Cannabinoids stimulate prostaglandin production by human gestational tissues through a tissue- and CB1-receptor-specific mechanism

Murray D. Mitchell, Timothy A. Sato, Anderson Wang, Jeffrey A. Keelan, Anna P. Ponnampalam, and Michelle Glass

Liggins Institute and Department of Pharmacology and Clinical Pharmacology, University of Auckland, Auckland, New Zealand

Endocannabinoids; prostaglandin; placenta; amnion; chorion; decidua

Endocannabinoids have been implicated in the mechanisms of implantation, maintenance of pregnancy, and parturition in women. Intrauterine prostaglandin production and actions are also critical in each of these mechanisms. Hence, we have evaluated the effects of cannabinoids on prostaglandin biosynthesis by human gestational membranes. Explants of term amnion and chorio-decidua were established and treated with the endogenous endocannabinoids 2-arachidonoyl glycerol and anandamide, as well as the synthetic cannabinoid CP55,940, to determine their ability to modulate PGE2 production. The explants were also treated with CP55,940 in the presence of either SR141716A (a potent and selective antagonist of the cannabinoid receptor CB1) or NS398 [a cyclooxygenase (COX)-2 inhibitor] to determine whether any observed stimulation of PGE2 production was mediated through the CB1-receptor and/or COX-2 activity. All three cannabinoids caused a significant increase in PGE2 production in the amnion but not in the chorio-decidua. However, separated fetal (chorion) explants responded to cannabinoid treatment in a similar manner to amnion, whereas maternal (decidual) explants did not. The enhanced PGE2 production caused by CP55,940 was abrogated by cotreatment with either SR141716A or NS398, illustrating that the cannabinoid action on prostaglandin production in fetal membranes is mediated by CB1 agonism and COX-2. Data from Western blotting show that cannabinoid treatment results in the upregulation of COX-2 expression. This study demonstrates a potential role for endocannabinoids in the modulation of prostaglandin production in late human pregnancy, with potentially important implications for the timing and progression of term and preterm labor and membrane rupture.

MATERIALS AND METHODS

Patients and consent. Placentas were obtained from women undergoing a Caesarean section at term before the onset of labor because of prior Caesarean section or cephalo-pelvic disproportion. All women gave informed consent for the use of their placentas as approved by the local human ethics committee.

Materials. DME-199 and Ham’s/F-12 culture media were obtained from Irvine Scientific (Santa Ana, CA). FCS and streptavidin-alkaline phosphatase were purchased from Invitrogen (Auckland, New Zealand). Bovine γ-globulin and LPS (serotype 055:B5) were purchased from Sigma Chemical (St. Louis, MO). 2-AG and AEA were purchased from Cayman Chemicals (Ann Arbor, MI), and the synthetic THC analog CP55,940 was from Tocris Cookson (Bristol, UK). SR141716A was provided by Research Biochemicals as part of the chemical synthesis program of the National Institute of Mental Health (contract NO1-MH-30003). Tritiated PGE2 was purchased from Amersham-Pharmacia Biotech (Aylesbury, UK). NS398 was purchased from Cayman Chemicals.

Explant culture. After the amnion was manually removed, chorio-decidual membranes were washed carefully in medium to remove residual red blood cells without causing damage to the integrity of the membrane. Tissue explants (6-mm disks) were excised with a cork borer as described previously (22). In some experiments, the decidua and chorion were further separated. The decidua was removed using glass slides until the semitransparent chorion remained. Explants were

The costs of publication of this article were defrayed in part by the payment of page charges. The article must therefore be hereby marked "advertisement" in accordance with 18 U.S.C. Section 1734 solely to indicate this fact.

Address for reprint requests and other correspondence: M. D. Mitchell, Liggins Institute, Univ. of Auckland, Private Bag 92019, Auckland, New Zealand (e-mail: m.mitchell@auckland.ac.nz).
pooled and randomly distributed into 12-well plates (3 explants per well; 3 wells per treatment) containing medium supplemented with 10% FCS and antibiotics. The explants were allowed to equilibrate overnight at 37°C in a humidified atmosphere of 5% CO2-95% air. The following day, media were replaced with serum-free media containing 0.1% bovine γ-globulin and antibiotics. Explants were then treated with the various test substances or the appropriate vehicle control. After an additional 24 h, media were collected and prostaglandin production rates were derived and normalized to the wet weight of the explants in the individual wells.

**Immunoassay.** PGE2 production was determined using RIA as described previously (10) using an antiserum generated in our laboratory. The lower limit of sensitivity for the assay is 0.76 pg/ml, and all samples tested were within the range of the standard curve (0–5,000 pg/ml).

**Data presentation and statistics.** Prostaglandin production rates, calculated as picograms per milligrams of wet weight per 24 h, are represented as a percentage of control for each experiment (mean ± SE). Results are pooled data from multiple experiments performed in triplicate. Statistical significance was determined by ANOVA followed by Dunnett’s test. A P value <0.05 was considered to be significant.

**RESULTS**

**Effects of cannabinoids on PGE2 production by human amnion explants.** Results presented in Fig. 1A demonstrate the effects of endocannabinoids (AEA and 2-AG) and a synthetic cannabinoid ligand (CP55,940) on PGE2 production by human amnion explants. Both the endogenous endocannabinoids (30 μM) as well as the synthetic cannabinoid (1 μM) stimulated a statistically significant increase in PGE2 production. CP55,940 exerted a significantly greater effect than either AEA or 2-AG.

To determine whether the cannabinoid-mediated stimulation of PGE2 production is mediated through the CB1 receptor, we treated explants with CP55,940 alone (1 μM) and in the presence of SR141716A (0.1 μM), a potent and selective antagonist of the CB1 receptor (19). CP55,940 induced a severalfold increase in PGE2 production that was abolished by SR141716A (Fig. 1B). By itself, SR141716A (10⁻¹⁰–10⁻⁶ M) had no effect on amnion PGE2 production.

**Effecs of endocannabinoids on choriodecidual PGE2 production.** Neither 2-AG, AEA, nor CP55,940 had a statistically significant effect on PGE2 production by human choriodecidual explants (Fig. 2A). However, when the membranes were separated into isolated chorion and decidual explants (Fig. 2B), 2-AG, AEA, and CP55,940 all exerted significant stimulatory effects on PGE2 production.
effects on PGE$_2$ production by chorionic (fetal) tissue but not by decidual (maternal) explants. Indeed, AEA significantly reduced PGE$_2$ production by decidual tissue (Fig. 2B).

**Effect of the cyclooxygenase-2 inhibitor NS398 on cannabinoid-induced PGE$_2$ production.** To determine whether cannabinoid-induced PGE$_2$ production occurs through the cyclooxygenase (COX)-2 pathway, we treated explants with CP55,940 alone and in the presence of NS398 (20 μM), a COX-2 inhibitor. We observed that the enhanced PGE$_2$ production caused by CP55,940 was abrogated by cotreatment with NS398 in both amnion (Fig. 3A) and chorion (Fig. 3B) explants. NS398 treatment alone did not have any significant effect on the basal level of PGE$_2$ production in the explants.

**Effect of CP55,940 on the protein expressions of COX-2, COX-1, and cytosolic PGE synthase.** The effect of CP55,940 on the protein levels of COX-2, COX-1, and cytosolic PGE synthase was determined by Western blotting. COX-2 expression was induced by CP55,940 treatment (Fig. 4). However, no differences in the levels of COX-1 and cytosolic PGE synthase protein expression were observed between treatment groups.

**DISCUSSION**

We have demonstrated for the first time that endocannabinoids acting via CB1 receptors stimulate increased fetal membrane production of PGE$_2$. This is a critical event in the mechanisms of labor at term and preterm. The tissue specificity for fetal tissues and not the adjacent maternal decidua is intriguing. Our data also imply that the upregulation of PGE$_2$ synthesis by cannabinoids is caused through the induction of COX-2. The most exciting finding, however, is that the CB1 receptor may present a new therapeutic target for the treatment of preterm labor.

The events that initiate the onset of labor involve increased local production of prostaglandins (2). The amnion is considered the most important tissue in this regard, being the most abundant source of PGE$_2$, whereas the chorion as the major site of expression of the prostaglandin-metabolizing enzyme 15-hydroxyprostaglandin dehydrogenase (PGDH) is significant with respect to metabolic inactivation of prostaglandins. Results presented in this study strongly indicate that endogenous endocannabinoids may contribute to the production of prostaglandins by human fetal membranes. Interestingly, this effect does not appear to be manifested in the adjacent maternal (decidual) membrane, suggesting that the effects observed represent a fetal, but not maternal, response. The decidua has been shown to be responsive to CB1 agonism, although the effects observed on decidual formation were inhibitory (11). It has been shown that the plasma levels of AEA in women in labor at term are increased dramatically compared with those not in labor (2.5 ± 0.22 vs. 0.68 ± 0.09 nM; Ref. 7). While it is not known whether concentrations within the amniotic cavity and fetal membranes are also increased, it is tempting to speculate that elevated endocannabinoid concentrations at or during labor may be involved in driving increased prostaglandin production by the fetal membranes at this time.

The concentration of the endocannabinoids used in this study were high but in line with those used by others (3, 20).
Concentration-dependency experiments indicated that 10−30 μM was the optimal concentration to observe increased PGE2 production by the amnion explants (data not shown). The physiological concentration of the endocannabinoids present in human gestational tissue remains unknown. The concentrations required to produce a robust response may be influenced by the ability of endocannabinoids to penetrate the tissue, as these studies were performed in intact explants. The permeability issue in conjunction with the endocannabinoids propensity to stick to plastic raises the possibility that the effects that we observed may be a result of much lower endocannabinoids concentrations than were originally added to the culture media.

We have previously shown that the CB1 and CB2 receptors are present in both early and late human gestational tissues (8, 17). The CB1 receptor is present in all layers of the fetal membranes, with particularly strong expression in the amnionic epithelium and reticular cells, and cells of the decidua. Data from the present study imply that the effect of endogenous cannabinoids on prostaglandin production in placenta is mediated predominantly through CB1 and involves COX-2 induction. This is in agreement with the study by Dennedy et al. (4), which clearly demonstrated a CB1-mediated effect of endocannabinoids on human pregnant myometrium. The ability of the synthetic cannabinoid CP55,940 to stimulate PGE2 production via COX-2 induction in a CB1-receptor-dependent manner has been shown previously in guinea pigs (24). COX-2 induction by endocannabinoids has also been demonstrated (9, 18). In addition to breakdown into arachidonic acid, AEA and 2-AG can also be metabolized by COX into prostaglandin ethanolamides and prostaglandin glycerols, respectively (12, 27). We have previously demonstrated that PGE2-ethanolamide cross-reacts significantly in our PGE2 RIA, raising the possibility that the increased PGE2 production measured may reflect endocannabinoid conversion to prostamides (6). However, since CP55,940 is structurally unrelated to arachidonate, prostamide cross-reactivity cannot explain the stimulatory ability of this ligand.

In addition to the upregulation of biosynthesis via increased COX expression and activity, prostaglandin concentrations can also be regulated by metabolism. A reduction of chionic PGDH activity and expression has been demonstrated in association with preterm birth, particularly in pregnancies with intrauterine infection (23). While the effects of cannabinoids on chonic PGE2 production could theoretically be due to inhibition of PGDH activity, in the amnion levels of PGDH are low or undetectable, so this mechanism cannot contribute to the effects observed.

In conclusion, the results presented in this study demonstrate a potential role for endocannabinoids in the modulation of prostaglandin production in late human pregnancy, with potentially important implications for the timing and progression of term and preterm labor and rupture of membranes. It has been observed that ~40% of CB1−/− mice show pregnancy loss (16, 26). If these results are also relevant to the placenta, endocannabinoid-mediated effects on prostaglandin production may also have importance in the implantation and maintenance of placental capillary tone. Further studies will be necessary to ascertain the precise role of endocannabinoids in regulating prostaglandin pathways during human pregnancy.

ACKNOWLEDGMENTS

We thank the theatre staff at National Women’s Hospital for the collection of placentas, with special thanks to O. Tupusi for the organization of patient consent; C. O’Oochoko for technical assistance; and E. Robinson (Department of Community Health, University of Auckland, New Zealand) for advice on the statistical analyses of the data.

Present address of J. A. Keelan: School of Women’s and Infant’s Health, University of Western Australia, King Edward Memorial Hospital, Perth, Australia.

GRANTS

This work was funded by a Programme Grant to M. D. Mitchell from the Health Research Council of New Zealand. A. P. Ponnampalam is supported by a fellowship from Invitrogen. M. D. Mitchell is supported by NRCPD.

REFERENCES


