 5D, insert).

Finally, we evaluated the effects of STI and PFT treatment in etoposide-induced apoptosis in germ cells. As we have shown previously (Ortiz et al., 2009), etoposide induces a significant increase in the number of apoptotic germ cells 24 h after treatment, along with an increase in caspase-3, -8 and -9 activity, as compared with rats treated with vehicle only (Fig. 6A–C, *P < 0.05). The increase in caspase activity 24 h after etoposide treatment was prevented by co-injection with 50 μg/ml STI571 or 100 μM PFT (Fig. 6C). In addition, the presence of STI571 or PFT prevented the increase of germ cell apoptosis (apoptotic index) induced by etoposide treatment (Fig. 6A and B). STI or PFT alone did not show any effect on germ cell apoptosis (Fig. 6B). Thus, up-regulation of p73 is associated with apoptosis induction in male germ cells.

These results show the activation of p73 after etoposide treatment in vivo, and more specifically the activation of its pro-apoptotic isofrom TAp73, which can be modulated using the c-Abl inhibitor STI571 and PFT. This supports the participation of p73 in the apoptosis caused by etoposide in male germ cells.
Discussion

Etoposide (a pharmacological inhibitor of topoisomerase II), along with cisplatin and bleomycin, are the most common drugs utilized in testicular cancer chemotherapy (Flechon et al., 2008), but their effects on germ cell death are poorly understood. The data shown in the present work suggest that c-Abl and p73 play a role in etoposide-induced germ cell apoptosis, which can be counteracted by using STI571 (Imanitib, Gleevec) or PFT.

Recently, we showed that etoposide induces an increase in caspase activity, particularly caspase-9, in pubertal rat testis (Ortiz et al., 2009). In addition, spermatocyte apoptosis was accompanied by an increase in BAX and PUMA mRNA levels, along with the increase in p53 levels. In this work, we have extended our results and shown that p73, a member of the p53 family, could assist p53 in germ cell demise after etoposide treatment. It has been shown that p73 is involved in both developmental and apoptotic processes, and that it can act both dependently and independently of p53 (Melino et al., 2003; Billon et al., 2004; Ramadan et al., 2005). Hamer et al. (2001) showed the participation of the c-Abl/p73 pathway in radiation-induced apoptosis in germ cells, but no studies have been carried out for etoposide or other anti-cancer drugs in the testis. In the present work, we show that both in vivo and in vitro, etoposide induces an increase at the protein levels of p73 and c-Abl, suggesting a role for the signaling module in both systems. In vitro, by using shRNA, we showed that p73 and p53 are required for apoptosis induced by etoposide in GC-2 cells. Even though the reduction in protein levels of p73 was not as drastic as it was for p53, cell viability was significantly higher than cells transfected with the nonsense shRNA after etoposide treatment. Interestingly, viability in cells transfected with shp73 and shp53 was similar, despite the fact that the reduction of p53 protein was more dramatic than that observed for p73. The fact that we did not obtain viability levels similar to controls, may be due to inefficient transfection of these cells, meaning the amount of transfected cells is low in relation with the cells affected by etoposide, which results in a dilution of the cell survival effect.

STI571 specifically inhibits the c-Abl tyrosine kinase and Bcr-Abl tyrosine kinase, a constitutively expressed, abnormal tyrosine kinase resulting from the Philadelphia chromosome (Ph+), an abnormality associated with chronic myeloid leukemia (Druker, 2001). However,
the concentrations required for inhibition of the Bcr-Abl tyrosine kinase also inhibit the c-kit, platelet derived growth factor (PDGF) and ABL-related gene (ARG) receptors (Buchdunger et al., 2000). Previous works have shown that STI571 delayed the formation of the germ-line stem cell pool, reduced proliferation of type A spermatogonia and induced germ cell apoptosis when administered to 5–6-day-old male rats, suggesting that STI571 inhibits pro-survival signals (probably PDGF or c-kit) in germ cells (Nurmio et al., 2007, 2008). However, in the present work, we showed that STI571 has a pro-survival activity, probably by the inhibition of the apoptotic effect of c-Abl/p73. A reasonable explanation for this apparent contradiction is that STI171 has a differential effect, depending on the developmental age and cell type. It is possible that meiotic spermatocytes are not fully dependent on PDGF signaling in order to survive, as are mitotically dividing spermatogonia. In this context, it is feasible to hypothesize that whereas STI571 induces apoptosis in spermatogonia, it protects spermatocytes from apoptosis. Our in vivo results clearly show that STI571 protects germ cells from apoptosis induced by etoposide by preventing c-Abl/p73 pathway. Even more, we also show here that etoposide induces activation of c-Abl/p73 in GC-2 cells. However, STI571 itself induces an increase in apoptosis (data not shown), suggesting that this compound inhibits tyrosine kinase-dependent survival signals (probably PDGF or c-kit) in this cell line, similar to those observed in young rats (Nurmio et al., 2007, 2008).

Therefore, further studies are necessary in order to study this dual effect of STI571 on different cell types in pubertal and adult testes.

We show that p73 is involved in germ cell apoptosis, probably assisting p53 in response to DNA damage. Interestingly, we found that PFT, a classical p53 inhibitor, was capable of preventing the increase of p73 levels caused by etoposide. The molecular mechanism of action of PFT is not very clear, but it has been reported that PFT inhibits the action of p53 by blocking its nuclear transport (Komarova et al., 2003; Murphy et al., 2004). Other studies show that it can also inhibit p73 activity (Davidson et al., 2008) and apoptosis independently of p53 (Sohn et al., 2009). Further studies are needed to understand how PFT can apparently modulate p53 and p73 activities and apoptosis in germ cells. In spite of this, we were able to show a direct correlation between the drop in p73 levels, the decrease in caspase activation and the inhibition of germ cell apoptosis both in vivo and in vitro, supporting the participation of p73 in this process.

**Acknowledgements**

We thank Mr Raul Lagos for his help with the histological sections, Mr Jurriaan Brouwer-Visser for his excellent assistance in English grammar.
**Funding**

This work was partially financed by a grant from the Chilean Research Council (Fondecy 1070360 to R.D.M. and 1080221 to A.A.). V.A.C. is a PhD fellowship from Chilean Research Council (Conicyt).

**Authors’ roles**

V.A.C.: data collection and analysis; M.C.: data collection; A.R.A.: data analysis, financial support, writing and final approval of manuscript; R.D.M.: experimental design, data analysis, financial support, writing and final approval of manuscript.

**References**


