Brilliant Cresyl Blue stain selects largest oocytes with highest mitochondrial activity, maturation-promoting factor activity and embryo developmental competence in prepubertal sheep

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Abstract

The aim of this study was to test the Brilliant Cresyl Blue (BCB) stain to select prepubertal sheep oocytes for in vitro blastocyst production. Oocyte diameter, mitochondrial activity, maturation-promoting factor activity and mRNA relative expression (RE) of genes related to metabolism (ATPase Na+/K+ transporting α1 (ATP1A1) and cytochrome c oxidase subunit 1 (COX1)) and constitutive function of the cell (cytoplasmic polyadenylation-element-binding protein (CPEB) and S100A10) were assessed. Immature oocytes were exposed to different BCB concentrations (13, 26, 39 and 52 μM) and classified according to their cytoplasm colouration as grown BCB+ (blue cytoplasm) and growing BCB− (colourless cytoplasm). Staining oocytes with 13 μM BCB during 60 min allows selection of (BCB+) the largest (123.66 μm) and most competent oocytes to develop to the blastocyst stage (21%) with a higher number of cells (69.71 ± 6.19 S.E.M.) compared with non-stained BCB− oocytes (106.82 μm, 9% and 45.91 ± 3.35 S.E.M. respectively). Mitochondrial activity, assessed by MitoTracker Orange CMTMRos probe, was significantly higher in BCB+ than in BCB− oocytes after in vitro maturation (3369 and 1565 AU respectively). MPF activity was assessed by CDC2 kinase activity assay showing significantly higher activity at metaphase II stage in BCB+ than in BCB− oocytes (1.479 ± 0.09 and 1.184 ± 0.05 optical density respectively). The genes analysed in this work, ATP1A1, COX1, CPEB and S100A10, did not show significant effect in mRNA RE between BCB selected oocytes. In conclusion, BCB stains larger and more competent oocytes to develop to the blastocyst stage with more active mitochondria and MPF activity and higher blastocyst cell number.

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Introduction

In vitro embryo production is closely related to oocyte source and quality (Rizos et al. 2002, Cogne et al. 2003). Thus, the efficiency of in vitro techniques is low when using prepubertal animals as oocyte donors. Prepubertal oocytes are characterised as having abnormal cytoplasmic maturation and lower ability to achieve the blastocyst stage than those coming from adult donors (Armstrong 2001). This has been shown in cattle (Revel et al. 1995), sheep (O’Brien et al. 1996) and pigs (Peters et al. 2001). Ovaries from prepubertal animals have a high percentage of antral follicles with a diameter smaller than 3 mm (Martino et al. 1994), making it difficult to release the cumulus–oocyte complexes (COCs) by traditional aspiration. For this reason, oocytes are routinely obtained by slicing the ovary surface, resulting in oocytes with heterogeneous diameter, different COC morphology and at varying stages of atresia. It is known that there is a direct and positive relationship among follicle size, oocyte diameter and embryo development (Gilchrist et al. 1995, Barnes & Sirard 2000). In prepubertal goats, we have previously shown that oocytes with a diameter larger than 125 μm produced higher percentages of blastocyst after IVF (Anguita et al. 2007) and ICSI (Jimenez-Macedo et al. 2007) and oocytes coming from follicles larger than 3 mm develop to the blastocyst stage in a significantly higher percentage than oocytes from follicles smaller than 3 mm (Romaguera et al. 2010). Brilliant Cresyl Blue (BCB) stain is known to be a non-invasive methodology that allows the selection of oocytes with larger diameters among a heterogeneous pool. The BCB test determines the intracellular activity of glucose-6-phosphate dehydrogenase (G6PDH), a pentose phosphate pathway enzyme that gradually decreases its activity as oocytes...
reach their growth phase. BCB dye can be reduced by G6PDH activity, therefore oocytes that have reached their growth phase cannot reduce BCB to a colourless compound and exhibit a blue coloured cytoplasm (BCB +). However, growing oocytes are expected to have a high level of G6PDH activity and be able to reduce the blue compound, resulting in a colourless oocyte cytoplasm (BCB −). In our previous studies in prepubertal goats (Rodriguez-Gonzalez et al. 2002) and cows (Pujol et al. 2004), we have shown the usefulness of the BCB stain to select the larger and more competent oocytes for in vitro blastocyst production.

Blastocyst viability is related to the timing of blastocyst formation (Majerus et al. 2000), embryo cryptotolerance assessed by blastocyst re-expansion rates post-warming (Leoni et al. 2009) and the number of blastomeres at a given age and their allocation to the inner cell mass (ICM) and the trophectoderm (TE; Papaioannou & Ebert 1988). The blastocyst is composed of two different cell lineages: TE and the ICM. The inside cells develop into the ICM of the blastocyst and the outside cells progressively lose their pluripotency, differentiating into an extraembryonic tissue, the TE.

Mitochondria are maternally inherited organelles that use oxidative phosphorylation to supply energy (ATP) to the cell (Stojkovic et al. 2001). The distribution of mitochondria changes during oocyte maturation and fertilisation with the aim of bringing mitochondria to the region of the cell where a higher level of ATP (Van Blerkom & Runner 1984) or calcium (Sousa et al. 1997) is required. It has been demonstrated that mitochondrial function and the cytoplasmic ATP level can affect fertilisation, resulting in a significant increase in blastocyst rates or their total failure after IVF (Van Blerkom et al. 1995, Liu et al. 2000). Mitochondrial distribution and activity are modified during oocyte in vitro maturation (IVM) and this differs among species such as cattle (Stojkovic et al. 2001, Tarazona et al. 2006), dogs (Valentini et al. 2010), goats (Velilla et al. 2006), horses (Torner et al. 2007), humans (Van Blerkom et al. 1995, 2008, Dell’Aquila et al. 2009), mice (Calarco 1995) and pigs (Torner et al. 2004, Brevini et al. 2005). Using the fluorescence probe MitoTracker Green, Sun et al. (2001) concluded that in vitro matured pig oocytes present changes in the distribution of mitochondria causing the incomplete movement of mitochondria into the inner cytoplasm affecting the cytoplasmic maturation. In our laboratory, we found differences in the distribution pattern of mitochondria between adult and prepubertal goat oocytes (Velilla et al. 2006).

Meiosis and mitosis are regulated by the activity of the maturation-promoting factor (MPF). This universal cell cycle regulator is a heterodimer protein composed of two subunits, the catalytic subunit p34cdc2 (serine–threonine kinase activity) and the regulatory subunit cyclin B1. The association of these two subunits is a requirement for the activation of the protein kinase activity; also the phosphorylation of p34cdc2 on threonine 161 by the protein kinase CDC2-activation kinase (CAK) and dephosphorylation on threonine 14 and tyrosine 15 by CDC25 phosphatase is necessary. MPF activity appears just before germinal vesicle breakdown (GVBD) increasing until metaphase I; its activity is decreased in anaphase–telophase while its maximum level is reached at metaphase II (MII). It has been shown that incompetent goat oocytes have a limited amount of cyclin B1 (Hue et al. 1997) and p34cdc2 (Anguita et al. 2007). MPF activity in calf and lamb oocytes were significantly lower than in cow and ewe oocytes (Ledda et al. 2001, Salamone et al. 2001), whereas (Han et al. 2010) showed in mice that the MPF activity of prepubertal oocytes was significantly higher than that of adult oocytes. In prepubertal goats, Anguita et al. (2007) showed higher MPF activity and oocyte competence to develop up to the blastocyst stage in oocytes with a diameter larger than 135 μm. In conclusion, MPF activity could be a useful tool in analysing differences in oocyte quality.

Competence is acquired during oocyte growth, when the synthesis and storage of proteins and RNA take place (Crozet et al. 1981, Brevini-Gandolfi & Gandolfi 2001). The mRNA content in oocytes is affected by animal nutrition (Psani et al. 2008), follicle diameter (Caixeta et al. 2009), IVM culture media (Salhab et al. 2011), in vivo and in vitro conditions (Wells & Patrizio 2008) and apoptosis (Li et al. 2009). Thus, mRNA stored in oocytes could represent a valuable tool as a molecular marker for oocyte quality. In this study, we decided to analyse the expression of two genes involved in metabolism (ATPase Na+/K+ transporting alpha 1 (ATP1A1) and cytochrome c oxidase subunit 1 (COX1)) and two genes involved in the constitutive function of the cell (cytoplasmic polyadenylation-element-binding protein (CPEB) and calcium-binding protein (S100A10)).

To our knowledge, there are no reports regarding in vitro developmental competence of prepubertal sheep oocytes selected by the BCB test. The aim of this study was to evaluate the BCB test as an indirect measure of oocyte growth to select more competent lamb oocytes for IVM, IVF and embryo culture. Also, we aimed to assess oocyte diameter, mitochondrial activity and distribution assessed by MitoTracker Orange CMTMRos probe, the MPF activity and the relative mRNA expression of four maturation gene candidates by real-time PCR in BCB selected oocytes.

Results

Embryo development of prepubertal sheep oocytes selected with different BCB concentrations

The percentage of BCB+ obtained after staining with different concentrations of BCB was 19, 28, 36 and 47% for 13, 26, 39 and 52 μM BCB respectively (Table 1).
Table 1 Immature prepubertal sheep oocytes exposed at different concentrations of Brilliant Cresyl Blue (BCB).

<table>
<thead>
<tr>
<th>BCB concentration (μM)</th>
<th>Total COC</th>
<th>BCB +, n (%)</th>
<th>BCB −, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>226</td>
<td>44 (19)A</td>
<td>182 (81)B</td>
</tr>
<tr>
<td>26</td>
<td>225</td>
<td>64 (28)A</td>
<td>161 (72)B</td>
</tr>
<tr>
<td>39</td>
<td>234</td>
<td>85 (36)A</td>
<td>149 (64)B</td>
</tr>
<tr>
<td>52</td>
<td>283</td>
<td>132 (47)A</td>
<td>151 (53)A</td>
</tr>
</tbody>
</table>

Values in the same column (A,B,C) or row (A,B) with different letters differ significantly (Fisher test; P<0.05).

Although staining with 13 μM BCB showed a lower percentage of stained oocytes (BCB+), the number of blastocysts obtained in this group (21%) was significant higher (P<0.05) than with 39 μM (10%) and 52 μM BCB (8%; Table 2). Of 174 inseminated oocytes from the control group (not exposed to BCB), 116 (67%) were cleavage oocytes and 14 (8%) reached the blastocyst stage. This percentage of blastocysts was significantly different from BCB+ but not from BCB − oocytes. After 24 h of IVM there were no significant differences in the percentage of oocytes (stained with 13 μM BCB) reaching the MII stage in BCB+, BCB − and the control group (86, 72.5 and 80% respectively). After 17 h of IVF, the percentage of normal fertilisation (2PN) was significantly different (P<0.05) between the BCB+(40%) and BCB − groups (22%), and between BCB+ and controls (23%) selected with 13 μM BCB (Table 3).

The analysis of the cell number at day 8 post-insemination of all blastocysts produced in vitro from prepubertal sheep oocytes selected with 13 μM BCB is summarised in Table 4. BCB+ oocytes produced blastocysts with a significantly (P<0.001) higher number of cells than BCB − oocytes, 69.71±6.19 and 45.91±3.35 respectively. The ICM and TE cell number were significantly higher in BCB+ (18.82±1.77 and 50.88±5.06) than BCB − (12.55±1.12 and 33.36±3.16 respectively). The ICM:TE ratio was not significant between BCB selected groups (1:2.70 and 1:2.65 respectively).

Before maturation, the mean diameter of BCB + oocytes was 123.66±2.72 (±s.e.m.), significantly higher (P<0.0001) than BCB − (106.82±2.88). After 24 h of IVM, the BCB+ group maintained their diameter while BCB − showed a significant increase of 12 μm of the internal zona diameter (from 106.82±2.88 to 118.86±3.26 μm; P=0.006).

**Mitochondrial activity in prepubertal sheep oocytes selected by BCB**

Figure 1 shows representative images for the different mitochondrial distribution parameters. At the GV stage, 43.9% of oocytes presented homogeneous (Fig. 1B) and 56.1% showed peripheral (Fig. 1C) distribution. After maturation, 53.2% showed a homogeneous distribution while the peripheral distribution decreased up to 6.4%, the rest of the oocytes exhibited a polarised distribution (40.4%) marked by the position of active mitochondria around the metaphase spindle and polar body (Fig. 1D; P<0.001). No differences were found in mitochondrial distribution between BCB+ and BCB − oocytes.

Mitochondrial activity is represented in Fig. 2 by the analysis of the fluorescence intensity in oocytes prelabelled with the mitochondrial-specific probe. Our results indicate a relationship between mitochondrial activity, BCB oocyte status and maturation stage. Before IVM, BCB+ and BCB − oocytes showed no significant differences in mitochondrial activity between groups (2834±223.42 and 3519±288.48 AU respectively). After IVM, BCB − oocytes mitochondrial activity descened abruptly (from 3519±288.48 to 1565±113.8 AU; P<0.0001) while activity in the BCB+ group did not show any changes. Between matured BCB+ and BCB − oocytes, mitochondrial activity differed significantly (P<0.0001). Considering the overall oocytes and comparing mitochondrial activity at the GV and MII stages, we observed a decreasing activity during meiosis (3175±253.9 to 2385±233 AU ±s.e.m., respectively P<0.05).

**MPF activity in prepubertal sheep oocytes selected by BCB**

Results in MPF activity of oocytes with different cytoplasmic quality and stage of maturation assessed by CDC2 kinase activity are presented in Fig. 3. No differences were observed in MPF activity at collection

Table 2 Embryo development of prepubertal sheep oocytes selected with different Brilliant Cresyl Blue (BCB) concentrations.

<table>
<thead>
<tr>
<th>BCB concentration (μM)</th>
<th>Inseminated oocytes</th>
<th>Cleavage</th>
<th>Blastocyst</th>
<th>Inseminated oocytes</th>
<th>Cleavage</th>
<th>Blastocyst</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>107</td>
<td>85 (79)a</td>
<td>22 (21)A</td>
<td>204</td>
<td>128 (63)b</td>
<td>18 (9)b</td>
</tr>
<tr>
<td>26</td>
<td>114</td>
<td>77 (68)b</td>
<td>19 (17)A</td>
<td>192</td>
<td>122 (64)b</td>
<td>9 (5)</td>
</tr>
<tr>
<td>39</td>
<td>136</td>
<td>90 (66)b</td>
<td>14 (10)bc</td>
<td>202</td>
<td>145 (72)b</td>
<td>13 (6)a</td>
</tr>
<tr>
<td>52</td>
<td>123</td>
<td>86 (70)b</td>
<td>10 (8)b</td>
<td>207</td>
<td>120 (58)b</td>
<td>9 (4)a</td>
</tr>
</tbody>
</table>

Values in the same column (a,b,c) or row (A,B) with different letters differ significantly (Fisher test; P<0.05).

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time in BCB+ and BCB− oocytes (0.285±0.03 and 0.212±0.01 optical density (OD) respectively). After IVM, MPF showed a significantly (P<0.05) increased activity in BCB+ with respect to BCB− oocytes (1.479±0.09 and 1.184±0.05 OD respectively). In both cases BCB+ and BCB− oocytes showed a significantly (P<0.001) increasing MPF activity from the GV to the MII stage of maturation.

**Relative mRNA expression of ATP1A1, COX1, CPEB and S100A10 of BCB selected oocytes**

Figure 4 shows the relative expression (RE) of the four maturation gene candidates analysed by real-time PCR in relation to BCB status and IVM. No differences in gene expression were observed in relation to BCB classification. The only difference we found was in BCB+ oocytes that showed a significantly lower amount of S100A10 transcript after IVM (P<0.05).

**Discussion**

This study was carried out to determine the best concentration of BCB stain to select competent prepubertal sheep oocytes for in vitro embryo production and to analyse mitochondrial distribution and activity, MPF activity and changes in the RE of ATP1A1, COX1, CPEB and S100A10 as maturation gene candidates in those BCB selected oocytes.

In cows (Pujol et al. 2004, Alm et al. 2005), goats (Rodriguez-Gonzalez et al. 2002) and mice (Wu et al. 2007) the concentration of BCB stain with the best results was 26 µM BCB for 90 min, while in pigs 13 µM BCB was sufficient to increase sperm penetration of BCB+ oocytes (Roca et al. 1998, Egerszegi et al. 2010). In our work, we decided to work with 13 µM BCB for 60 min, as it was the most specific concentration, increasing blastocyst rate from 9% (BCB−) to 21% (BCB+). We considered BCB stain not to be detrimental for oocytes because no differences were found between treatments and the control group as described by Wongsrikeao et al. (2006) in pigs.

Oocyte diameter is a determinant factor for completion of meiosis and acquisition of full competence for embryo development (Lonergan et al. 1994, Crozet et al. 2000). In our work, we found that the BCB test was helpful in selecting larger oocytes with 123.66±2.72 µm diameter (BCB+) compared with those of 106.82±2.88 µm (BCB−). This confirmed previous reports in cattle (152.6 vs 147 µm; Pujol et al. 2004), goats (136.6 vs 125.5 µm; Rodriguez-Gonzalez et al. 2002) and pigs (113.08 vs 100.29 µm; Roca et al. 1998) for BCB+ and BCB− respectively. After IVM, we found a significant increase of 12 µm of the internal zona diameter in BCB− oocytes, while BCB+ oocytes maintained the same diameter after 24 h of in vitro culture. Oocyte quality is assessed by male pronuclear formation (2PN zygotes), blastocyst yield and blastocyst cell number. In this study, we have observed significantly higher 2PN zygote and blastocyst production in BCB+ than BCB− oocytes. This increase in 2PN zygote and blastocyst development has been shown in BCB+ oocytes of buffalo (Manjunatha et al. 2007), cattle (Pujol et al. 2004, Alm et al. 2005, Bhojwani et al. 2007, Torner et al. 2008), goats (Rodriguez-Gonzalez et al. 2002), mice (Wu et al. 2007) and pigs (Egerszegi et al. 2010).

Assessment of blastocyst cell number indicates that BCB+ oocytes produce blastocysts with a higher cell number than BCB−. In prepubertal goat oocytes, Romaguera et al. (2010, 2011) did not find differences in blastocyst quality, assessed by blastomere ploidy and cryptotolerance, between oocytes coming from different diameter follicles and between oocytes from adult and prepubertal goats, concluding that oocyte quality was positively related to blastocyst production but not to blastocyst quality. In cattle, Majerus et al. (2000) observed that the percentage of blastocysts obtained from calf oocytes was reduced in comparison with those from adult animals (26 vs 46%); however, the number of blastocyst cells was not different (89 and 100 respectively) and the ICM:TE ratio was similar (1:2.70 and

### Table 3

<table>
<thead>
<tr>
<th>Oocyte classification</th>
<th>Oocytes at MII (%)</th>
<th>Inseminated oocytes</th>
<th>Fertilised oocytes, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(13 µM BCB)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>80</td>
<td>68</td>
<td>16 (23)</td>
</tr>
<tr>
<td>BCB+</td>
<td>86</td>
<td>60</td>
<td>24 (40)</td>
</tr>
<tr>
<td>BCB−</td>
<td>72.5</td>
<td>64</td>
<td>14 (22)</td>
</tr>
</tbody>
</table>

Different letters (a,b) within are significantly different (Student’s t-test; P<0.05).

### Table 4

<table>
<thead>
<tr>
<th></th>
<th>Cell number (mean ± s.e.m.)</th>
<th>Percentage/total cells (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Total</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ICM:TE ratio</td>
</tr>
<tr>
<td>BCB+</td>
<td>24</td>
<td>69.71 ± 6.19a</td>
</tr>
<tr>
<td>BCB−</td>
<td>22</td>
<td>45.91 ± 3.35b</td>
</tr>
</tbody>
</table>

ICM, inner cell mass; TE, trophectoderm. Different letters (a,b) within are significantly different (Student’s t-test; P<0.05).
1:2.85 respectively). Selecting lamb oocytes according to the number of cumulus layers, Kelly et al. (2007) concluded that the percentage of day 8 blastocysts was affected by COC grade but the number of blastocyst cells was not significantly different (range 49.2–54.6 cells per blastocyst). To our knowledge, no studies on oocytes selected by BCB and embryo quality have been done. In this study, we have shown a positive relationship between BCB oocytes and the number of blastomeres per blastocyst.

Mitochondrial distribution and activity inside the oocyte could be a good marker of oocyte competence to develop to the blastocyst stage. The primary function of mitochondria is to generate ATP. Van Blerkom et al. (1995) described in human oocytes the relationship between ATP content and embryo developmental capacity where a transient decrease in ATP content can lead to embryo arrest. Therefore, these data suggest that mitochondrial activity is a determinant factor of quality and changes in mitochondrial activity can alter oocyte quality in a remarkable way. In cattle (Tarazona et al. 2006), horses (Torner et al. 2007), humans (Van Blerkom 2004) and pigs (Torner et al. 2004) an increase in mitochondrial activity after IVM was described. In cattle, Torner et al. (2008) observed higher mitochondrial activity in BCB− oocytes than in BCB+. These authors speculated that the reason for the increasing respiratory activity in low-quality oocytes was to provide ATP for still unfinished processes for cytoplasmic maturation. In pig oocytes, Egerszegi et al. (2010) found a higher mitochondrial activity in BCB+ compared with BCB− oocytes before IVM, but after IVM, no differences were found between either kind of oocyte. They attribute this to BCB+ oocytes increasing their respiratory activity to provide ATP for the energy-demanding processes of GVBD and the subsequent condensation of chromatin up to MII, while BCB− oocytes showed no changes in mitochondrial activity during meiosis and only a few of them reached MII stage. In our study with prepubertal sheep oocytes, we found a decrease in mitochondrial activity from the GV to the MII stage (3175 ± 253.9–2385 ± 233 AU ± S.E.M.). Analysing BCB+ and BCB− oocytes separately, we found that at the GV stage there were no differences in mitochondrial activity between groups. However, after IVM, BCB− oocytes showed a significant reduction in mitochondrial activity while BCB+ mitochondrial activity remained constant. This would indicate a positive relationship between mitochondrial activity at MII stage and embryo development.

Stojkovic et al. (2001) showed that mitochondrial reorganisation was different between morphologically good and poor quality oocytes. In our study, mitochondria migrated throughout the IVM process. Oocytes at the GV stage presented a homogeneous (43.9%) or peripheral (56.1%) mitochondrial distribution. After 24 h of IVM, MII oocytes presented a homogeneous (53.2%) distribution or mitochondria polarised around the metaphase spindle and inside the polar body (PB; 40.4%). We have previously shown (Velilla et al. 2006), in prepubertal goat IVM oocytes, that total mitochondria migrate from a cortical and perinuclear distribution in GV oocytes to a polarised distribution opposite the metaphase spindle and inside the PB (86%) after IVM, whereas ovulated adult goat oocytes presented a mitochondrial distribution inside the PB and aggregated to the metaphase spindle (Velilla et al. 2006) as we have found here in lamb oocytes. In pigs, Torner et al. (2004)
found that mitochondria moved from a homogeneous to a peripheral distribution; however, Brevini et al. (2005) showed a peripheral distribution in immature pig oocytes that became diffused after IVM. In our study, we did not find differences in mitochondrial distribution between BCB oocyte groups, while Egerszegi et al. (2010) concluded that, in pigs, BCB− oocytes showed more heterogeneous and non-aggregated mitochondrial distribution than BCB+ oocytes. Different authors have reported differences in mitochondrial distribution patterns among species, during IVM and in vivo maturation (Stojkovic et al. 2001, Sun et al. 2001, Torner et al. 2004, Velilla et al. 2006, Torner et al. 2007, Dell’Aquila et al. 2009, Egerszegi et al. 2010).

Previous studies showed that GV-oocytes do not present MPF activity (Dedieu et al. 1996) but, in our study, we detected MPF activity before IVM; this may be due to the BCB staining time. We presume that oocytes could restart meiosis and so they were in GVBD instead of GV when MPF analysis took place. After IVM, we observed significantly higher MPF activity in BCB+ oocytes than in BCB− oocytes. Salamone et al. (2001) reported that calf oocytes undergo cleavage and blastocyst production at significantly lower rates than cow oocytes and this was correlated to a lower activity of MPF in these oocytes. Closer to our study, comparing prepubertal and adult sheep oocytes, Ledda et al. (2001) showed that the low competence in prepubertal oocytes could be due to morphological anomalies and alterations in physiological activity due to the evidence of low MPF activity after IVM. Bogliolo et al. (2004) showed a higher MPF activity in in vivo matured oocytes than in in vitro matured cat oocytes, suggesting a possibly incomplete cytoplasmic maturation after culture. High MPF activity was observed by Anguita et al. (2007) in oocytes with larger diameter and better competence to develop to the blastocyst stage. In addition, MPF activity has also been related to an increase in developmental competence of oocytes treated with caffeine during nuclear transfer (Kawahara et al. 2005). In relation to mitochondrial and MPF activities analysed in this work, we could speculate that there is a positive relationship between the ATP produced by the active mitochondria and the ATP production needed to phosphorylate p34<sup>Cdc2</sup> and activate the MPF complex.

The genes analysed in this work were related to metabolism (ATP1A1 and COX1) and constitutive function of the cell (CPEB and S100A10). Oocytes selected by BCB did not show any differences in RE in any of the studied genes, in spite of the higher embryo development observed in BCB+ oocytes. However, in bovine oocytes, Opiela et al. (2010) found higher RE of the COX1 gene in immature BCB+ with respect to BCB− and Torner et al. (2008) showed a higher RE of S100A10 in matured BCB− than BCB+ oocytes. During IVM in prepubertal sheep oocytes, we found a significant decreasing mRNA RE in S100A10 in BCB+ oocytes.

In conclusion, exposing prepubertal sheep oocytes to 13 μM BCB for 60 min stains the largest and most competent oocytes to develop to the blastocyst stage. After IVM, the more competent oocytes (BCB+) presented higher mitochondrial and MPF activity with respect to BCB− oocytes. BCB+ oocytes produced blastocysts with higher numbers of cells than BCB− oocytes. Mitochondrial distribution and mRNA expression of ATP1A1, COX1, CPEB and S100A10 were not affected by oocyte quality.

Materials and Methods

Chemical

All chemicals were purchased from Sigma–Aldrich Chemical Co. unless otherwise specified.

Oocyte collection

Ovaries from prepubertal ewes (3–6 months old), were obtained from a local abattoir and transported to laboratory in sterile dulbecco’s (PBS) held at 34–37°C and were washed...
in PBS containing antibiotic–antimycotic (AB, Gibco cat. no. 14240-062). COCs were recovered by slicing the surface of the ovary in HEPES-buffered TCM-199 medium with 0.5 g/l fraction V BSA. Oocytes with two or more complete layers of compact cumulus cells and homogeneous cytoplasm were used.

**BCB test**

Immediately after collection, COCs were washed three times in mPBS (PBS supplemented with 1 g/l glucose, 36 mg/l sodium pyruvate, 0.5 g/l BSA and 0.05 g/l gentamicin) and exposed to different concentrations of BCB (13, 26, 39 and 52 μM) diluted in mPBS for 1 h at 38.5 °C in a humidified air atmosphere. After BCB incubation, oocytes were washed three times in mPBS and classified into two groups depending on their cytoplasm colouration: oocytes with blue cytoplasm or hypothetically grown oocytes (BCB+) and oocytes without blue cytoplasm colouration or hypothetically growing oocytes (BCB−).

**IVM of oocytes**

Groups of 35–40 COCs of BCB+, BCB− and control (oocytes not exposed to BCB stain), were washed and cultured for 24 h at 38.5 °C in a humidified air atmosphere with 5% CO2 in 500 μl of maturation medium covered with mineral oil. Maturation medium consisted of TCM-199 supplemented with 5 μg/ml LH, 5 μg/ml FSH, 1 μg/ml 17β oestradiol, 10 ng/ml epidermal growth factor, 0.2 mM sodium pyruvate, 2 mM glutamine, 100 μM cysteamine, 10% (v/v) fetal bovine serum (FBS) and 2% (v/v) AB.

**IVF and embryo culture**

Fresh semen, obtained from three rams of proven fertility, was kept at room temperature (25 °C) for 90 min (Ptak et al. 1999). Highly motile spermatozoa were selected by Ovipure density gradient (Nidacon EVB S.L., Barcelona, Spain) and fertilised with 1×106 spermatozoa/ml. Matured oocytes were partially denuded by gentle pipetting and transferred into fertilisation medium consisting of synthetic oviductal fluid (SOF; Holm et al. 1999). Fertilisation was carried out in drops of 50 μl of SOF medium supplemented with 10% of oestrous sheep serum with a maximum of 15 oocytes per drop and incubated for 20 h at 38.5 °C, 5% CO2 and 5% O2 in a humidified atmosphere.

After IVF, presumptive zygotes were completely denuded with gently pipetting and cultured in groups of six zygotes for 8 days in 20 μl culture drops consisting of SOF medium supplemented with 10% (v/v) FBS under the same atmospheric conditions.

**Blastocyst differential staining**

Blastocyst differential stain protocol was taken and modified from Thouas (2001). Briefly, 8-day-old blastocysts were first incubated for ~15 s or until TE visibly changed colour in solution 1 (PBS–BSA free with 1% Triton X-100 and 100 μg/ml propidium iodide). Immediately afterwards they were transferred to solution 2 (100% ethanol with 25 μg/ml Hoechst 33258) for 1 h.

Stained blastocysts were transferred from solution 2 directly to a glass with a drop of glycerol, taking care to avoid carrying over an excessive amount of solution, flattened with a coverslip and visualised under a microscope for cell counting. We used an Olympus BX50 with a u.v. lamp and excitation filter of 460 nm for blue and red fluorescence.

The intense pink colour represents the chromatins in nuclei of permeabilised TE cells that are stained both red (propidium iodide) and blue (Hoechst). ICM nuclei remain blue, because these cells have not been permeabilised.

**Oocyte diameter and nuclear stage of 13 μM BCB selected oocytes**

Oocyte diameter was measured after selection by the BCB test (0 h) and after IVM (24 h). Oocytes were denuded and fixed with 3% paraformaldehyde and mounted on poly-l-lysine-treated coverslips fitted with a self-adhesive reinforcement ring and then covered with a drop of Vectashield Mounting Medium (Vector Laboratories, Inc., Burlingame, CA, USA). Oocytes were measured (inside zona pellucida) by taking a picture under the microscope and analysed with MetaMorph imaging software (MetaMorph 6.2.6 Software, Universal Imaging Corporation).

To evaluate the nuclear and pronuclear stages, matured and fertilised (after 17 h of IVF) COCs were denuded as described before and fixed during 24 h in ethanol: acetic (3:1) and stained it with 1% lacmoid. Oocytes were considered correctly matured when they reached the MII stage and correctly fertilised when one sperm tail and 2 pronuclei (2PN) were visible, polyspermic when two or more sperm tails or more than 2 pronuclei (PS) were visible and asynchronous when only one pronucleus and a non-decondensed sperm were present.

**Mitochondrial activity of BCB selected oocytes**

Prepubertal sheep oocytes selected with 13 μM BCB at 0 and 24 h post IVM were totally denuded with gentle pipetting and incubated in mPBS with 3% (v/v) BSA containing 200 nM MitoTracker Orange CMTMRos (Molecular Probes, Inc., Eugene, OR, USA) under culture conditions for 60 min. The probe is readily sequestered only by active organelles depending on their oxidative activity. Immediately after staining, oocytes were washed three times in mPBS and fixed for 60 min at 38 °C in 3% paraformaldehyde. After fixation, oocytes were properly washed in PBS 0.1% (v/v) BSA and stained for 5 min in 1 μg/ml Hoechst 33342 solution. Finally, groups of ten oocytes were mounted on poly-l-lysine-treated coverslips fitted with a self-adhesive reinforcement ring and covered with a drop of Vectashield mounting medium. Slides were then sealed with nail varnish and stored at −20 °C protected from light for 6 days until their analysis under a confocal microscope.
Confocal analysis

A laser scanning confocal microscope (Espectral Leica TCS-SP5, Mannheim, Germany) was used to examine active mitochondria (MitoTracker Orange CMTMRos, excitation 554 nm) and chromatin (Hoechst; excitation 405 nm). The mitochondrial distribution pattern (representative images in Fig. 1) was characterised with 60× magnification under mineral oil and classified as homogeneous (fluorescence throughout the cytoplasm, Fig. 1B), peripheral (fluorescence in the cortex, Fig. 1C) or polarised (fluorescence near the MII spindle, Fig. 1D) according to mitochondrial distribution.

For mitochondrial intensity the microscope objective, pinhole, filters, offset, gain, pixels and laser potency were kept constant throughout the experiment. Twenty serial cuts of 1 μm each in the region of major intensity were performed. The 20 images of each oocyte were added in a unique picture and analysed with MetaMorph imaging software. To express the fluorescence intensity, we used arbitrary unit of the mean fluorescence intensity, which is defined as the sum of fluorescence intensity in grayscale of every pixel in the cytoplasm of the oocyte divided by the sum of all pixels of the same region.

MPF activity of BCB selected oocytes

Before and after IVM, groups of 20 oocytes BCB+, BCB− (three replicates) were washed three times in PBS, and placed in tubes containing 5 μl of lysis buffer (50 mM Tris–HCl, pH 7.5, 0.5 M NaCl, 5 mM EDTA, 0.01% Brij35, 1 mM PMSF, 0.05 mg/ml leupeptin, 50 mM 2-mercaptoethanol, 25 mM β-glycerophosphate and 1 mM Na-orthovanadate). The samples were frozen in liquid nitrogen and sonicated three times at 1 °C for 25 s. Cell extracts were stored at −80 °C until use.

CDC2 assay was performed by the MESACUP CDC2 kinase assay kit (MBL, Madrid, Spain) following the manufacturer's protocol. Oocyte extracts (5 μl each) were mixed with 10× CDC2 Reaction Buffer (25 mM Hepes buffer pH 7.5 and 10 mM MgCl2) and 10% biotinylated MV Peptide (SLYSPPGAYC). The phosphorylation reaction was started adding 0.1 mM ATP (Sigma–Aldrich), in a final volume of 50 μl. The mixture was incubated at 30 °C for 30 min. The reaction was finished by adding 200 μl of phosphorylation Stop Reagent (PBS containing 50 mM EGTA). The phosphorylated MV peptide was detected by ELISA at 492 nm and expressed as OD.

Real-time PCR quantification of ATP1A1, COX1, CPEB and S100A10 of BCB selected oocytes

Groups of 15 denuded prepubertal sheep oocytes (four replicates) stained with 13 μM BCB were taken at 0 and 24 h post IVM and stored at −80 °C in 100 μl Trizol (Invitrogen) until use. For RNA extraction, the addition of a known amount of luciferase (0.2 pg/μl, Promega) was added as an exogenous standard. To avoid contamination with genomic DNA, total RNA preparations were incubated during 10 min with RQ1 DNase (Promega) as described in the manufacturer's protocol.

Reverse transcription was performed by extended cDNA using Oligo (dt) 15 primers during 5 min at 70 °C and 1 h at 65 °C using reverse transcriptase. Relative quantitative PCR analysis was performed in MyiQ apparatus (Bio-Rad Laboratories). Samples were distributed in the plate by a robotic distributor (Eppendorf) and reactions were performed in duplicate using SYBR Green Fluorophore kit (Bio-Rad). Reactions were performed in 20 μl final volume (in duplicate) and PCR cycling conditions were 95 °C for 1 min followed by 40 cycles of denaturing (30 s, 95 °C), annealing (30 s, 60 °C) and elongation (20 s, 72 °C). The specificity of each PCR product was determined by a melting curve analysis and the amplicon size determination in agarose gels. For each gene, a standard curve was included, consisting of corresponding plasmid DNA fragments from 1 pg to 0.1 fg, purified with QIAquick PCR Purification Kit (Qiagen). Correlation coefficients and PCR efficiencies were considered between 85 and 100%. Primer sequences are listed in Table 5. The results for mRNA were normalised according to the relative concentration of the internal standard, luciferase and 18S.

Statistical analysis

Analysis among treatments (BCB stain, IVM and IVF) were performed by Fisher’s exact test. Blastocyst cell numbers were analysed by Student’s t-test. Gene and MPF analysis was performed by one-way ANOVA in GraphPad Prism v 3 (GraphPad Software, San Diego, CA, USA).

Table 5 Oligonucleotide primer sequences used in this study.

<table>
<thead>
<tr>
<th>Gene</th>
<th>Primer</th>
<th>Sequence 5′–3′</th>
<th>GenBank accession no.</th>
<th>Product size (bp)</th>
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<td></td>
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<td>Sense</td>
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<td></td>
</tr>
</tbody>
</table>

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The individual mitochondrial intensity (arbitrary unit) data were analysed as log10 to normalise them. Statistical analysis was conducted by PROC MIXED (with number of treatments as random parameter) of SAS (version 9.2 Inst., Inc., Cary, NC, USA) according to Tukey’s multiple comparison test. The statistical model contained the fixed effects of BCB (+ versus −) and maturation state (0 vs 24 h) and first-order interaction between BCB and maturation state and residual error. Differences were declared significant at \( P < 0.05 \).

Declaration of interest

The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

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References


Lamb oocyte competence selected by BCB 525

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