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Development and Validation of a Canine-Specific Profiling Array to Examine Expression of Pro-Apoptotic and Pro-Survival Genes in Retinal Degenerative Diseases


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Abstract

We developed an expression profiling array to examine pro-apoptotic and pro-survival genes in dog retinal degeneration models. Gene-specific canine TaqMan assays were developed and included in a custom real-time quantitative reverse transcription-PCR (qRT-PCR) array. Of the 96 selected genes, 93 belonged to known relevant pro-apoptotic and pro-survival pathways, and/or were positive controls expressed in retina, while three were housekeeping genes. Ingenuity Pathway Analysis (IPA) showed that the selected genes belonged to expected biological functions (cell death, cell-mediated immune response, cellular development, function, and maintenance) and pathways (death receptor signaling, apoptosis, TNFR1 signaling, and induction of apoptosis by HIV1). Validation of the profiling array was performed with RNA extracted from cultured MDCK cells in the presence or absence of treatment with 10 μ M staurosporin for 5 or 10 h. The vast majority of the genes showed positive amplifications, and a number of them also had fold change (FC) differences $> \pm 3$ between control and staurosporin-treated cells. To conclude, we established a profiling array that will be used to identify differentially expressed genes associated with photoreceptor death or survival in canine models of retinal degenerative diseases with mutations in genes that cause human inherited blindness with comparable phenotypes.

Keywords

dog model, retinal degenerative diseases, RVA expression profiling array, real-time quantitative reverse transcription-PCR, pro-apoptosis genes, pro-survival genes, cell death, cell survival, madin-darby canine kidney cells, staurosporin

Disciplines

Disease Modeling | Eye Diseases | Medical Cell Biology | Medical Genetics | Ophthalmology | Veterinary Medicine

Development and Validation of a Canine-Specific Profiling Array to Examine Expression of Pro-Apoptotic and Pro-Survival Genes in Retinal Degenerative Diseases

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Abstract

We developed an expression profiling array to examine pro-apoptotic and pro-survival genes in dog retinal degeneration models. Gene specific canine TaqMan assays were developed and included in a custom real-time quantitative reverse transcription-PCR (qRT-PCR) array. Of the 96 selected genes, 93 belonged to known relevant pro-apoptotic and pro-survival pathways, and/or were positive controls expressed in retina, while 3 were housekeeping genes. Ingenuity Pathway Analysis (IPA) showed that the selected genes belonged to expected biological functions (cell death, cell-mediated immune response, cellular development, function, and maintenance) and pathways (death receptor signaling, apoptosis, TNFR1 signaling, and induction of apoptosis by HIV1). Validation of the profiling array was performed with RNA extracted from cultured MDCK cells in the presence or absence of treatment with 10 μ M staurosporin for 5 or 10 hrs. The vast majority of the genes showed positive amplifications, and a number of them also had fold change (FC) differences $> +/−3$ between control and staurosporin-treated cells. To conclude, we established a profiling array that will be used to identify differentially expressed genes associated with photoreceptor death or survival in canine models of retinal degenerative diseases with mutations in genes that cause human inherited blindness with comparable phenotypes.

46.1 Introduction

Photoreceptors, like other specialized cells, have the innate ability to die through varied molecular mechanisms, and in response to multiple insults, whether genetic or acquired (Melino et al. 2005). Since the description of apoptosis as one of the final pathways in photoreceptor cell death (Chang et al. 1993; Portera-Cailliau et al. 1994), many studies have examined different molecules and mechanisms involved in the process.

Multiple pathways have been reported to be relevant for both retinal cell death (Cottet and Schorderet 2009; Doonan et al. 2005; Kunchithapautham and Rohrer 2007; Lohr et al. 2006; Rohrer et al. 2004; Sancho-Pelluz et al. 2008; Werdehausen et al. 2007) and survival (Barnstable and Tombran-Tink 2006; Bazan 2006; Jomary et al. 2006; Ueki et al. 2009; Wenzel et al. 2005). These are dependent on the underlying mutation, the model, whether naturally occurring or induced, the speed of the degenerative process, the cell class involved, and other factors. Despite the abundance of such studies, the signaling pathways and molecular mechanisms that link the mutations to the observed phenotypes are still unknown for many of the photoreceptor degenerative diseases. One of these diseases is canine X-

linked progressive retinal atrophy 2 (XLPRA2), caused by a 2-bp deletion in exon ORF15 of the *RPGR* gene (Zhang et al. 2002). In two recent studies from our group, we characterized by TUNEL labeling the time course of cell death in affected dogs (Beltran et al. 2006), and identified by microarray analysis a number of non-classical apoptosis and mitochondria-related genes that seemed to be involved in the degenerative process (Genini et al. 2010). However, limitations of the latter study included the use of a custom canine cDNA array with a limited number of genes, and without relevant pro- and anti-apoptotic genes. Although for humans and rodent models a comprehensive suite of commercially-available products can be used to analyze RNA and protein expressions of a large panel of genes associated with biological pathways or specific disease states, these tools do not work or are currently not available for the dog.

The aim of this study was to fill this gap by developing and validating a canine specific real-time quantitative reverse transcription-PCR (qRT-PCR) profiling array containing key genes that are directly or indirectly involved in pro-apoptotic and pro-survival processes, autophagy, and/or are related to microglia/macrophages, cells that have been recently associated with retinal disease processes (Langmann 2007; Sasahara et al. 2008).

46.2 Materials and Methods

46.2.1 Development of the Canine-Specific qRT-PCR Array

The canine-specific custom-designed qRT-PCR profiling array (Table 46.1) was developed in conjunction with Applied Biosystems (ABI, Foster City, CA). Canine specific sequences of selected genes, identified from studies in other species, were submitted to ABI to develop gene specific TaqMan assays (http://www3.appliedbiosystems.com/AB_Home/index.htm). These contained unlabeled forward and reverse primers and FAM dye labeled TaqMan MGB probes. The Ingenuity Pathway Analysis (IPA, Ingenuity System Inc., Redwood City, CA) database was interrogated with the 96 genes on the array to better characterize biological functions and pathways involved.

46.2.2 Validation of the qRT-PCR Array Using Madin-Darby Canine Kidney (MDCK) Cells

46.2.2.1 Cell Culture—MDCK cells were grown to 80% confluency in 60-mm Petri dishes in Dulbecco's modified Eagle's medium (DMEM, with low glucose and L-glutamine, without sodium bicarbonate) supplemented with 10% fetal bovine serum (FBS), 1% penicillin and streptomycin, 1% sodium pyruvate, and 1% MEM non-essential amino acids (Sigma-Aldrich, St. Louis, MO). At 5 and 10 hrs prior cell collection, control cells received fresh supplemented DMEM medium, while treated cells received fresh supplemented DMEM medium containing 10 μ M staurosporin (Sigma-Aldrich). For each time point (5 or 10 hrs) and cell type (control or staurosporin-treated), the experiment was done in duplicate, one Petri dish was used to assess cellular viability and the other for qRT-PCR analysis.

46.2.2.2 Assessment of Cellular Viability—Cellular viability of the cultured control and staurosporin-treated MDCK cells was assessed with a LIVE/DEAD® Viability/Cytotoxicity Assay Kit (Invitrogen-Life Technologies, Carlsbad, CA) following the manufacturer's recommendation. Petri dishes containing the cells were examined by epifluorescence microscopy (Axioplan, Carl Zeiss Meditech, Oberkochen, Germany). Images were digitally captured (Spot 4.0 camera), and displayed with a graphics program (Photoshop, Adobe, Mountain View, CA).

46.2.2.3 qRT-PCR Analysis—MDCK cells used for qRT-PCR analysis were harvested by adding PBS and removing the cells from the Petri dishes with a plastic 16-cm cell scraper. Total RNA from cell pellets was extracted, DNase treated, and reverse-transcribed

as previously described (Genini et al. 2010). qRT-PCR reactions containing 30 ng of mixed cDNA at a ratio of 2:1 (5 hrs:10 hrs) also were performed as recently described (Genini et al. 2010).

46.3 Results

We developed a profiling array containing 96 canine specific TaqMan probes to test the expression of genes related to pro-apoptotic and anti-apoptotic processes. The selected genes belong to 7 main categories that inform on signaling pathways and disease mechanisms, e.g. 1) pro-death, mitochondria-dependent; 2) pro-death, mitochondria-independent; 3) autophagy; 4) pro-survival; 5) microglia/macrophage related; 6) expressed in retina [rods or cones (*ARR3*, *OPN1SW*, *OPN1MW*, and *RHO*), Müller cells and astrocytes (*GFAP* and *VIM*), bipolar cells (*PKCA*), and in the retinal pigment epithelium (*BEST1*)]; 7) housekeeping genes (*18S*, *ACTB*, and *GAPDH*). Table 46.1 provides a summary of the 96 genes included in the array with their symbols, descriptions, categories, TaqMan assay numbers (ABI), and location on the array.

To evaluate in detail and to confirm the nature of the 96 selected genes, we analyzed them with the IPA program. As expected, the five most relevant IPA molecular and cellular functions identified were cell death, cell-mediated immune response, cellular development, function, and maintenance, as well as DNA replication, recombination, and repair (Table 46.2). Inflammatory disease, immunological disease, neurological disease, cancer, and skeletal and muscular disorders were the five IPA biological functions related to “diseases and disorders” with the highest number of genes (Table 46.2). Furthermore, relevant IPA pathways included death receptor signaling, apoptosis signaling, TNFR1 signaling, induction of apoptosis by HIV1, and tumoricidal function of hepatic natural killer cells (Table 46.2).

The profiling array was validated, and the functionality of the TaqMan assays was tested, with RNA extracted from control and staurosporin-treated MDCK cells. To examine the highest number of genes possible, we mixed with a ratio of 2:1 the cDNAs of the staurosporin-treated cells at 5 hrs (to detect early apoptotic genes) and 10 hrs (to detect late apoptotic genes). The cDNAs from age-matched untreated cells at 5 and 10 hrs post addition of fresh DMEM medium were processed similarly. While the untreated cells were mostly all alive at 5 hrs (Fig. 46.1A) and 10 hrs (Fig. 46.1C), several staurosporin-treated cells were dead at 5 hrs (Fig. 46.1B) and almost all at 10 hrs (Fig. 46.1D) of treatment.

The qRT-PCR results showed that retina-specific control genes did not amplify (*BEST1*, *OPN1LW*, and *OPN1SW*), or had very high CT values between 35 and 38 (*ARR3*, *GFAP*, and *RHO*) in both untreated and treated cells. Furthermore, the additional genes *BNIP3L*, *BID*, *CASP14*, *CD40*, *CD40LG*, *FADD*, *IL10*, *TNFA*, *TNFRSF9*, *TNFSF8*, *TNFRSF21*, and *TYROBP* did not amplify in MDCK cells. For the remaining genes, CT values ranged from 10 (*18S*) to 34 (*FASLG*, *NTF3*, *NTF4*, *PRDX3*, *PTPRC*, and *TP73*). The calculated mean CT values of *GAPDH* and *ACTB* were used for normalization because they did not change between treated and control samples, while *18S* was excluded as it was unstable and highly variable.

A total of 8 genes (*BCL2L1*, *BCL2L11*, *CASP10*, *CCL2*, *DDIT3*, *HSP70*, *NGF*, and *TRAF2*) showed FC differences >3 in control vs. staurosporin-treated cells, while 4 (the retinal genes *ARR3*, *GFAP*, and *RHO*, as well as *IL6*) showed opposite regulation. The expressions of *BNIP3*, *TNFA*, and *GFAP* were also assessed with single assays done separately. The same experimental conditions used for qRT-PCR on the profiling array were applied, with the exception that the quantity of cDNA was augmented to 100 ng per gene and that other

primers for *BNIP3* (Genini et al. 2010) were used. The results demonstrated no changes in expression of *BNIP3*, up-regulation of *GFAP* (raw CT values of 34 and 36, respectively) and *TNFA* (raw CT values of 35 and 37, respectively) in staurosporin-treated vs. control cells.

46.4 Discussion and Conclusions

In the present study, we developed a qRT-PCR profiling array containing key genes that are directly or indirectly involved in pro-apoptotic and pro-survival processes, autophagy, and/or are related to microglia/macrophages. For all the selected genes, canine-specific TaqMan assays are now inventoried and available for the research community. The array was validated in canine origin MDCK cell cultures treated with staurosporin, and we identified a number of genes that are important in pro-apoptotic and pro-survival processes, defined as part of signaling pathways that activate apoptosis, attempt to block apoptosis, or attempt to down or up-regulate protective cell functions. A precise and final classification of one gene to one category was a very complex task, because several genes fit into different categories depending on several factors (e.g. cell type, disease, age, interacting molecules) and because this classification is a dynamic process that alters as more information becomes available.

Specific characterization of the selected genes with IPA confirmed their expected biological functions and pathways, including cell death and cell mediated immune response, and provided additional information to better evaluate and dissect the general pattern of the genes on the profiling array.

A few genes, in particular those that are retinal-specific, could not be successfully amplified in MDCK cells with 30 ng of cDNA. This might be due to absence or very low levels of gene expression in MDCK cells, as shown with the single assay for *TNFA* that worked when we used 100 ng of cDNA. Alternatively, this may have been caused by primers not annealing to the sequence of interest. MDCK cells were used for this initial validation step in order to save precious and limited canine retina samples; however additional validation with RNA from retina will clarify the reasons for the failed amplification of certain genes.

This profiling array will be useful in future studies to identify genes, molecular mechanisms, and signaling pathways associated with photoreceptor degeneration in *XLPR2* and also additional canine models, e.g. *rcd1*, *rcd2*, *XLPR1*, that carry mutations in other genes known to cause retinal degeneration in humans. Inclusion of 3 housekeeping genes used for normalization in the profiling array represents an advantage as it will enable selection of the optimal combination for each different experiment that will be performed.

It is expected that such quantitative analyses of gene expression will be valuable in identifying common, as well as disease-specific pro-death/pro-survival pathways that may represent future novel therapeutic targets.

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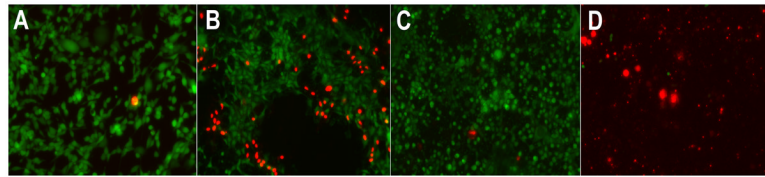


Fig. 46.1. LIVE/DEAD Viability/Cytotoxicity assay showing live (green) or dead (red) cells in control (A, 5 hrs; C, 10 hrs) or staurosporin-treated (B, 5 hrs; D, 10 hrs) MDCK cultures. Note the marked reduction in number of live cells after 10 hrs exposure to staurosporin.

Table 46.1

List of the 96 genes included in the profiling array. Genes are reported with their symbols (in parenthesis the alternative symbols), descriptions, categories, TaqMan assay numbers (ABI), and location on the array. Main categories were: 1) pro-death, mitochondria-dependent; 2) pro-death, mitochondria-independent; 3) autophagy; 4) pro-survival; 5) microglia/macrophage related; 6) positive control expressed in retina; 7) housekeeping.

| Gene symbol (alternative symbol) | Gene description | Gene category | TaqMan® assay | Location on array |
|----------------------------------|--|---------------|---------------|-------------------|
| <i>18S</i> | eukaryotic 18S rRNA | 7 | Hs99999901_s1 | A1 |
| <i>AIFM1 (AIF)</i> | apoptosis-inducing factor, mitochondrion-associated 1 | 1 | Cf02636601_m1 | A2 |
| <i>SLC25A4 (ANT-1)</i> | solute carrier family 25, member 4 | 1 | Cf02730291_g1 | A3 |
| <i>APAF1</i> | apoptotic peptidase activating factor 1 | 1 | Cf02695305_m1 | A4 |
| <i>ATG3</i> | autophagy related 3 homolog | 3 | Cf00684119_m1 | A5 |
| <i>ATG5</i> | autophagy related 5 homolog | 3 | Cf02637561_m1 | A6 |
| <i>ATG7</i> | autophagy related 7 homolog | 3 | Cf02656560_m1 | A7 |
| <i>ATG12</i> | autophagy related 12 homolog | 3 | Cf02641158_m1 | A8 |
| <i>BAD (BBC2/BCL2L8)</i> | BCL2-antagonist of cell death | 1 | Cf02627333_m1 | A9 |
| <i>BAK1</i> | BCL2-antagonist/killer 1 | 1 | Cf02627218_m1 | A10 |
| <i>BAX</i> | BCL2-associated X protein | 1 | Cf02622186_g1 | A11 |
| <i>BBC3 (PUMA)</i> | BCL2 binding component 3 | 1 | Cf02708330_m1 | A12 |
| <i>BCL2</i> | B-cell CLL/lymphoma 2 | 4 | Cf02622425_m1 | B1 |
| <i>BCL2L11 (BAM/BIM)</i> | BCL2-like 11 | 1 | Cf00708025_s1 | B2 |
| <i>PABPN1 (BCL2L2)</i> | poly(A) binding protein, nuclear 1 | 4 | Cf02664611_m1 | B3 |
| <i>BCL2L1 (BCL-XL)</i> | BCL2-like 1 | 4 | Cf02622161_m1 | B4 |
| <i>BDNF</i> | brain-derived neurotrophic factor | 4, 5 | Cf02622349_g1 | B5 |
| <i>BECN1 (ATG6)</i> | beclin 1 | 3 | Cf02643377_m1 | B6 |
| <i>BID</i> | BH3 interacting domain death agonist | 1 | Cf03460096_m1 | B7 |
| <i>GRP78 (BIP)</i> | 78 kDa glucose-regulated protein | 4 | Cf02631877_m1 | B8 |
| <i>BNIP3 (NIP3)</i> | BCL2/adenovirus E1B 19kDa interacting protein 3 | 1 | Cf02654885_m1 | B9 |
| <i>BNIP3L (NIX)</i> | BCL2/adenovirus E1B 19kDa-interacting protein 3-like | 1 | Cf03460134_m1 | B10 |
| <i>CASP10</i> | caspase 10 | 1 | Cf03460108_m1 | B11 |
| <i>CASP14</i> | caspase 14 | 2 | Cf03460139_m1 | B12 |
| <i>CASP2</i> | caspase 2 | 1 | Cf02624522_m1 | C1 |
| <i>CASP3</i> | caspase 3 | 1 | Cf02622232_m1 | C2 |
| <i>CASP4</i> | caspase 4 | 1 | Cf02623472_m1 | C3 |
| <i>CASP6</i> | caspase 6 | 1 | Cf02652513_m1 | C4 |
| <i>CASP7</i> | caspase 7 | 1 | Cf03460102_m1 | C5 |
| <i>CASP8</i> | caspase 8 | 1 | Cf02627553_m1 | C6 |
| <i>CASP9 (APAF3)</i> | caspase 9 | 1 | Cf02627331_m1 | C7 |
| <i>SFRS2IP (CASP11)</i> | splicing factor, arginine/serine-rich 2, interacting protein | 2 | Cf02703447_m1 | C8 |
| <i>CAPN1</i> | calpain 1, (mu/I) large subunit | 1 | Cf02704115_m1 | C9 |

| Gene symbol (alternative symbol) | Gene description | Gene category | TaqMan® assay | Location on array |
|-----------------------------------|--|---------------|---------------|-------------------|
| <i>CAPN2</i> | calpain 2, (mu/II) large subunit | 1 | Cf02645870_m1 | C10 |
| <i>CAST</i> | calpastatin | 2 | Cf02664849_m1 | C11 |
| <i>CTSD</i> | cathepsin D | 3 | Cf02625552_m1 | C12 |
| <i>CTSS</i> | cathepsin S | 3 | Cf02625930_m1 | D1 |
| <i>CCL2</i> | chemokine (C-C motif) ligand 2 | 4, 5 | Cf02671955_g1 | D2 |
| <i>CD40 (TNFRSF5)</i> | TNF receptor superfamily member 5 | 2, 4, 5 | Cf02626290_m1 | D3 |
| <i>CD40LG (CD154/TNFSF5)</i> | CD40 ligand | 2, 4, 5 | Cf02623314_m1 | D4 |
| <i>PTPRC (CD45)</i> | protein tyrosine phosphatase, receptor type C | 1, 5 | Cf02653185_m1 | D5 |
| <i>CNTF</i> | ciliary neurotrophic factor | 4, 5 | Cf03460095_sH | D6 |
| <i>CREB1</i> | cAMP responsive element binding protein 1 | 4 | Cf02667607_m1 | D7 |
| <i>CYCS</i> | cytochrome c, somatic | 1 | Cf02640410_g1 | D8 |
| <i>TYROBP (DAP12/KARAP)</i> | TYRO protein tyrosine kinase binding protein | 5 | Cf02642009_m1 | D9 |
| <i>DIABLO (SMAC/SMAC3)</i> | diablo homolog | 1 | Cf02665346_m1 | D10 |
| <i>ENDOG</i> | endonuclease G | 1 | Cf02703061_u1 | D11 |
| <i>FADD (GIG3/MORT1)</i> | FAS-associating death domain-containing protein | 1 | Cf03460155_m1 | D12 |
| <i>FAS (TNFRSF6/APO-1/CD95)</i> | TNF receptor superfamily, member 6 | 1 | Cf02651136_m1 | E1 |
| <i>FASLG (TNFSF6/CD95L/CD178)</i> | FAS ligand | 1 | Cf02625215_s1 | E2 |
| <i>BFGF (FGF2)</i> | basic fibroblast growth factor | 4, 5 | Cf03460065_g1 | E3 |
| <i>DDIT3 (GADD153/CHOP10)</i> | DNA-damage-inducible transcript 3 | 2 | Cf02654858_m1 | E4 |
| <i>GAPDH</i> | glyceraldehyde-3-phosphate dehydrogenase | 7 | Hs02786624_g1 | E5 |
| <i>GDNF</i> | glial cell derived neurotrophic factor | 4, 5 | Cf02691052_s1 | E6 |
| <i>HIF1A</i> | hypoxia-inducible factor 1, alpha subunit | 4 | Cf02741632_m1 | E7 |
| <i>HRK (DP5/HARAKIRI)</i> | BCL2 interacting protein | 1 | Cf02702255_g1 | E8 |
| <i>HSPB1 (HSP27)</i> | heat shock 27kDa protein 1 | 4 | Cf02628297_m1 | E9 |
| <i>HSPD1 (HSP60)</i> | heat shock 60kDa protein 1 (chaperonin) | 1, 4 | Cf02668830_gH | E10 |
| <i>HSP70 (HSPA1)</i> | heat shock protein 70 | 4 | Cf02622418_g1 | E11 |
| <i>HSP86 (HSP90AA1)</i> | heat shock protein HSP90-alpha | 4 | Cf03460183_s1 | E12 |
| <i>IGF1R (CD221)</i> | insulin-like growth factor 1 receptor | 4 | Cf02625178_m1 | F1 |
| <i>IL6 (IFNB2)</i> | interleukin 6 | 2, 5 | Cf02624282_m1 | F2 |
| <i>IL10</i> | interleukin 10 | 4, 5 | Cf02624265_m1 | F3 |
| <i>MAP1LC3A (LC3)</i> | microtubule-associated protein 1 light chain 3 alpha | 3 | Cf02630406_m1 | F4 |
| <i>LYZ</i> | lysozyme | 3 | Cf02642933_m1 | F5 |
| <i>PRKCZ (PKC2)</i> | protein kinase C, zeta | 4 | Cf02674616_m1 | F6 |
| <i>PRDX3</i> | peroxiredoxin 3 | 4 | Cf03460191_sH | F7 |
| <i>NGF</i> | nerve growth factor | 4, 5 | Cf02625041_s1 | F8 |
| <i>NTF3</i> | neurotrophin 3 | 4, 5 | Cf02700489_s1 | F9 |
| <i>NTF4</i> | neurotrophin 4 | 4 | Cf02705704_s1 | F10 |
| <i>SOD1</i> | superoxide dismutase 1, soluble | 1, 4 | Cf02624276_m1 | F11 |
| <i>STAT1</i> | signal transducer and activator of transcription 1 | 1 | Cf02662970_m1 | F12 |

| Gene symbol (alternative symbol) | Gene description | Gene category | TaqMan® assay | Location on array |
|----------------------------------|---|---------------|---------------|-------------------|
| <i>STAT3</i> | signal transducer and activator of transcription 3 | 4, 5 | Cf02666647_m1 | G1 |
| <i>BIRC5 (IAP4)</i> | baculoviral IAP repeat-containing 5 (survivin) | 4 | Cf02628995_m1 | G2 |
| <i>TNFA</i> | tumor necrosis factor alpha | 1, 2, 5 | Cf02628236_m1 | G3 |
| <i>TNFRSF1A</i> | tumor necrosis factor receptor superfamily, member 1A | 1, 2 | Cf02622751_m1 | G4 |
| <i>TNFRSF21 (DR6)</i> | tumor necrosis factor receptor superfamily, member 21 | 2 | Cf03460083_s1 | G5 |
| <i>TNFRSF25 (APO-3/DDR3)</i> | tumor necrosis factor receptor superfamily, member 25 | 1, 2 | Cf02653814_g1 | G6 |
| <i>TNFSF10 (APO-2L/TRAIL)</i> | tumor necrosis factor (ligand) superfamily, member 10 | 1, 2 | Cf03460069_m1 | G7 |
| <i>TNFRSF9 (4-1BB/CD137)</i> | tumor necrosis factor receptor superfamily, member 9 | 2 | Cf03460132_m1 | G8 |
| <i>TNFSF8 (CD153/CD30L)</i> | tumor necrosis factor (ligand) superfamily, member 8 | 2 | Cf03460158_m1 | G9 |
| <i>TP53</i> | tumor protein p53 | 1 | Cf02623148_m1 | G10 |
| <i>TP73</i> | tumor protein p73 | 1, 4 | Cf02680478_mH | G11 |
| <i>TRADD</i> | TNFRSF1A-associated via death domain | 1, 2 | Cf02661903_m1 | G12 |
| <i>TRAF2 (TRAP)</i> | TNF receptor-associated factor 2 | 2 | Cf02662893_m1 | H1 |
| <i>TRAF3</i> | TNF receptor-associated factor 3 | 2 | Cf02659700_m1 | H2 |
| <i>XIAP (API3/BIRC4)</i> | X-linked inhibitor of apoptosis | 4 | Cf02625207_m1 | H3 |
| <i>ACTB</i> | actin, beta | 7 | Hs03023880_g1 | H4 |
| <i>RHO</i> | rhodopsin | 6 | Cf02625669_m1 | H5 |
| <i>OPN1SW</i> | opsin 1 (cone pigments), short-wave-sensitive, blue opsin | 6 | Cf03460200_m1 | H6 |
| <i>OPN1LW</i> | opsin 1 (cone pigments), long-wave-sensitive, red/green opsin | 6 | Cf02622926_m1 | H7 |
| <i>ARR3 (CAR/ARRX)</i> | retinal cone arrestin 3 | 6 | Cf03460116_m1 | H8 |
| <i>VIM</i> | vimentin | 6 | Cf02668853_g1 | H9 |
| <i>GFAP</i> | glial fibrillary acidic protein | 6 | Cf02655695_m1 | H10 |
| <i>PKCA (PRKCA)</i> | protein kinase C, alpha | 6 | Cf02655322_m1 | H11 |
| <i>BEST1 (VMD2)</i> | bestrophin 1 | 6 | Cf02697409_gH | H12 |

Table 46.2

Five most significant IPA biological functions (“molecular and cellular functions” or “disease and disorders”) and canonical pathways identified with the 96 genes included in the profiling array.

IPA biological functions*Molecular and cellular functions*

- Cell death
- Cell-mediated immune response
- Cellular development
- Cellular function and maintenance
- DNA replication, recombination, and repair

Diseases and disorders

- Inflammatory disease
- Immunological disease
- Cancer
- Neurological disease
- Skeletal and muscular disorders

IPA canonical pathways

- Death receptor signaling
 - Apoptosis signaling
 - Induction of apoptosis by HIV1
 - TNFR1 signaling
 - Tumoricidal function of hepatic natural killer cells
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