Identifying new human oocyte marker genes: a microarray approach

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Running Title: Profiling COC’s markers

Key words: cumulus-oocyte complex, microarray, cell cycle, marker genes.

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Abstract

Efficiency in classical IVF (cIVF) techniques is still impaired by poor implantation and pregnancy rates after embryo transfer. This is mostly due to a lack of reliable criteria for the selection of embryos with sufficient development potential. Several studies have provided evidence that some genes’ expression levels could be used as objective markers of oocytes and embryos competence and of their capacity to sustain a successful pregnancy. These analyses usually used reverse transcription-polymerase chain reaction to look at small sets of pre-selected genes. However, microarray approaches permit to identify a wider range of cellular marker genes. Thus they allow the identification of additional and perhaps more suited genes that could serve as embryo selection markers. Microarray screenings of circa 30 000 genes on U133P Affymetrix™ gene chips made it possible to establish the expression profile of these genes as well as other related genes in human oocytes and cumulus cells. In this study, we identified new potential regulators and marker genes such as BARD1, RBL2, RBBP7, BUB3 or BUB1B, which are involved in oocyte maturation.
Introduction

The quality of oocytes obtained under ovarian stimulation for classical IVF (cIVF) varies considerably. Whilst most oocytes are capable of being fertilized, only half of those fertilized complete preimplantation development and fewer still implant.

After oocyte retrieval several layers of cumulus oophorus cells still surround mature oocytes (metaphase II, MII) and immature oocytes (germinal vesicle (GV) and MI). Granulosa cell derived cumulus cells surround the oocyte in the antral follicle and play an important role in regulating oocyte maturation (Dekel et al., 1980; Larsen et al., 1986). Ebner et al. (Ebner et al., 2006) demonstrated that, in vitro, the culture of human oocytes with attached cumulus cells may improve preimplantation embryo development.

Gene expression alterations in oocytes and their supporting cells can be correlated with defects or variations in the ovulation or maturation processes. Gene expression in granulosa cells is altered in patients with empty follicle syndrome (Inan et al., 2006). A number of studies suggest that changes in gene expression, such as GDF9 or Bone Morphogenic Protein-15 (BMP15) in oocytes, or Pentraxin 3 (PTX3) in cumulus cells, can be monitored for selecting oocytes for fertilization and embryos for implantation (Elvin et al., 1999; Yan et al., 2001; Zhang et al., 2005).

Therefore, gene expression studies in human oocyte and cumulus cells could contribute not only to identify factors involved in the oocyte maturation pathway, but could also provide valuable molecular markers of abnormal gene expression in oocytes with reduced competence.

Specific gene expression screenings for caspase and cell death proteins (Spanos et al., 2002), FSH receptor and LH receptor (Patsoula et al., 2003) or cell adhesion molecules (Bloor et al., 2002) have also been attempted to determine the status of embryos. More recently, Wells et al (2005a, 2005b) analyzed by quantitative polymerase chain reaction (Q-PCR) a panel of cell
division and DNA damage marker genes (BRCA1 & 2, ATM, TP53, RB1, BUB1, MAD2 and APC.) to establish a correlation between their expression levels and the quality grade of preimplantation embryos (Wells et al., 2005b). The aim of the present study, based in parts on data obtained by Assou et al. (2006), was to apply a microarray approach to identify new potential regulators and marker genes which are involved in human oocyte maturation as well as in cumulus cell function.
Materials and Methods

Oocytes and cumulus cells

Oocytes and cumulus cells were collected from patients consulting in our centre for cIVF or for intracytoplasmic sperm injection (ICSI). This study has received institutional review board approval. Patients were stimulated with a combination of gonadotropin-releasing hormone agonist (GnRH-a) (Decapeptyl PL 3) and recombinant FSH (Puregon or Gonal F) or hMG (Menopur). Ovarian response was evaluated by serum estradiol level and daily ultrasound examination to observe follicle development. Retrieval of oocytes occurred 36 hours after hCG administration and was performed under ultrasound guidance. Cumulus cells were removed from one or two mature oocytes (MII) 21 hours post insemination. Immature oocytes (GV and MI) and unfertilized MII oocytes were collected 21 hours or 44 hours post insemination or post microinjection by ICSI. Cumulus cells and oocytes were frozen at -80°C in RLT buffer (RNeasy kit, Qiagen, Valencia, CA, USA) before RNA extraction. Pools of 20 GV (7 patients, age 30 years ±4.6), 20 MI (6 patients, age 30.1 years ±6.7), 2 pools of 16 (6 patients, age 34 years ±4.5) and 21 MII oocytes (8 patients, age 33.2 years± 6.4) and 2 pools of cumulus cells (2 patients, age 31 and 37) were separately analyzed on 6 Affymetrix™ DNA microarrays. All these oocytes or cumulus cells were from couples referred to our centre for cIVF (tubal infertility) or for ICSI (male infertility).

Complementary RNA (cRNA) preparation and microarray hybridization

RNA was extracted using the micro RNeasy Kit (Qiagen) and the total RNA quantity was measured with a Nanodrop ND-1000 spectrophotometer (Nanodrop Technologies Inc., DE, USA) and RNA integrity was assessed with an Agilent 2100 Bioanalyzer (Agilent, Palo Alto, CA, USA). cRNA was prepared with two rounds of amplification according to the manufacturer’s protocol “small sample protocol II” starting from total RNA (ranging from ~4 ng for pooled oocytes to 100 ng for cumulus cells), and hybridized to HG-U133 plus 2.0
GeneChip pangenomic oligonucleotide arrays (Affymetrix™, Santa Clara, CA, USA). HG-U133 plus 2.0 arrays contain 54,675 sets of oligonucleotide probes (“probeset”) which correspond to \( \approx 30,000 \) unique human genes or predicted genes. Primary image analysis of the arrays was performed with the GeneChip Operating Software 1.2 (GCOS) (Affymetrix™), resulting in a single value for each probe set (“signal”). Data from each different array experiment were scaled to a target value of 100 by GCOS using the “global scaling” method. This algorithm determines whether a gene is expressed with a defined confidence level or not (“detection call”). This “call” can either be “present” (when the perfect match probes are significantly more hybridized than the mismatch probes, p-value < 0.04), “marginal” (for p-values > 0.04 and < 0.06) or “absent” (p-value > 0.06). A gene was denoted as “absent” in a sample when all its probeset displayed an “absent” or “marginal” detection call for this sample. The dataset was floored to 2, i.e. each signal value under 2 was given the value 2.

**Statistical analysis**

Samples were analyzed by pair wise comparison using the GCOS 1.2 software (Affymetrix™).

For hierarchical clustering, we used the probesets included in table 1 (for a gene, the probeset with the highest signal in one of the samples). Signal values lower than 2 were arbitrarily floored to the value of 2. Data were log transformed, mean centred, and processed with the CLUSTER and TREEVIEW software packages with the average linkage method and un-centered correlation (Eisen et al., 1998).

**Gene search**

We search through the gene annotation lists (Unigene Build 190) to identify related genes based on their description. The gene annotation lists included the following terms: gene symbol; gene name; the Gene Ontology “biological process”, “Cellular component” and “Molecular function”; genetic pathway. We filtered the genes with the following criteria: lists
comprising the terms “retinoblastoma” (for \textit{RB1}), “bub” for \textit{BUB1}, “atm” OR “atr” for \textit{ATM}, “tp53” for \textit{TP53}, “brca” for \textit{BRCA1} \& 2, “mad” for \textit{MAD2L1}, and “adenomatosis” for \textit{APC} identified the genes presented in this study.

Database

The expression, including signal values, of all genes cited in Table 1 can be examined on our web site as online supplemental data: Expression of these genes in various normal tissues transcriptome datasets, including ovarian and testis samples, is provided through the “Amazonia!” database web page: \url{http://amazonia.montp.inserm.fr/}
Results

Analysis of “marker genes” expression in human oocytes and cumulus cells

We evaluated the gene expression level of BRCA1 & 2, ATM, TP53, RB1, BUB1, MAD2, APC and ACTB in cumulus cells, in unfertilized MII oocytes and in immature oocytes GV and MI stages. These genes are presented in bold type at the top of each section in Table 1. For cumulus cells and MII oocytes, the presented average signal values were calculated from two independent sample chip hybridization experiments for each. All genes were detected in cumulus cell and oocyte samples with the following exceptions: BRCA1 was absent in cumulus cells, TP53 was absent in MI oocytes, and RB1 was absent in MII oocytes. In addition, ACTB and MAD2L1 were present in all samples and presented the highest signal levels (circa 20 fold higher on average). The signal fold increase between cumulus cell average signal and all oocyte average signals (Figure 1) indicates that RB1 is down-regulated in oocytes. On the other hand, BUB1, BRCA1 & 2 and MAD2L1 are down-regulated in cumulus cells whereas ATM and APC are slightly up regulated in oocytes. Although weaker in GV and MI oocytes, ACTB expression varied little between samples.

Expression profile of new marker genes

We used the “marker genes” names or symbol names as a keyword list to search the GeneNote annotations associated with each probeset present on the chip in order to identify eight groups of genes related to the marker genes cited above (β-Actin was not included in the search). Thus, 149 probesets were retrieved, of which one for each of the 40 corresponding genes is listed in Table 1. The signal values of the probesets for each sample are indicated (highest sample signal in bold type, value in grey when absent). The highest fold change between sample-pairs is also indicated (Table 1). Three of these genes (TP53I-11, TP53I-13 and APCDD1 – full names can be found in Table 1) were never detected in our samples and
are listed at the bottom of the table. In general retrieved genes corresponded to proteins belonging to the regulatory pathway, to interacting partners or to paralogous proteins of the “marker genes”.

The hierarchical clustering analysis of the probesets signal values from Table 1 across all samples showed that oocytes cluster together and suggested that some gene expression levels could be specific to the degree of oocyte nuclear maturation. As expected, the cumulus cell lineage is the most distant from oocytes. The main expression groups are for genes over-expressed in cumulus cells or in oocytes. For the latter, sub-groups of genes specific to MII or to GV and MI oocytes are also apparent (Figure 2). The lesser distinction was observed between GV and MI oocytes.

**RB1 group**

The *RB1* profile was also found for *RBL1, RBBP6* and *RBBP9*, which were also absent in MII oocytes. However, the *RB1* pathway was not completely down-regulated in oocytes. On the contrary, the highest expression levels were detected with *RBBP7, RBBP4, RAP140, and RBBP8* in oocyte samples. *RBBP8* gene was highest in GV oocytes, *RBBP4* in MI oocytes and *RBBP7* and *RBL2* in MII oocytes.

**BUB1 group**

*TBC1D1, BUB1B* and *BUB3* displayed patterns similar to that of *BUB1. BUB1B* and *BUB3* mimicked *BUB1* expression but at much higher levels (6 and 3 fold respectively), although *BUB3* was high in cumulus cells as well.
ATM group

ATR and the ATM/ATR substrate ASCIZ differed from ATM in that their expression was high in cumulus and strongest in immature oocytes, particularly in GV oocytes.

TP53 group

Unlike TP53 for which the highest expression levels were found in MII oocytes, many targets or TP53 partners were not expressed in MII oocytes: Two targets of TP53 (TP53TG3, TP53INP1) were found at higher levels in oocytes whereas four partners (TP53RK, PERP, TP53BP1 & 2) and one target (TP53I3) were specific or over expressed in cumulus cells. Among the genes expressed in oocytes, RPRM, RRM2B and TP53INP2 were evenly expressed across the four samples (no significant change). TP53TG3 and TP53INP1 were up-regulated in GV and MII oocytes respectively.

BRCA1 and BRCA2 group

BRCA1 and BRCA2 partners remained mostly confined to oocytes with the strongest expression generally found in immature oocytes or cumulus cells. BRCA1 was stronger in GV oocytes and BRCA2 in MII oocytes. The cofactor COBRA1 was highest in cumulus cells but was actually not significantly different between all samples, whereas BRCC3 and BAP1 low expression was turned down in oocytes compared to cumulus cells. BRIP1 was only found in GV and MI oocytes. Expression of BARD1 represented the strongest signals, increasing from GV to metaphase MI and MII oocytes. BRAP and BCCIP were similar but with reduced expression in MII oocytes.
**MAD2 group**

Genes related to MAD2L1 did not match its high expression levels. MAD2L2 is similar but found at much lower levels. MAD2L1BP and MAD1L1 appeared GV specific and were not found or low in MII.

**APC group**

Following our search criteria, only one gene related to APC, APC2, was expressed in our sample although at low levels and only in cumulus cells: We found no expression for the APCDD1 gene.

**Discussion**

**Marker gene expression in cumulus cells and immature oocytes**

Recently, we reported the expression of circa 30 000 human genes in our cumulus-oocyte complex gene expression profiling studies (Assou et al., 2006). Some of them were previously described as potential markers for the evaluation of human oocyte or embryo quality, based on their expression pattern in preimplantation embryos (Wells et al., 2005a, b). These genes were BRCA1 & 2, ATM, TP53, RB1, BUB1, MAD2, APC and ACTB, which are involved in cell cycle checkpoint and DNA repair control.

The analysis of cumulus cell expression provided additional information on the gene expression profile of oocyte supporting cells. Overall, we observed similar expression patterns in all oocyte stages for these genes, but differences were nevertheless observed. Wells et al. (2005a, b) reported the strongest signal for APC in a “typical” oocyte and used this value as a 100% scale reference for all the genes tested. In our study, ACTB and MAD2L1 were present in all samples and presented the highest signal levels (circa 20 fold higher on average). Apart from these two genes, the strongest signals came from RB1 in cumulus cells
(signal value = 920), *BRCA1* in GV oocytes (988), *BUB1* in MI oocytes (888) and *BRCA2* in MII oocytes (575). The variations in levels of expression (e.g. for the *MAD2L1* and *APC* genes) could be due to the detection methods (microarray vs. quantitative RT-PCR). The use of specific marker genes to normalize expression data should help in the comparison of expression values measured in different laboratories. The genes for glyceraldehyde-3-phosphate dehydrogenase (*GAPDH*) or beta-2-microglobuline (*B2M*) are commonly used as ubiquitously expressed reference markers. The IkappaB kinase alpha gene (*CHUK*) was also recently proposed as a better internal standard for oocytes and pre-embryo cells (Falco *et al.*, 2006). *MAD2L1* was already observed at very high levels in single oocyte microarray analyses (Bermudez *et al.*, 2004). High *MAD2L1* expression in our MII oocytes could also reflect that these unfertilized oocytes are blocked in pro-metaphase II (Wassmann *et al.*, 2003). However, these variations do not interfere with the quality of these genes as oocyte and embryo fitness markers. Thus, for this set of genes expression was similar to that of previous reports with the additional detection of *RB1* in cumulus cells.

The analysis of expression in immature oocytes (GV and MI) and in unfertilized MII oocytes provided supplemental insights into the *BRCA1* and *BRCA2* expression profiles: the two genes are co-expressed but expression of the former is down-regulated whereas the latter increased slightly during oocyte maturation.

**Identification of new marker genes.**

**Transcriptional control**

The restriction of *RB1* expression to cumulus cells was intriguing for a gene usually found in most tissues. Expression of other factors interacting with RB1, in particular *RBL1*, which is strictly restricted to cumulus cells, further suggest that regulation by RB1 is involved in these cells. Although it is absent from oocytes and preimplantation embryos (Wells *et al.*, 2005a), its expression was detected in hatching blastocysts (Wells *et al.*, 2005b). Finding high *RBBP8*
expression in GV oocytes is consistent with its binding to and modulation of BRCA1 expression (Yu et al., 2000; Yu et al., 2004). The high expression levels of RBBP7, RBBP4 and RBL2 in MI and MII oocytes suggested that this regulation pathway could be active during oocyte maturation. For TP53 genes, the strongest signals were observed in MII oocytes for RRM2B and TP53INP1, which are both induced by TP53, with TP53INP1 having the same positive action as TP53 on catalases and proteasome endopeptidases (Tomasini et al., 2005). TP73, a potential TP53INP1 activator and TP53 homolog was not expressed in our microarrays.

**DNA repair markers**

ATM and ATR both phosphorylate BRCA1 (Gatei et al., 2001) and were differentially expressed during maturation with ATR appearing mostly in immature oocyte.

Expression of BARD1 is interesting because it displayed the strongest signals in its group and was co-expressed in oocytes with both BRCA1 and BRCA2. BARD1 is an important regulator of BRCA1 activity: binding of BARD1 with BRCA1 maintains both proteins in the nucleus thus preventing apoptosis (Fabbro et al., 2004b). BARD1 is very similar to BRCA1 and both proteins induce apoptosis when they are confined to the cytoplasm (Schuchner et al., 2005). BARD1 is also a key factor in DNA repair (reviewed by Henderson, 2005). The BRCA1-BARD1 complex is also required for ATM/ATR (ataxia-telangiectasia-mutated/Rad3-related)-mediated phosphorylation of P53 (Ser-15) (Fabbro et al., 2004a).

**Cell cycle checkpoint markers**

The expression profile and the interaction networks of BUB and MAD2 genes also suggest that they could also provide new marker genes. The proteins BUB3 and BUB1B interact with CDC20 at checkpoint activation (Tang et al., 2001). MAD2L2 negatively regulates the
CDC20/Anaphase promoting complex APC (Chen et al., 2001). MAD2L1 together with BUB1B inhibits CDC20/APC to prevent premature separation of sister chromatids (Fang, 2002). MAD2L1BP and MAD1L1 bind MAD2L1 and are crucial for localization of MAD2L1 to kinetochores where it binds to CDC20 (Sironi et al., 2001).

**Identifying new oocyte or embryo marker genes**

Gene expression is a first step in the identification of potential marker genes and it has been undertaken by different research groups using microarray approaches (Bermudez et al., 2004; Richards et al., 2005; Assou et al., 2006). The Affymetrix™ GeneChip is a reliable microarray system (http://www.Affymetrix™.com/community/publications/index.affx), presenting little inter-laboratory variability (Irizarry et al., 2005). Different criteria can be used to pre-select candidate marker genes. Stronger expression may be easier to detect but variation in expression could be less visible or less relevant. Genes that are more specific reflect tighter regulation and could provide better reporter genes because variations may be more readily detectable. However, after their identification on the basis of gene expression profiles and the verification of their patterns by Q-PCR, understanding the function of factors in regulating pathways will be the next validation step to select marker genes. In the end, experimental data linking their expression levels with oocyte or embryo quality status will determine their practical value. The list of genes presented here was filtered on the basis of keywords and not pathway oriented. In the case of APC related genes, the search criteria were clearly not appropriate. Analyzing other genes like CTNNB1 (highly expressed in oocytes in Bermudez et al., 2004), AXIN2, WNT1 or WNT8A, which are partners of APC in the WNT signalling pathway could be more relevant. Likely, other ATM/ATR targets, not initially reported with our search criteria, may represent alternate markers to ATM: H2AFX’s and CHEK1’s profiles are similar to that of ATM but with stronger signals, and CHEK2 was only
detected in GV and MI oocytes (data not shown). The fact that some genes analyzed in this study were not detected at all or only in some samples raises different interpretations. They may be truly absent, their expression levels could be below the detection threshold of the microarray approach or the lack of detection could reflect sample or experimental discrepancies. We favour the two former possibilities because only a couple of signal values are sporadic and could result from the latter explanation. Indeed, most absent signals were either duplicated in separate experiments (Cum and MII samples) or were concomitantly observed within groups of related samples such as immature oocytes or all oocytes. Therefore, absent signals reported here should be viewed as very low or absent transcripts.

With the present study, some factors are clearly put in perspective as potential markers of oocyte competence (Figure 3). Their expression profiles suggest different roles played in supporting cumulus cells or in oocytes during successive maturation stages. RBL1 appears as a very specific marker in cumulus cells. However, most of the genes presented here are preferentially expressed in oocytes and different criteria should be used to identify cumulus cell markers that could reflect oocyte quality. A number of oocyte factors interact within the \textit{BRCA1} regulation pathway and are co-expressed in MII oocytes. RBBP8, BRAP and ATR bind and modulate BRCA1 activity (Li \textit{et al.}, 1999) and are co-expressed with BRCA1. RBBP8 also binds RB1 and BARD1 (Yu \textit{et al.}, 2000). RBBP4 and RBBP7 bind BRCA1 like RB1 (Yarden \textit{et al.}, 1999). The interaction of BUB1B and BUB3 with RBL2 (Cam \textit{et al.}, 2004) also link them to the RB1 and BRCA1 regulation pathways. \textit{BUB1B} or \textit{RBBP7} were already observed as highly expressed genes in previous studies (Bermudez \textit{et al.}, 2004; Assou \textit{et al.}, 2006). Thus we identified genes with relevant expression patterns to serve as a resource for potential new oocyte markers. Interestingly, the factors encoded by these genes intersect in common regulatory pathways.
Our aim was to show the relevance of the microarray approach to identify and bring forward new potential regulators and marker genes. Such study is qualitative and partly quantitative within the limits of the microarray approach. The adjunction of additional independent series could strengthen these results further. However, once a discrete number of genes as been selected, the validation of differential expression by Q-PCR is more reliable, faster and more cost-effective. Thus, Q-PCR analyses on specific genes presented herein will be the focus of future studies. Finally, the account of oocyte and cumulus cells gene expression profiles should be strengthened by functional analyses since protein activity often depends on post-translational modification and interactions with other partners. Proteomics approaches and interactome analyses may have the last word to determine the real activity of genes and proteins.

Acknowledgments

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Figures Legends

Figure 1. Marker genes up or down-regulated in cumulus cells and oocytes.
Histogram representation of the fold increase in the signal between cumulus cell and oocyte average signals for nine genes (cumulus versus oocyte in grey bars and oocyte versus cumulus in white bars). Probe set values are from table 1.

Figure 2. Hierarchical clustering of 46 genes signal values across cumulus cell and oocyte samples.
Signal values were floored (minimal signal value = 2), log transformed and mean centered. Average linkage with un-centered correlation was evaluated using the Cluster software (Eisen et al. 1998). On the right side, genes are clustered by their preferential expression in the four samples. Red and green mark over- and under-expression, respectively and black colour represents mean values. GV = germinal vesicle; M = metaphase.

Figure 3. New marker genes involved in oocyte maturation.
Factors identified in this study with restricted expression in immature germinal vesicle (GV) and metaphase I (MI) oocytes, in unfertilized metaphase II (MII) oocytes and in cumulus cells. Factors in darker shade are shared by MI and MII oocytes.
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Table 1. Affymetrix™ GeneChip signal values of 46 genes expressed in oocytes and cumulus cells.

<table>
<thead>
<tr>
<th>Reference†</th>
<th>Symbol</th>
<th>Gene name*</th>
<th>Cum† ‡</th>
<th>GV† ‡</th>
<th>MI† ‡</th>
<th>MII† ‡</th>
<th>Highest fold increase in*</th>
</tr>
</thead>
<tbody>
<tr>
<td>203132_at</td>
<td>RB1</td>
<td>retinoblastoma 1 (including osteosarcoma)</td>
<td>920.2</td>
<td>48.7</td>
<td>39.2</td>
<td>9.0</td>
<td>23.5 x in Cum / MI</td>
</tr>
<tr>
<td>212781_at</td>
<td>RBBP6</td>
<td>retinoblastoma binding protein 6</td>
<td>327.7</td>
<td>39.1</td>
<td>13.1</td>
<td>55.9</td>
<td>25.0 x in Cum / MII</td>
</tr>
<tr>
<td>205296_at</td>
<td>RBL1</td>
<td>retinoblastoma-like 1 (p107)</td>
<td>30.9</td>
<td>9</td>
<td>2</td>
<td>9.7</td>
<td>nd Cum only</td>
</tr>
<tr>
<td>226696_at</td>
<td>RBBP9</td>
<td>retinoblastoma binding protein 9</td>
<td>129.4</td>
<td>27.3</td>
<td>34.9</td>
<td>49.0</td>
<td>4.7 x in Cum / GV</td>
</tr>
<tr>
<td>205169_at</td>
<td>RBBP5</td>
<td>retinoblastoma binding protein 5</td>
<td>40.9</td>
<td>94.1</td>
<td>165.5</td>
<td>616.9</td>
<td>15.1 x in MII / Cum</td>
</tr>
<tr>
<td>210371_s_at</td>
<td>RBBP4</td>
<td>retinoblastoma binding protein 4</td>
<td>315.9</td>
<td>1131.8</td>
<td>2914.8</td>
<td>1679.2</td>
<td>9.2 x in MII / Cum</td>
</tr>
<tr>
<td>203031_at</td>
<td>RBBP7</td>
<td>retinoblastoma binding protein 7</td>
<td>1765.1</td>
<td>3678.4</td>
<td>8732.3</td>
<td>9743.3</td>
<td>5.5 x in MII / Cum</td>
</tr>
<tr>
<td>201092_at</td>
<td>RBBP8</td>
<td>retinoblastoma binding protein 8</td>
<td>549.0</td>
<td>2344.6</td>
<td>6372.3</td>
<td>2054.3</td>
<td>5.2 x in MII / GV</td>
</tr>
<tr>
<td>225912_at</td>
<td>RBAF600</td>
<td>retinoblastoma-associated factor 600</td>
<td>33.0</td>
<td>3802</td>
<td>6299.9</td>
<td>1033.1</td>
<td>190.9 x in MII / MI</td>
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<tr>
<td>201855_s_at</td>
<td>ATR</td>
<td>ataxia telangiectasia and Rad3 related</td>
<td>449.4</td>
<td>781.7</td>
<td>511.6</td>
<td>205.4</td>
<td>3.8 x in GV / MII</td>
</tr>
<tr>
<td>209903_s_at</td>
<td>ATM</td>
<td>ataxia telangiectasia (comp. groups A, C and D)</td>
<td>101.6</td>
<td>98.6</td>
<td>165</td>
<td>562.0</td>
<td>5.7 x in MII / GV</td>
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<tr>
<td>225402_at</td>
<td>TP53RK</td>
<td>TP53 regulating kinase</td>
<td>112.5</td>
<td>7.2</td>
<td>2.4</td>
<td>22.5</td>
<td>4.2 x in MII / MI</td>
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<tr>
<td>209924_at</td>
<td>ASCIZ</td>
<td>ATM/ATR-Substrate Chk2-Interacting Zn2+-finger protein</td>
<td>392.6</td>
<td>1369.3</td>
<td>712.4</td>
<td>117.4</td>
<td>3.5 x in GV / MII</td>
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<tr>
<td>203120_at</td>
<td>TP53BP2</td>
<td>tumour protein p53 binding protein, 2</td>
<td>611.4</td>
<td>158.8</td>
<td>200.6</td>
<td>101.7</td>
<td>3.8 x in Cum / GV</td>
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<tr>
<td>20167_s_at</td>
<td>TP53T3G3</td>
<td>TP53T3G3 protein</td>
<td>118.0</td>
<td>571.3</td>
<td>457.7</td>
<td>247.4</td>
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<tr>
<td>22912_at</td>
<td>TP53INP1</td>
<td>tumour protein p53 inducible nuclear protein 1</td>
<td>704.7</td>
<td>438</td>
<td>553.6</td>
<td>1770.8</td>
<td>4.0 x in MII / GV</td>
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<td>219370_at</td>
<td>RPRM</td>
<td>reprimo, TP53 dependant G2 arrest mediator candidate</td>
<td>49.1</td>
<td>34.5</td>
<td>73.3</td>
<td>200.6</td>
<td>nd MI only</td>
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<td>223342_at</td>
<td>RRM2B</td>
<td>ribonucleotide reductase M2 B (TP53 inducible)</td>
<td>789.8</td>
<td>848.4</td>
<td>1429.7</td>
<td>2028.9</td>
<td>2.1 x in Cum / GV</td>
</tr>
</tbody>
</table>

† Reference identifier
‡ Symbol identifier
* Gene name
Cum: cumulus cell
GV: GV stage
MI: MI stage
MII: MII stage

Fold increase indicates the change in gene expression between two stages, with the reference stage set to 1.
<table>
<thead>
<tr>
<th>Genes undetected in cumulus cells and oocytes: TP53I11, tumour protein p53 inducible protein 11; TP53I13, Tumour protein p53 inducible protein 13; APCDD1, adenomatosis polyposis coli down-regulated 1.</th>
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</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Genes</th>
<th>Functions</th>
<th>Affymetrix Probeset References</th>
<th>Sample Values</th>
<th>Best Fold Increase (&gt;2 and p&lt;0.001) Found</th>
<th>Abbreviations</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP53INP2 tumour protein p53 inducible nuclear protein 2</td>
<td>430.6 362.8 394.4 183.2</td>
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<tr>
<td>BRCA1 breast cancer 1, early onset</td>
<td>11.4 988.2 226.9 106.0 x 9.3</td>
<td>in GV / MII</td>
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<tr>
<td>BARD1 BRCA1 associated RING domain 1</td>
<td>61.0 1214.7 2897.5 4351.0 x 71.3</td>
<td>in MII / Cum</td>
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<tr>
<td>BRIP1 BRCA1 interacting protein C-terminal helicase 1</td>
<td>10.6 80.6 127.3 75.0</td>
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<td>BRAP BRCA1 associated protein</td>
<td>125.7 521.9 687.2 151.2 x 5.5</td>
<td>in MI / Cum</td>
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<td>BRCC3 BRCA1/BRCA2-containing complex, subunit 3</td>
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<td>BAP1 BRCA1 associated protein-1 (ubiquitin carboxy-terminal hydrolase)</td>
<td>131.8 95.6 30.3 30.6</td>
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<td>COBRA1 cofactor of BRCA1</td>
<td>210.8 199 175.5 177.4</td>
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<td>BRCA2 breast cancer 2, early onset</td>
<td>5.9 270.9 246.3 575.2 x 97.5</td>
<td>in MI / Cum</td>
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<tr>
<td>BCCIP BRCA2 and CDKN1A interacting protein</td>
<td>541.6 1239.8 1594.8 343.1 x 4.6</td>
<td>in MI / MII</td>
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<tr>
<td>MAD2L1 MAD2 mitotic arrest deficient-like 1 (yeast)</td>
<td>81.7 3217 4035.1 9559.6 x 117.1</td>
<td>in MII / Cum</td>
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<tr>
<td>MAD2L1BP MAD2L1 binding protein</td>
<td>140.7 405.1 310.7 44.8 x 9.0</td>
<td>in GV / MII</td>
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<tr>
<td>MAD1L1 MAD1 mitotic arrest deficient-like 1 (yeast)</td>
<td>11.1 78.4 32.1 8.2 x 2.4</td>
<td>in GV / MI</td>
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<tr>
<td>MAD2L2 MAD2 mitotic arrest deficient-like 2 (yeast)</td>
<td>130.7 100.4 110.7 294.6</td>
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<td>APC adenomatosis polyposis coli</td>
<td>210.8 841.5 590.3 131.3 x 6.4</td>
<td>in GV / MII</td>
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<tr>
<td>APC2 adenomatosis polyposis coli 2</td>
<td>18.6 8.1 2 30.5</td>
<td>nd</td>
<td></td>
<td>Cum only</td>
<td></td>
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</tbody>
</table>

**a)** Affymetrix probeset reference; **b)** symbol name and gene name (Unigene build 190). **c)** for each probeset line, sample with highest signal in bold type or italicized and greyed when “Absent”. **d)** for cumulus cells and MI oocytes samples, the values represent the average value derived from independent samples hybridized to two DNA chip arrays. **e)** best fold increase (>2 and p<0.001) found for the pair-wise comparison indicated in the last column and not determined (nd) between “Absent” genes or when not significant (—). Abbreviations: Cum = cumulus cells, GV = germinal vesicle, MI & MII = metaphase I & II oocytes respectively.