Up-regulation of rat myometrial phospholipases Cβ1 and Cβ3 correlates with increased term sensitivity to carbachol and oxytocin

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Abstract

In the present study, we compared rat uterine contractility and myometrial inositol phosphate (InsP) production in response to activation of muscarinic and oxytocin receptors during pregnancy and at term. The level of myometrial phospholipase (PL) Cβ was also determined by Western blotting at different stages of pregnancy and following administration of oestradiol, progesterone or vehicle. The results showed an increased potency of both agonists to induce contraction of the circular but not the longitudinal muscle. For both InsP production and contractile activity, the maximal response of CCh was unaltered, while that of OT was significantly increased. Interestingly, the increased responsiveness to CCh and OT was associated with an up-regulation of PLCβ1 and PLCβ3 enzymes. Such regulation is under the control of oestradiol since administration of this steroid to pregnant rats increased the amount of both enzymes by 200–260%. In contrast, progesterone administration was without effect. The present study presents the first evidence that the expression of rat myometrial PLCβ1 and PLCβ3 is under the positive control of oestradiol. This could participate in the enhancement of myometrial InsP accumulation and uterine contraction at term in response to CCh and OT. Based on contraction studies, we also propose that the longitudinal and circular uterine muscles differ in the regulation of the PLC pathway during pregnancy.

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Introduction

Phospholipase (PL) C, by hydrolyzing the membrane phosphatidylinositol 4,5-biphosphate into diacylglycerol and inositol 1,4,5-triphosphate (InsP₃), increase InsP₃-dependent liberation of Ca²⁺ from intracellular stores. The subsequent activation of myosin light chain kinase promotes the interaction between actin and myosin, thereby resulting in contraction. Among the large PLC family (11 genes), the four members of the PLCβ subfamily (PLCβ1, PLCβ2, PLCβ3 and PLCβ4) are activated by G protein-coupled receptors. PLCβ1 and PLCβ4 are only activated by the Gαi subunit whereas PLCβ2 and PLCβ3 are also sensitive to the Gβγ complex (Rebecchi & Pentyala 2000).

The PLC signalling pathway plays an important role in the regulation of uterine contractility. Indeed, contractant factors like oxytocin (OT), prostaglandins or norepinephrine utilize PLC-coupled receptors (OT receptors (OTR), prostaglandin F₂α receptors (FP) and α₁-adrenergic receptors (AR) respectively) to increase intracellular concentrations of Ca²⁺.

During pregnancy, these signalling pathways are silent due to the negative control exerted by progesterone. For instance, progesterone inhibits the expression of OTR, and FP (Larcher et al. 1995, Ou et al. 2000). Progesterone can also indirectly modulate the PLC signalling pathway by enhancing the expression of β-AR and their cognate Gαα protein (Vivat et al. 1992, Elwardy-Mérézak et al. 1994). It has been shown that the subsequently produced cAMP reduces myometrial inositol phosphate (InsP) production through phosphorylation of PLCβ by protein kinase A in the rat (Dodge et al. 1999). Activation of rat myometrial β-AR was also reported to reduce basal and agonist-stimulated InsP production during pregnancy through a cAMP-independent mechanism involving K⁺ channels (Khad et al. 1996, Mhaouty-Kodja et al. 2004). At term, the concomitant progesterone withdrawal and increase of oestradiol concentrations are thought to promote transcriptional activation of OTR and FP (Larcher et al. 1995, Ou et al. 2000). This results in enhanced phosphoinositide hydrolysis and uterine responsiveness to OT and prostaglandins (Goureau et al. 1992, Dodge et al. 1999).
Acetylcholine released from uterine parasympathetic nerves was also described to regulate rat uterine contractility through activation of muscarinic receptors (mRs) (Houdeau et al. 2003). However, its role in the initiation of labour remains a controversial question. Indeed, while some studies reported a declined sensitivity and maximal response to the muscarinic agonist carbachol (CCh) (Riemer et al. 1986), others have described an enhanced CCh-mediated generation of myometrial InsP at the end of pregnancy (Lajat et al. 1996). Characterization of myometrial mR revealed the presence of M2 and M3 receptor subtypes that couple to adenyl cyclase and PLC respectively (Lajat et al. 1996, Choppin et al. 1999). In contrast to the PLC-coupled receptors described above, no detectable changes in the density and properties of the M3 receptor were observed during the course of pregnancy (Lajat et al. 1996). In correlation with these data, oestradiol treatment did not affect the expression of M3 receptor in rat myometrial cells (Abdalla et al. 2004). However, we have previously shown that the expression of Gqα, the transducer protein that links mR and OTR to PLCβ, increases at the end of pregnancy (Cohen-Tannoudji et al. 1995). Furthermore, we recently described an up-regulation of rat myometrial PLCβ1 and PLCβ3 at term (Mhaouty-Kodja et al. 2004).

In the light of these findings, the present study was designed to evaluate the effect of CCh on myometrial InsP production and uterine contractile activity in pregnant and term rats. Uterine responses to OT, which utilizes the same signal pathway as mR to induce uterine contraction, were also determined. Finally, the effects of oestradiol and progesterone on the expression of rat myometrial PLCβ1 and PLCβ3 were evaluated.

**Materials and Methods**

**Animals and treatments**

Sprague–Dawley rats were obtained from Janvier (Le Genest, France). The females were caged with males overnight and successful mating was determined by the presence of spermatozoa in the vaginal smear (day 1 of pregnancy). Animals were killed by cervical dislocation on days 12, 15, 16 and 21 of pregnancy or at term during the expulsion of the fetoplacental units, in accordance with the guidelines for the care and use of laboratory animals (NIH Guide). The uterine horns were quickly isolated, cut open lengthwise and the fetoplacental units removed. The myometrium was then freed of adherent endometrium except for uterine tension studies.

Oestradiol-treated animals received subcutaneous injections of 0·5 ml olive oil containing 6 mg oestradiol (Sigma, L’Isle d’Abeau, France) at 1000 and 1600 h on day 15 of pregnancy and were killed by cervical dislocation at 1000 h the following day (day 16). Progesterone-treated rats received subcutaneous injections of 0·5 ml olive oil containing 5 mg progesterone (Sigma) on day 21 of pregnancy (1000 h) and were killed by cervical dislocation 30 h after injection (day 22). Control rats received the same volume of oil subcutaneously on the same schedule. The doses of progesterone and oestradiol administered significantly increased the myometrial levels of both steroids as we have determined in previous works (Elwardy-Mérézak et al. 1994, Cohen-Tannoudji et al. 1995).

**Isometric tension measurement**

Four millimetre long uterine strips were prepared from pregnant rats and mounted in organ baths containing 8 ml Krebs solution (144 mM NaCl, 6·2 mM KCl, 0·5 mM MgSO4, 1 mM NaH2PO4, 30 mM NaHCO3, 2·5 mM CaCl2 and 2·8 mM glucose, pH 7·4) bubbled with 95% O2/5% CO2 and warmed to 30 °C. Dependent on the orientation of the uterine strips in the organ bath, we measured isometric contractions of longitudinal muscle or circular muscle using a Bioscience UF1 tension transducer (Phymep, Paris, France) under 0·7 g resting force. A 30-min equilibration period was allowed before adding cumulative doses of CCh or OT (0·1 nM to 100 µM; Sigma). The concentration–response curves were recorded by computerized calculation of the integral under the tension/time curve for 3 min using Prism 4 software (Graph Pad, San Diego, CA, USA) for sigmoidal dose–response (non-linear regression fit). Isometric changes in tissue tension and maximal effects (Emax) are expressed as a percentage above the spontaneous activity in the absence of agonists, and potency as EC50.

**Myometrial InsP production**

InsP production was measured as previously described (Mhaouty-Kodja et al. 2001). Myometrial strips were incubated at 37 °C for 4 h with 7 µCi myo-[3H]inositol (10–25 Ci/mmol; Perkin Elmer Life Sciences, Paris, France) in 1 ml Krebs bicarbonate buffer (117 mM NaCl, 4·7 mM KCl, 1·1 mM MgSO4, 1·2 mM KH2PO4, 24 mM NaHCO3, 0·8 mM CaCl2 and 1 mM glucose, pH 7·4) in the presence of 95% O2/5% CO2. Increasing concentrations of CCh or OT (0·1 nM to 100 µM) were added after 10–min incubation of myometrial strips with 10 mM LiCl (Sigma) in Krebs bicarbonate buffer. Assays were stopped 15 min later by freezing the strips in liquid N2.

Strips were homogenized in 7% trichloroacetic acid and the supernatant obtained was extracted with diethyl ether, neutralized with Tris–base and then chromatographed over anion–exchange resin (AG1-X8; Bio-Rad Laboratories, Marnes-la-Coquette, France). Total InsP eluted with 1 M ammonium formate/0·1 M formic acid was counted by liquid scintillation in a 1214 Rack-beta spectrometer (LKB, Turku, Finland) for tritium.
Western blot analysis

Rat myometrium was homogenized in 0.5 mM EDTA and 10 mM Tris pH 7.4 supplemented with a cocktail of protease inhibitors (Sigma). After centrifugation at 4 °C, supernatants were collected and submitted to 100 000 g centrifugation at 4 °C for 1 h to separate plasma membranes from cytosol. Protein concentration of cytosolic fraction was determined according to Bradford (1976) with bovine serum albumin as standard. Samples were stored at −80 °C until use.

Twenty micrograms of proteins were subjected to SDS-PAGE in 7.5% gels and transferred to polyvinylidene difluoride membranes (Perkin Elmer Life Sciences). The blots were blocked overnight at 4 °C in Tris-buffered saline containing 5% non-fat dried milk, and incubated for 1 h at room temperature with polyclonal anti-PLCβ (Santa Cruz Biotechnology, Santa Cruz, CA, USA) diluted 1:500. Incubation with peroxidase-conjugated goat anti-rabbit antibody (Jackson ImmunoResearch, West Grove, PA, USA) diluted 1:10 000 was carried out for 45 min at room temperature. Immunoreactive bands were visualized by the chemiluminescence detection system (Amersham Pharmacia Biotech, Les Ulis, France) and quantified. The quantification of PLCβ expression was determined by densitometric scanning followed by computer analysis using the NIH image 1.62 program.

Statistical analysis

Results are expressed as means ± S.E.M. Statistical significance was assessed by Student’s t-test for unpaired data. P values less than 0.05 were considered significant.

Results

Uterine contraction in response to CCh and OT in pregnant and term rats

We compared rat uterine activity in response to CCh and OT on day 15 of pregnancy and at term. For this, we measured isometric contractions of the longitudinal and circular muscles depending on the orientation of the uterine strips in the organ bath as described in Materials and Methods. All uterine strips exhibited spontaneous rhythmic contractions a few minutes after being mounted in the bath (data not shown). Addition of increasing concentrations of CCh or OT dose dependently enhanced the activity of the circular and longitudinal uterine muscles (Figs 1 and 2). This indicated the presence of functional mRs and OTRs in both myometrial layers during pregnancy and at term. In the circular muscle, EC50 values for CCh and OT were respectively sevenfold and sixfold decreased at term when compared with day 15 of pregnancy, indicating that both agonists were more potent at inducing contraction at term (P<0.05; Fig. 2a and b and Table 1). The Emax to CCh was not significantly different between pregnant and term rats (Fig. 2a) whereas that of OT was increased by 100% at term (P<0.05; Fig. 2b). In the longitudinal muscle, no major changes in the potency and maximal response of CCh were observed between day 15 of pregnancy and term (Fig. 2c and Table 1). For OT, a significant increase in the Emax was seen only at 1 µM
concentration ($P<0.05$; Fig. 2d) while a twofold decrease of the EC$_{50}$ occurred at term ($P<0.05$; Table 1).

The responsiveness of the circular muscle to CCh and OT was therefore increased at term. To assess whether this correlates with changes in mRs and OTR signalling pathways, we compared myometrial InsP responses to CCh and OT between day 15 of pregnancy and at term.

### Basal and agonist-stimulated InsP production in pregnant and term rat myometrium

We incubated myometrial strips from pregnant and term rats in the absence or presence of increasing concentrations of CCh or OT. At term, basal InsP production was augmented by 72% ($9325 \pm 351$ c.p.m./100 mg tissue on day 15 of pregnancy versus $16 053 \pm 812$ c.p.m./100 mg tissue at term; $P<0.0001$). In order to evaluate the net responses due to the specific activation of mRs or OTRs, agonist-stimulated InsP production was therefore expressed as percent of basal. Results illustrated in Fig. 3 show that CCh and OT increased InsP production dose dependently on both day 15 of pregnancy and at term. The EC$_{50}$ values for both agonists were significantly lower at term when compared with day 15 ($P<0.05$; Table 1) as evidenced by the leftward shift in the dose–response curves (Fig. 3). The $E_{\text{max}}$ for CCh was unaltered at term while a 50% increase occurred for OT ($P<0.05$; Fig. 3). It is therefore interesting to note that total myometrial InsP responses correlated well with contractile activity of the circular muscle, thereby suggesting that the important changes in CCh and OT responses between pregnancy and term occur in this muscle layer.

### Quantification of rat myometrial PLCβ1 and PLCβ3 during pregnancy

In contrast to OTR, the density of myometrial PLC-coupled M$_3$ receptor is unchanged during the course of pregnancy in the rat (Lajat et al. 1996). The increased uterine sensitivity to CCh might thus be related to changes occurring downstream of mRs. We recently showed that the amount of myometrial PLCβ1 and PLCβ3 is greatly increased in term rats versus day 15 of pregnancy (Mhaouty-Kodja et al. 2004). Interestingly, the level of their cognate Gq$_{11}$ protein is also increased at the end of pregnancy as we have previously reported (Cohen-Tannoudji et al. 1995). To verify whether the pattern of myometrial PLCβ expression correlates with that of Gq$_{11}$ protein, we therefore extended our immunodetection analysis of PLCβ isozymes to different days of pregnancy. Since PLCβ1 and PLCβ3 are highly enriched in the cytosolic compartment of pregnant and term rat myometrium (Mhaouty-Kodja et al. 2004) all the subsequent studies focused on the cytosolic expression of both enzymes.

By using specific antibodies, we detected 150 kDa signals corresponding to PLCβ1 and PLCβ3 in pregnant and term rat myometrium as previously reported (Mhaouty-Kodja et al. 2004). Figure 4 shows that the level of both proteins was very low on days 12 and 15 of pregnancy and increased by 300% at term ($P<0.05$). An interesting finding was that the up-regulation of PLCβ1 and PLCβ3 was maximal from day 21 of pregnancy (Fig. 4). It thus appears that, as for many contraction-associated proteins, the up-regulation of PLCβ isozymes takes place before term, during uterine preparation to labour. Since this period is characterized by important changes in the steroid hormone environment, we assessed whether progesterone and/or oestradiol modulate the expression of rat myometrial PLCβ1 and PLCβ3.

#### Table 1 EC$_{50}$ values for contractile activity of the circular and longitudinal muscles and myometrial InsP production elicited by CCh and OT on day 15 of pregnancy and at term.

<table>
<thead>
<tr>
<th></th>
<th>CCh (µM)</th>
<th>OT (nM)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Day 15</td>
<td>Term</td>
</tr>
<tr>
<td>Contraction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Circular muscle</td>
<td>20 ± 5</td>
<td>3 ± 0.9*</td>
</tr>
<tr>
<td>Longitudinal muscle</td>
<td>2.6 ± 0.3</td>
<td>1.5 ± 0.5</td>
</tr>
<tr>
<td>InsP production</td>
<td>2.3 ± 0.9</td>
<td>0.004 ± 0.001*</td>
</tr>
</tbody>
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$aP<0.05$ compared with day 15 of pregnancy.

Figure 3 InsP production of myometrial strips from rats on day 15 of pregnancy and at term in response to (a) CCh and (b) OT. Results are expressed as percent of basal InsP production and are means ± S.E.M. of four to five independent experiments. *$P<0.05$ versus the same concentration on day 15 of pregnancy.
The effects of progesterone and oestradiol on rat myometrial PLCβ1 and PLCβ3 expression

To determine whether sex steroids regulate the expression of rat myometrial PLCβ1 and PLCβ3, pregnant rats received subcutaneous injections of progesterone or oestradiol. The days of steroid administration were chosen on the basis of our previous studies where myometrial concentrations of progesterone and oestradiol were determined during the course of pregnancy (Elwardy-Mérézak et al. 1994, Cohen-Tannoudji et al. 1995). Progesterone and oestradiol were thus delivered to rats when their myometrial endogenous levels are low, i.e. day 21 of pregnancy for progesterone and day 15 of pregnancy for oestradiol.

Immunoblotting studies illustrated in Fig. 5 show that progesterone failed to alter the level of rat myometrial PLCβ1 and PLCβ3, which remained similar to that determined on day 21 of pregnancy (98 ± 2% and 107 ± 18% of day 21 in progesterone-treated rats for PLCβ1 and PLCβ3 respectively). In contrast, oestradiol administration increased the amount of PLCβ1 to a level similar to that observed on day 21 of pregnancy as shown in Fig. 6a and b (+260% above day 15 of pregnancy in oestradiol-treated rats; P<0.05). Such treatment also increased the level of PLCβ3 (+200% above day 15 of pregnancy in oestradiol-treated rats; P<0.05) (Fig. 6c and d). In control rats receiving oil, the levels of PLCβ1 and PLCβ3 did not change from the values determined on day 15 of pregnancy.

These data revealed, for the first time, that the expression of rat myometrial PLCβ1 and PLCβ3 is under the control of oestradiol. The oestradiol-dependent up-regulation of both enzymes at the end of pregnancy, together with the increased amount of Gqα protein, could underlie the enhanced uterine sensitivity to CCh and OT near term.

Discussion

The present study reports the first comparison of CCh- and OT-induced uterine activity and myometrial InsP production between pregnant and term rats. Our results

Figure 4 Quantification of amounts of rat myometrial PLCβ1 and PLCβ3. (a and c) Representative Western blots for 150 kDa PLCβ1 and PLCβ3 on days 12, 15 and 21 of pregnancy and at term. (b and d) Quantitative data are expressed as percent of term. Values are means ± S.E.M. of three to four independent experiments. *P<0.05 versus term or day 21 of pregnancy.

Figure 5 The effect of progesterone on rat myometrial PLCβ1 and PLCβ3 expression. (a and c) Representative Western blots for PLCβ1 and PLCβ3 on days 15, 21 or 22 of pregnancy after administration of progesterone or vehicle. (b and d) Quantitative data are expressed as percent of day 21 of pregnancy. Values are means ± S.E.M. of three independent experiments. *P<0.01 versus day 21 of pregnancy. ns, not significant.

Figure 6 The effect of oestradiol on rat myometrial PLCβ1 and PLCβ3 expression. (a and c) Representative Western blots for PLCβ1 and PLCβ3 on days 15, 21 or 16 of pregnancy after administration of oestradiol or vehicle. (b and d) Quantitative data are expressed as percent of day 15 of pregnancy. Values are means ± S.E.M. of four experiments. *P<0.05 versus day 15 of pregnancy. ns, not significant.
showed that the potency of CCh to induce both uterine contraction and InsP production increases at term. At this time, it is interesting to note that the EC50 value calculated for CCh-induced uterine contraction was similar to that reported in cyclic oestrous rats (Houdeau et al. 2003), i.e. following oestrogen impregnation. Furthermore, it was observed that administration of oestradiol to non-pregnant rats resulted in a sharp decrease in the EC50 value for CCh-induced uterine contraction (Abdalla et al. 2004), similar to that observed in our study between pregnancy and term. Because an abrupt increase in plasma and myometrial oestrogen occurred at the onset of parturition, we suggest that the mR signalling pathway is influenced by changes in the hormonal status between day 15 of pregnancy and term. The higher potency of CCh to increase InsP accumulation and uterine contraction thus occurs when the uterus is under oestrogen dominance. In contrast to a previous report (Lajat et al. 1996), we found no major changes in the ability of mRs to trigger a maximal InsP production between pregnancy and term. This discrepancy is probably due to the presently observed enhancement (+72%) in basal levels of myometrial InsP accumulation at term, which was taken into account in our studies to determine the specific effects of CCh. Moreover, our contraction studies confirmed that no changes in the Emax for CCh occur between pregnancy and term. In similar experimental conditions, we found that both uterine sensitivity and maximal response to OT were increased at term, which is in agreement with previous reports (Riemer et al. 1986).

Rat myometrial M3 receptor and OTR are differently sensitive to sex steroids. Indeed, while OTR is down-regulated by progesterone during pregnancy and up-regulated by oestradiol near term (Larcher et al. 1995), the density of rat myometrial M3 subtype remains unchanged throughout pregnancy (Lajat et al. 1996). Furthermore, neither ovariectomy nor oestradiol treatment affected the density of rat myometrial M3 subtype (Choppin et al. 1999, Abdalla et al. 2004). The increased potency of CCh to induce InsP production and uterine contraction at term is therefore probably related to changes occurring downstream of the M3 receptor, at the level of G protein and/or PLCβ enzymes. In many physiological and cellular models, M3 receptor was shown to couple to both PLCβ1 and PLCβ3 via activation of the Gqα protein (Kim et al. 1997, Piiper et al. 1997, Strassheim & Williams 2000). Interestingly, we have recently shown that among the three PLCβs (PLCβ1, PLCβ3 and PLCβ4) predominantly expressed in pregnant rat myometrium PLCβ3 is increased at mid-pregnancy while PLCβ1 and PLCβ3 are up-regulated at term (Mhaouty-Kodja et al. 2004). Furthermore, the pattern of PLCβ1 and PLCβ3 expression correlates well with that of their cognate Gqα protein. Indeed, we have previously reported a 120% increase in the amount of rat myometrial Gqα protein between day 12 of pregnancy and term (Cohen-Tannoudji et al. 1995). In addition, as for PLCβ1 and PLCβ3, the amount of Gqα protein is maximal from day 21 of pregnancy (Cohen-Tannoudji et al. 1995).

From all these data we can conclude that the increased uterine sensitivity to CCh depends on changes occurring downstream of the mR while uterine hypersensitivity to OT involves up-regulation at both the OTR and post-OTR levels. First, this provides an explanation for the selective increase of the maximal response to OT stimulation at term. Secondly, it suggests that, for a given receptor, amelioration of affinity towards agonists requires an increased availability of G protein and effectors, whereas an enhancement of maximal response requires a further increase of receptor expression level.

The current study provides the first evidence that PLCβ1 and PLCβ3 are targets of oestradiol. Indeed, up to date, only corticoids were reported to regulate the expression of PLCβ enzymes (Dwivedi & Pandey 1999, Cueille et al. 2003). Furthermore, although oestradiol was suggested to facilitate norepinephrine-, CCh- and OT-induced PLC activation at a post-receptor level in the myometrium (Riemer et al. 1987, Phaneuf et al. 1995, Abdalla et al. 2000, 2004), no studies have addressed its direct effect on PLCβ expression. Our findings indicated that administration of oestradiol to rats triggers the expression of myometrial PLCβ1 and PLCβ3 to a level normally observed between day 21 of pregnancy and term. This treatment thus anticipates the PLCβ1 and PLCβ3 increase that occurs at the end of pregnancy, probably following the enhancement of the oestrogen:progesterone ratio. Our results also indicated that, under our treatment conditions, myometrial PLCβ1 and PLCβ3 are insensitive to progestosterone. Using a similar protocol, we have previously reported that progesterone significantly reduces the expression of rat myometrial Gqα (Cohen–Tannoudji et al. 1995).

Together, these data add a supplemental step in the regulation of rat myometrial InsP production and thus uterine contraction by sex steroids. It appears then that progesterone and oestradiol not only regulate the expression of receptors like OTR and FP specifically but also act on transduction entities common to different receptors, i.e. Gqα protein and PLCβ enzymes. During pregnancy, down-regulation of Gqα by progesterone (Cohen-Tannoudji et al. 1995) associated with low levels of PLCβ1 and PLCβ3 (Mhaouty-Kodja et al. 2004, the present study) may participate in the prevention of uterine activation. At term, the increased expression of Gqα and PLCβ1 and PLCβ3 due to progesterone withdrawal and oestrogen increase respectively may underlie the enhancement of uterine responsiveness to uterotonic factors. In myometrium, the expression of many proteins including OTR, connexin-43, cyclo-oxygenase 2 and GIIα protein was shown to be regulated at the translational level by oestradiol (Larcher et al. 1995, Lefebvre et al. 1995, Cohen-Tannoudji et al. 1995, Wu et al. 1997). Whether
or not oestradiol controls the expression of PLCβ1 and PLCβ3 at the transcriptional or post-transcriptional level remains to be determined. Analysis of the recently cloned promotor sequence of human PLCβ1 (Peruzzi et al. 2002) and rat PLCβ3 (Kang et al. 1997) did not reveal the presence of any known oestrogen-response element. However, it is now clearly established that oestrogens can also control the expression of target genes indirectly through association of their receptors with transcription factors such as Sp1 or AP-1 (Klinge 2001). Interestingly, multiple binding sites for these factors were identified in the 5′-promoter regions of PLCβ1 and PLCβ3 (Kang et al. 1997, Peruzzi et al. 2002).

Our contraction studies have shown that the sensitivity of the circular but not the longitudinal muscle to CCh and OT increases at term. It is of interest that InsP accumulation measured in the whole myometrium also rises at this time, thereby suggesting that the underlying changes in the expression of OTR, Gqα, PLCβ1 and PLCβ3 occur mainly in the circular muscle. In keeping with this hypothesis, the regulation of OTR by progesterone appears to be restricted to the circular muscle (El Alj et al. 1993). Indeed, this muscle layer contains fivefold less OTR (Kitazawa et al. 2001) and is less sensitive to OT than the longitudinal muscle at mid-pregnancy (Mhaouty-Kodja et al. 2004). In addition, rat α1-ARs, which are selectively expressed in the circular muscle (Legrand et al. 1991, Mhaouty-Kodja et al. 2004), are also less potent to induce Gqα-mediated PLC activation during pregnancy (Limon-Boulez et al. 1997). We therefore propose that, during pregnancy, progesterone maintains quiescence of the uterine circular muscle through direct down-regulation of the PLC signalling molecules (OTR and Gqα). In the longitudinal muscle, progesterone might act indirectly on the PLC system through sensitization of the β-adrenergic signalling pathway (Vivat et al. 1992, Elwardy-Mérézak et al. 1994). Activation of rat β-ARs, which are selectively localized in this muscle layer (Legrand et al. 1991), significantly decreases myometrial InsP production through both cAMP-dependent and -independent mechanisms (Khac et al. 1996, Dodge et al. 1999, Mhaouty-Kodja et al. 2004). At the end of pregnancy, progesterone withdrawal and the subsequent β-AR desensitization (Cohen-Tannoudji et al. 1991) probably relieve the PLC system from inhibitory constraints in the longitudinal muscle. Concomitantly, the increase in oestradiol concentrations enhances transcription of the transduction entities involved in the PLC signalling pathway (OTR, PLCβ1 and PLCβ3) in the circular muscle. Further studies are required to verify this hypothesis in order to enhance our understanding of the regulatory mechanisms underlying the contractile responses of the longitudinal and circular muscles of the uterus.

In summary, we report that the potency of CCh and OT to induce rat uterine contraction and myometrial InsP production increases at term. Interestingly, this correlates well with the up-regulation of myometrial PLCβ1 and PLCβ3 at this time. This could, together with the previously reported up-regulation of Gqα protein, participate in switching the rat uterus from a quiescent to an active state. The expression of both PLCβ1 and PLCβ3 is under the positive control of oestradiol and seems to be insensitive to progesterone. We also report that changes in uterine responsiveness to CCh and OT occur mainly in the circular muscle, thereby suggesting differences in the mechanisms underlying the regulation of the PLC system during the course of pregnancy between the longitudinal and circular muscles.

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