Effect of prostanoids and their precursors on the aggregation of rainbow trout thrombocytes

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Hill, D. J., M. B. Hallett, and A. F. Rowley. Effect of prostanoids and their precursors on the aggregation of rainbow trout thrombocytes. Am. J. Physiol. 276 (Regulatory Integrative Comp. Physiol. 45): R659–R664, 1999.—The role of prostanoids and their precursor fatty acids in the aggregatory response of thrombocytes (platelet equivalents of fish) from the rainbow trout, Oncorhynchus mykiss, was studied. Aggregation of these cells was induced by the thromboxane mimetic U-46619 or arachidonic acid (AA) in the presence of human or trout fibrinogen. The production of TXB2 by thrombocytes in response to stimulation with AA was inhibited by aspirin, ibuprofen, and indomethacin. However, thrombocyte aggregation in response to AA stimulation was not significantly altered by these agents at the concentrations tested (10–100 µM), with the exception of indomethacin at 20 and 40 µM. Effects on cytosolic calcium concentration have been suggested as an alternative mechanism for the inhibitory action of indomethacin on human platelet aggregation. The present study, however, failed to identify this as a mechanism for the inhibition of U-46619-induced trout thrombocyte aggregation by indomethacin. The polyunsaturated fatty acids docosahexaenoic acid and eicosapentaenoic acid both exhibited an inhibitory effect on U-46619-induced thrombocyte aggregation similar to that observed with mammalian platelets. Unlike the case in mammalian hemostasis, prostacyclin inhibited thrombocyte aggregation only at high concentrations (>5 µM). Prostaglandin E2, however, inhibited thrombocyte aggregation at much lower concentrations (>0.01 µM), suggesting that it may be the major inhibitory eicosanoid in trout.

eicosanoids; platelet equivalent; hemostasis; fish
the four species studied (16). Leucocytes from the dogfish, Scyliorhinus canicula, have been shown to generate PGF$_{2\alpha}$, PGE$_2$, and PGD$_2$ on stimulation with the calcium ionophore A-23187, and smaller amounts of TXB$_2$ were also produced (25). Purified thrombocytes from carp have also been reported to synthesize PGF$_{2\alpha}$, PGE$_2$, and PGD$_2$; however, no TXB$_2$ generation was observed (13). Conversely, whole blood and purified thrombocytes from the rainbow trout, Oncorhynchus mykiss, generated more TXB$_2$ than other eicosanoids on stimulation with calcium ionophore (14, 22). Given that TXA$_2$ is the most potent inducer of human platelet stimulation with calcium ionophore (14, 22). Given that TXA$_2$ is the most potent inducer of human platelet stimulation with calcium ionophore (14, 22). Given that TXA$_2$ is the most potent inducer of human platelet stimulation with calcium ionophore (14, 22).

Although our understanding of the hemostatic mechanisms in fish is improving (see Ref. 26 for review), little work has been performed regarding the role of eicosanoids and their precursors in this process. The present study was therefore undertaken to study the effect of a range of prostanoids and their precursor fatty acids have on the hemostatic response of thrombocytes from the rainbow trout, O. mykiss.

**MATERIALS AND METHODS**

Fish and chemicals. Adult rainbow trout, O. mykiss, were obtained from Lliw Mill Trout Farm, Pont Lliw, South Wales. They were maintained in large external tanks and fed ad libitum on Mainstream expanded trout diet (BP Nutrition, Cheshire, UK). The fatty acids AA, DHA, and EPA, the TX mimetic U-46619 (9,11-dideoxy-9α,11α-methanoepoxy PGF$_{2\alpha}$), and PGE$_2$ were obtained from Cascade Biochem (Reading, UK). PGJ$_2$ was supplied by Alexis Biochemicals (Nottingham, UK). Fura 2 acetoxymethyl ester (AM) was purchased from Molecular Probes (Eugene, OR). All other chemicals were of the highest grade available commercially.

Thrombocyte isolation. Before blood collection, fish were given terminal anesthesia by immersion in MS-222 (final concentration 0.1 g/l) for 10–15 min. Blood (~7 ml) was collected from the caudal vessel into a syringe containing heparin (final concentration ~10 IU/ml). A two-step Percoll density gradient centrifugation procedure was used to isolate thrombocytes from the peripheral blood of rainbow trout, as described previously (9, 14). Each fish yielded 5–7 × 10$^7$ thrombocytes of ~86% purity. The contaminating cells were mainly lymphocytes, neutrophilic granulocytes, and erythrocytes.

Thrombocyte aggregation studies. The aggregatory response of trout thrombocyte suspensions purified on Percoll gradients was measured turbidimetrically by a method similar to Born (1), using a Payton Minigator II aggregometer (Payton Associates, Scarborough, ON, Canada). Aggregometers measure cell aggregation by changes in light transmittance. As cells aggregate, the light transmittance through a cell suspension increases, which is measured by a detector in the aggregometer. Thrombocyte suspensions [500 µl aliquots; 1 × 10$^7$ cells/ml in Ca$^{2+}$-Mg$^{2+}$-containing Hanks’ balanced salt solution (HBSS)] were aggregated by the addition of the TXA$_2$ mimetic U-46619 (0.5 µM) in the presence of trout or human fibrinogen (400 µg/ml). The percentage aggregation was determined against a cell-free blank. To assess the involvement of various nonsteroidal anti-inflammatory drugs (NSAIDs), aspirin, ibuprofen (both 0–100 µM), and indomethacin (0–40 µM) were preincubated with thrombocyte suspension for 15 min before the induction of aggregation with U-46619 and fibrinogen. The effect of the AA, DHA, and EPA (0–10 µM) was studied by their addition immediately before the induction of aggregation. To assess the effect of PGE$_2$ and PGJ$_2$ on aggregation, these prostanoids (0.001–1.0 and 0.1–20 µM, respectively) were added to thrombocyte suspensions alone or immediately before the induction of aggregation with U-46619 and fibrinogen. Because PGJ$_2$ is unstable in aqueous media, particularly in the presence of cells, it was prepared immediately before its addition and all experiments performed within a few hours of its preparation.

TXB$_2$ ELISA. TXB$_2$ production by thrombocyte preparations was determined using a Biotrak enzyme immunoassay (EIA) system (Amersham Life Sciences, Little Chalfont, UK). Assay reagents were prepared and used according to the manufacturer’s instructions. The sensitivity of this assay was 3.6 pg/ml, with cross-reactivity of 100% with TXB$_2$, 60.5% with 2,3-dinor TXB$_2$, 0.18% with PGD$_2$, and <0.01% with PGE$_2$.

Measurement of cytosolic Ca$^{2+}$ concentration. Thrombocytes (~1 × 10$^7$ cells/ml) were loaded with fura 2-AM (1 µM) for 40 min at 12°C. The cells were then centrifuged and resuspended in Ca$^{2+}$- and Mg$^{2+}$-containing HBSS (1.8 mM CaCl$_2$) and kept at 4°C before use. Dual-excitation fluorescence measurements at 340 and 380 nm were achieved using a Spex Fluorolog dual-wavelength fluorimeter (Glen Spectra, Stanmore, UK) on cell suspensions maintained at 18°C challenged with U-46619 (0.3–20 µM) in the presence of indomethacin (10–40 µM) or ethanol (1 µl) as a control. Maximum and minimum 340/380 ratio values were determined in every experiment using digitonin (50 µM) and EGTA (20 mM), respectively, and the cytosolic free Ca$^{2+}$ concentration was calculated assuming a dissociation constant of 183 nM, as described previously (7).

Statistical analysis. Statistical analyses were performed with Instat2 (Graphpad Software) using Student’s t-tests or the Student-Newman-Keuls multiple comparison test as appropriate. All experiments reported were performed using at least three different batches of thrombocytes from each individual animal.

**RESULTS**

Previous studies have shown that trout thrombocytes aggregate in the presence of human fibrinogen (400 µg/ml) and the TXA$_2$ mimetic U-46619 (0.03–10 µM) in a dose-dependent manner (9). They also aggregate on stimulation with AA, but not EPA or DHA (10).

The proaggregatory response of thrombocytes in the presence of AA could have been due to its conversion to eicosanoids such as PGG$_2$, PGH$_2$, or TXA$_2$ rather than a direct effect. To ascertain if this was the case, the effect of three NSAIDs (which inhibit cyclooxygenase, the enzyme central to prostanoid synthesis), namely aspirin, ibuprofen, and indomethacin, on thrombocyte aggregation was studied. In these experiments, aspirin, ibuprofen (10–100 µM), or indomethacin (20–40 µM) were preincubated with thrombocyte suspensions before the addition of U-46619 (0.5 µM) or AA (10 µM) in the presence of human fibrinogen (400 µg/ml). Aspirin inhibited U-46619-induced aggregation, although this was only statistically significant at a concentration of 100 µM (Fig. 1A). Similarly, ibuprofen caused a significant decrease in U-46619-induced aggregation at a...
The concentration of 100 µM (Fig. 1B). The most inhibitory NSAID was indomethacin (Fig. 1C), with significant inhibition of U-46619- and AA-induced aggregation at 20 and 40 µM.

Fig. 1. Effect of aspirin (A), ibuprofen (B), and indomethacin (C) on thrombocyte aggregation induced by U-46619 (0.5 µM) or arachidonic acid (AA; 10 µM) in presence of human fibrinogen (400 µg/ml). *P < 0.05, **P < 0.01, ***P < 0.001 compared with appropriate control. Mean values ± SE, n = 3–6.

The effects of the three NSAIDs tested in inhibiting thrombocyte aggregation induced by both AA and U-46619 suggested the involvement of prostanoid formation in the mechanism of action of both agonists. To test this, the levels of immunoreactive TXB (stable breakdown product of TXA) produced by thrombocytes in response to U-46619 (0.5 µM) or AA (10 µM) were determined (Fig. 2). The addition of exogenous AA alone resulted in the generation of a significant amount of immunoreactive TXB, whereas the presence of each inhibitor significantly decreased the amount of this product released by thrombocytes (Fig. 2). Indomethacin exhibited a significantly greater inhibition of TXB produced by the addition of AA than seen with aspirin or ibuprofen (P < 0.05). The addition of U-46619 (0.5 µM) to thrombocyte suspensions resulted in minimal (not above background) generation of immunoreactive TXB that was not significantly affected by the NSAIDs tested.

Inhibition of calcium uptake has been implicated in the action of indomethacin on purified human platelets, and this has been suggested as a mechanism of its antiaggregatory activity (6). To ascertain if this inhibitor affected calcium ion movements in trout thrombocytes, cytosolic free Ca²⁺ ion concentration measurements were performed. After incorporation of fura 2, thrombocytes were challenged with U-46619 and an increase in cytosolic free Ca²⁺ ion concentration was observed (Fig. 3) that was largely dose dependent. However, there was no significant effect of indomethacin (40 µM) on the U-46619-induced Ca²⁺ signal (data not shown).

AA has been shown to induce the aggregation of thrombocytes in the presence of human fibrinogen (9). However, because the prominent PUFAs in trout are DHA and EPA (20), the effect of these fatty acids (0.03–10 µM) on trout thrombocyte preparations in the presence of fibrinogen was studied. Neither induced aggregation (data not shown). However, the addition of DHA to thrombocyte preparations immediately before the addition of U-46619 resulted in a significant dose-
dependent decrease in the amount of aggregation observed that was saturable at concentrations above 0.3 µM (Fig. 4). Experiments with EPA also indicated a similar inhibitory action on U-46619-induced thrombocyte aggregation (data not shown).

As well as TXB2 production by trout thrombocytes, another cyclooxygenase product, PGE2, is produced in significant amounts by both whole trout blood and purified thrombocytes (14, 22). Exogenous PGE2 (0.001–1 µM) exhibited no proaggregatory affect on trout thrombocytes in the presence of fibrinogen. The addition of PGE2 immediately before the addition of U-46619 resulted in a dose-dependent decrease in the resulting thrombocyte aggregation that was significant above concentrations of 0.01 µM (Fig. 5). As in mammals, PG12 is the most potent inhibitor of platelet function (18); therefore, the effect of PG12 on trout thrombocyte aggregation was studied. The addition of PG12 (5 and 10 µM) immediately before stimulation with U-46619 (0.5 µM) in the presence of human fibrinogen resulted in a significant decrease of thrombocyte aggregation (Fig. 6). No significant effect was observed at the other concentrations tested.

**DISCUSSION**

Both TXA2 and its precursor fatty acid, AA, have been shown to induce human platelet aggregation (11). Similarly, trout thrombocytes aggregate in response to AA in the presence of fibrinogen. In human platelets, inhibition of cyclooxygenase, the central enzyme responsible for the initial conversion of AA to PGs, abolishes platelet responses to AA. This suggests that AA has no direct effect on human platelet hemostatic responses. In the present study, the effect of three NSAIDs, namely aspirin, ibuprofen, and indomethacin, on trout thrombocyte aggregation varied. Both aspirin and ibuprofen significantly inhibited U-46619-induced aggregation at the highest concentration tested (100 µM). Conversely, these inhibitors were without significant effect on AA-induced aggregation. Finally, indome
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In the present study, trout thrombocyte aggregation was significantly inhibited by PGI₂, but only at concentrations of 5 and 10 µM. Although we cannot totally discount the possibility of some breakdown of PGI₂ to 6-keto PGF₁α, (biologically inactive breakdown product), this is unlikely to have happened to any great extent due to the precautions used in our studies. Hence we conclude that, unlike the observed case with mammalian platelets, PGI₂ is not the most potent inhibitor of thrombocyte aggregation in trout and that PGE₂ has a more prominent role in the regulation of thrombocyte aggregation. This is also the situation in chickens, in which PGE₂ is a more potent inhibitor of aggregation than PGI₂ (2).

In summary, the present study identified both similarities and differences between the responses of trout thrombocytes and mammalian platelets to various prostanoids and their precursors. These and other studies (2, 10, 24) do, however, show that at a relatively early stage in the evolution of vertebrates, a mechanism of platelet-thrombocyte aggregation evolved that was dependent on eicosanoids for its induction and regulation. From the present study, the mechanism of action for the inhibition of thrombocyte aggregation by DHA, EPA, PGE₂, PGI₂, and the three NSAIDs tested remains to be elucidated. Ultimately, such studies should lead to a greater knowledge of hemostasis in stress-related disorders of commercially important fish and provide a better understanding of the origins of the mammalian hemostatic mechanism.

Perspectives

This paper is part of a wider study on the evolution of hemostatic mechanisms. Lower animals, such as invertebrates, have a range of hemostatic mechanisms, including plasma gelation and blood cell aggregation. Initial studies in this laboratory have investigated if eicosanoids are involved in the aggregatory response of coelomocytes (blood cells) in echinoderms (C. E. Ray and A. F. Rowley, unpublished observations). These studies showed that the TX mimetic U-46619 had no effect on the aggregatory response of these cells, suggesting that in echinoderms, at least, the mechanism of aggregation is independent of TX and potentially of eicosanoids in general. Perhaps this may be the case in all invertebrates, but clearly studies with one species are unlikely to be representative of the diverse range of invertebrate phyla. Furthermore, to our knowledge, no one has shown that invertebrates generate TXA₂ in significant amounts, and this may explain the lack of effect of U-46619 on blood cell aggregation. The evolution of the first vertebrates was accompanied by the appearance of a hemostatic mechanism involving thrombocytes in which aggregation is initiated by TX generation. The present study showed striking similarities in the role of eicosanoids in initiating and controlling the aggregation of both fish thrombocytes and mammalian platelets. This implies that this is a relatively ancient mechanism that was established with the evolution of teleost fish. Clearly, it would be of interest to see if similar mechanisms also operate in cartilaginous fish.
such as sharks and rays as well as the evolutionarily more primitive agnathan fish (lampreys and hag-fishes). Finally, although we know the basis by which eicosanoids are involved in the aggregatory response of trout thrombocytes, we still have little idea of the underlying mechanisms at the molecular level.

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