Effects of Prostaglandin F$_{2\alpha}$ on Vasoconstrictor Responses in the Mesenteric Vascular Bed

PATRICIA M. ARISTEGUI AND MARÍA AMELIA ENERO

SUMMARY Prostaglandin F$_{2\alpha}$ (PGF$_{2\alpha}$) in a concentration that did not induce vascular contraction ($10^{-8}$ M) potentiated the dose-response curves to norepinephrine and 5-hydroxytryptamine and the contractile response induced by potassium (60 or 100 mM) in isolated mesenteric vascular bed of the rat. After prostaglandin inhibitor treatment with indomethacin ($10^{-6}$ M), the dose-response curve to norepinephrine was reduced, and the dose ($10^{-10}$ M) of PGF$_{2\alpha}$ which was ineffective in control tissues, facilitated the norepinephrine contractile response. In contrast, indomethacin did not change either the contractile response induced by potassium or the PGF$_{2\alpha}$ potentiation of this response. Calcium antagonists diltiazem or flunarizine reduced the potassium-induced contractile response. After diltiazem treatment, $10^{-10}$ M of PGF$_{2\alpha}$ was also effective in facilitating this response. The PGF$_{2\alpha}$ postjunctional effect was conserved after phosphoinositide hydrolysis inhibition. These results suggest that PGF$_{2\alpha}$ potentiation of the contractile response may be independent of PGF$_{2\alpha}$ contraction. Low doses of endogenous prostaglandins could be able to facilitate the norepinephrine contractile response in this tissue. This process may be independent of calcium influx and phosphoinositide hydrolysis.

(KEY WORDS: prostaglandins · postjunctional effect · phosphoinositide hydrolysis · Ca$^{2+}$ antagonists · norepinephrine · 5-hydroxytryptamine)

In all vascular smooth muscle the activation of the contractile process depends, under normal conditions, on an increase in cytosolic calcium concentration, whether derived from the extracellular fluid or from intracellular sources.$^{1,2}$ It is generally accepted that norepinephrine (NE) induces release of intracellular calcium (fast component) and influx of calcium (sustained component).$^{3}$ In addition, the contractile response induced by serotonin (5-HT) in rat aorta involves, like NE, two components, one calcium channel–mediated and the other through phosphoinositide hydrolysis.$^{4}$

On the other hand, prostaglandin F$_{2\alpha}$ (PGF$_{2\alpha}$) induces contraction by increasing membrane permeability to calcium in rat mesenteric artery.$^{5}$ The ability of prostaglandins to mobilize different calcium pools to produce contraction seems to be variable.

The purpose of the present study was to examine the interaction of PGF$_{2\alpha}$ at concentrations that do not induce vascular contraction, with the contractile response induced by NE or 5-HT and the depolarized medium evoked in perfused mesenteric arteries. We studied the effect on calcium influx of calcium entry blockers diltiazem and flunarizine and the role of phosphoinositide hydrolysis in this interaction. The results show that PGF$_{2\alpha}$ facilitates the contractile responses analyzed. This process may be independent of calcium influx and phosphoinositide hydrolysis.

Materials and Methods

Wistar rats (250 g) were anesthetized by ether and the mesenteric vascular bed was quickly removed. The complete vascular bed was isolated according to the method described by McGregor$^4$ and perfused at the rate of 2 ml/min with modified Krebs solution previously gassed with a 95% O$_2$, 5% CO$_2$ mixture. The whole system was maintained at 37°C. Perfusion pressure was monitored by a Statham pressure transducer P23 AC coupled to a Grass pen recorder (Model 7, Quincy, MA, USA). After an equilibration period of 60 minutes, dose-response curves to NE and 5-HT were obtained by injecting the agonist (0.1 ml) into the perfusion stream. The depolarized medium (60 or 100 mM potassium solution) was perfused into the Krebs solution until the steady state of the contractile response was attained. Three consecutive dose-response curves or potassium-stimulated responses were developed at 30-minute intervals in each experiment. Control experiments were performed and showed no significant differences among the three curves or potassium-stimulated responses.

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Results are expressed as the mean ± SEM. Differences between means were evaluated for statistical significance by using paired Student's t test.

The drugs used were norepinephrine (Sigma Chemical), 5-hydroxytryptamine (Sigma Chemical), prostaglandin F₂α (Syntial Laboratory), diltiazem (Laplex S.A.), flunarizine (Janssen Pharmaceutica), and 2-nitro-4-carboxyphenyl-N,N-diphenylcarbamate (NCDC) (Sigma Chemical).

Results
The maximum contractile responses to NE and 5-HT were 93.4 ± 5.5 mm Hg (n = 7) and 26.4 ± 8.2 mm Hg (n = 5), respectively. The concentrations of PGF₂α used, 10⁻¹⁰ and 10⁻⁸ M, did not induce vascular contractions. When the tissues were perfused with 10⁻¹⁰ M of PGF₂α the dose-response curves to NE and 5-HT did not change, whereas 10⁻⁸ M facilitated both contractile responses assayed, increasing the maximum of the dose-response curves by 30 to 40% (Figure 1). The potentiation observed on the contractile response to NE was maintained at low calcium concentration (0.5 mM) in the perfused Krebs solution (data not shown).

The contractile responses induced by potassium, 60 or 100 mM, perfused until its steady state were 46.5 ± 3.6 mm Hg (n = 4) and 125.3 ± 12.6 mm Hg (n = 4), respectively. When the tissues had previously been perfused with 10⁻¹⁰ M of PGF₂α the contractile response did not show significant changes, while 10⁻⁸ M of PGF₂α potentiated the contractile responses to 60 and 100 mM potassium by 40% and 60%, respectively (Table 1).

The inhibition of cyclooxygenase pathways with 10⁻⁶ M of indomethacin reduced the maximum contractile response to NE by about 20% (Figure 2A) without modifying the contractile response induced by a depolarized medium, 60 mM of potassium (control: 46.5 ± 3.6 mm Hg; 10⁻⁶ M indomethacin: 48.0 ± 9.0 mm Hg, n = 4). Inhibition of endogenous cyclooxygenase products with indomethacin facilitated the PGF₂α potentiation of the NE contractile response. Figure 2B shows that 10⁻¹⁰ M of PGF₂α, which was ineffective in control tissues, markedly facilitated the dose-response curve to NE in indomethacin-treated tis-

![Figure 1](image1.png)

**Figure 1.** Effect of PGF₂α on NE- or 5-HT-induced contractions in mesenteric vascular bed. The sequence of experiments was first, control dose-response curve to NE (○); second, dose-response curve after 10⁻¹⁰ M of PGF₂α (Δ and ■); and last, dose-response curve after 10⁻⁸ M of PGF₂α (●). Points and bars are the means ± SEM of three to five experiments. *p < 0.05 vs control group.

![Figure 2](image2.png)

**Figure 2.** Effect of indomethacin on PGF₂α potentiation in mesenteric vascular bed. The sequence of experiments was as follows. A. First, control dose-response curve to NE (○); second, dose-response curve 60 minutes after 10⁻⁶ M of perfused indomethacin (●). B. First, dose-response curve to NE 60 minutes after 10⁻⁶ M perfused indomethacin (●); second, dose-response curve with indomethacin plus 10⁻¹⁰ M PGF₂α (●). Points and bars are the means ± SEM of three to five experiments. *p < 0.05; **p < 0.025 vs control.

<table>
<thead>
<tr>
<th>Depolarized medium K⁺ (mM)</th>
<th>Maximum contractile response (%) Control PGF₂α (10⁻¹⁰ M)</th>
<th>PGF₂α (10⁻⁸ M)</th>
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<td>60</td>
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<tr>
<td>60</td>
<td>100</td>
<td>129.5 ± 13.3</td>
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Diltiazem (10⁻⁶ M)

|                           |                                                 |                 |
| 100                       | 100                                             | 43.2 ± 6.0*     | 45.2 ± 6.7*   |
|                           | 100                                             | 46.6 ± 4.6*     | 71.5 ± 5.8†   |
|                           | 100                                             | 39.6 ± 7.3*     | 82.3 ± 15.0†  |

Flunarizine (10⁻⁷ M)

|                           |                                                 |                 |
| 100                       | 100                                             | 40.0 ± 2.7*     | 82.9 ± 7.6†   |

The mean ± SEM of three to five experiments is shown. 1 = indomethacin.

Tissues were stimulated with K⁺ (60 or 100 mM) three times in each experiment. The first stimulation was the control (100% of the response). PGF₂α (10⁻¹⁰ or 10⁻⁸ M) was perfused 20 minutes before and during the second or third period of stimulation. Indomethacin 10⁻⁶ M and Ca²⁺ antagonists were perfused 60 and 20 minutes, respectively, before and during the period of stimulation. *p < 0.05 vs control; †p < 0.05 vs pretreatment.
sues. In contrast, this treatment did not modify the potentiation of \( \text{PGF}_{2\alpha} \) observed in control tissues stimulated with potassium (see Table 1).

The calcium antagonists diltiazem and flunarizine reduced the contractile response to 100 mM of potassium to 40% of maximum. Both concentrations of \( \text{PGF}_{2\alpha} \), \( 10^{-8} \) and \( 10^{-10} \) M, significantly facilitated the contractile response to potassium in tissues treated with \( 10^{-6} \) M of diltiazem. A similar potentiation was obtained for \( 10^{-8} \) M of \( \text{PGF}_{2\alpha} \) in tissues treated with \( 10^{-7} \) M of flunarizine (see Table 1). The \( \text{PGF}_{2\alpha} \) potentiation of the NE contractile responses also was not affected by nifedipine, \( 3 \times 10^{-6} \) M (data not shown).

NCDC (\( 3 \times 10^{-5} \) M) is an inhibitor of phospholipase C, which inhibits the stimulation of phosphoinositide synthesis by agonists.\(^4\) It reduced the NE-induced contraction. Pretreatment with NCDC failed to change \( \text{PGF}_{2\alpha} \) potentiation (Figure 3).

**Discussion**

Prostaglandin \( \text{F}_{2\alpha} \), in concentrations that did not affect the perfusion pressure of the mesenteric vascular bed, facilitated the dose-response curves to agonists NE and 5-HT, and the contractile response induced by potassium (60 or 100 mM). Endogenous products of cyclooxygenase pathways are involved in the contractile response to NE. After pretreatment with indomethacin, a cyclooxygenase inhibitor, the dose of \( \text{PGF}_{2\alpha} \) that was ineffective in control tissues facilitated this contractile response. The potentiation of \( \text{PGF}_{2\alpha} \) may be independent of calcium influx and phosphoinositide hydrolysis.

Cyclooxygenase products mediate prejunctional and postjunctional actions in noradrenergic tissues. \( \text{PGF}_{2\alpha} \) in concentrations insufficient to alter the vascular tone potentiated contractile response of strips of dog mesenteric arteries to transmural electrical stimulation, but did not affect the postsynaptic response to NE. Nakajima and Toda\(^7\) concluded that \( \text{PGF}_{2\alpha} \) potentiates the contractile response to nerve stimulation by increasing the release of NE and does not mediate any interaction at the postjunctional level.

In our study in the perfused mesenteric vascular bed of the rat, \( \text{PGF}_{2\alpha} \) at similar concentrations to those of Nakajima and Toda\(^7\) potentiated the dose-response curves to NE and 5-HT and the contractile response mediated by depolarized medium. The different animal species or the different preparation used could explain the postjunctional effect of \( \text{PGF}_{2\alpha} \) in our experiments.

Stimulation of \( \alpha \)-adrenergic receptors modifies prostaglandin synthesis. The \( \alpha \)-adrenergic receptors stimulated with methoxamine increase \( \text{PGF}_{2\alpha} \) synthesis and decrease \( \text{PGF}_{2\alpha} \) in mouse vas deferens.\(^5\) In isolated mesenteric vascular bed, \( \alpha \)-adrenergic receptors preferentially mediate vasoconstrictor response.\(^5\) Indomethacin reduced the dose-response curve to NE, suggesting that prostaglandins are involved in this response. Moreover, when the endogenous prostaglandin production was inhibited with indomethacin, a low dose of \( \text{PGF}_{2\alpha} \) (\( 10^{-10} \) M) was sufficient to obtain a marked potentiation of the NE contractile response. In contrast, indomethacin did not change either the contractile response induced by potassium or the \( \text{PGF}_{2\alpha} \) potentiation of this response. These results suggest that low levels of \( \text{PGF}_{2\alpha} \) produced by the tissues during \( \alpha \)-adrenergic receptor stimulation could regulate the contractile response in mesenteric vascular bed of the rat.

The calcium antagonists diltiazem and flunarizine\(^10\) reduced the potassium-induced contractile response. After diltiazem treatment, a low dose of \( \text{PGF}_{2\alpha} \) (\( 10^{-10} \) M) was sufficient to produce a similar potentiation to that observed in control tissue. Flunarizine also did not affect the postjunctional effect of \( \text{PGF}_{2\alpha} \). Nifedipine, a calcium antagonist, did not affect the \( \text{PGF}_{2\alpha} \) potentiation of NE responses (data not shown). These results indicate that, unlike \( \text{PGF}_{2\alpha} \)-induced contraction,\(^7\) the potentiation induced by \( \text{PGF}_{2\alpha} \) on vasoconstrictor responses in mesenteric bed could be independent of the influx of extracellular calcium. From this point of view, the contraction and the potentiation induced by \( \text{PGF}_{2\alpha} \) on vascular smooth muscle may stimulate different receptors or mechanisms.

Previous studies demonstrated that NE-elicited contraction includes two components. One is calcium channel-mediated and the other is activated by the products of phosphoinositide hydrolysis.\(^11,12\) An inhibitor of phospholipase C, NCDC, inhibits the activity of phosphoinositide-specific phospholipase C from smooth muscle.\(^4\)

In our experiments, NCDC in concentrations that partially inhibit phosphoinositide hydrolysis\(^4\) reduced the dose-response curve to NE in mesenteric bed. The present data confirm that the \( \alpha \)-adrenergic receptors stimulated in this tissue are coupled to phosphoinositide hydrolysis. The \( \text{PGF}_{2\alpha} \) postjunctional action studied was maintained after NCDC treatment. Therefore, phosphoinositide hydrolysis might not be involved in the \( \text{PGF}_{2\alpha} \) potentiation of NE contractile response in this tissue.
In conclusion, this study shows that PGF$_{2\alpha}$ potentiation of the contractile response in mesenteric bed may be independent of PGF$_{2\alpha}$ contraction. This potentiation could be achieved with low concentrations of endogenous prostaglandin produced during the NE response. The process may be independent of calcium influx and phosphoinositide hydrolysis.

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