Effect of Oxidation on the Platelet-Activating Properties of Low-Density Lipoprotein

Suzanne J.A. Korporaal, Gertie Gorter, Herman J.M. van Rijn, Jan-Willem N. Akkerman

Objective—Because of the large variation in oxidizing procedures and susceptibility to oxidation of low-density lipoprotein (LDL) and the lack in quantification of LDL oxidation, the role of oxidation in LDL–platelet contact has remained elusive. This study aims to compare platelet activation by native LDL (nLDL) and oxidized LDL (oxLDL).

Methods and Results—After isolation, nLDL was dialyzed against FeSO₄ to obtain LDL oxidized to well-defined extents varying between 0% and >60%. The oxLDL preparations were characterized with respect to their platelet-activating properties. An increase in LDL oxidation enhances platelet activation via 2 independent pathways, 1 signaling via p38MAPK phosphorylation and 1 via Ca²⁺ mobilization. Between 0% and 15% oxidation, the p38MAPK route enhances fibrinogen binding induced by thrombin receptor (PAR-1)-activating peptide (TRAP), and signaling via Ca²⁺ is absent. At >30% oxidation, p38MAPK signaling increases further and is accompanied by Ca²⁺ mobilization and platelet aggregation in the absence of a second agonist. Despite the increase in p38MAPK signaling, synergism with TRAP disappears and oxLDL becomes an inhibitor of fibrinogen binding. Inhibition is accompanied by binding of oxLDL to the scavenger receptor CD36, which is associated with the fibrinogen receptor, α₅β₃.

Conclusion—At >30% oxidation, LDL interferes with ligand binding to integrin α₅β₃, thereby attenuating platelet functions. (Arterioscler Thromb Vasc Biol. 2005;25:867-872.)

Key Words: lipoproteins ■ platelets ■ oxidized LDL ■ scavenger receptor ■ lysophosphatidic acid

Patients with familial hypercholesterolemia (FH) show an increased incidence of premature coronary artery disease. These patients lack or have a defective receptor for low-density lipoprotein (LDL), the apolipoprotein (apo) B/E-receptor,¹ which results in an impaired uptake of LDL from the circulation. LDL accumulates and becomes oxidized in the vessel wall at sites of injured endothelium. Uptake of oxidized LDL (oxLDL) transforms macrophages into foam cells, which are characteristic for the fatty streak, the early atherosclerotic lesion.² Plasma levels of oxLDL are higher in coronary artery disease patients (31.1 ± 11.9 mg/L) compared with normal subjects (13.0 ± 8.8 mg/L).³ OxLDL accumulates in atherosclerotic lesions and there is ~6-fold more oxLDL in atherosclerotic plaques than in normal intima.⁴ Platelets are key elements in the development of arterial thrombosis and atherosclerosis. They adhere to injured endothelium, to exposed collagen, and to macrophages. On activation, platelets secrete cytokines and growth factors that contribute to migration and proliferation of smooth muscle cells and monocytes. Platelets of FH patients are hyper-reactive and show hyperaggregability in vitro and enhanced activity in vivo as illustrated by increased plasma levels of the α-granule product β-thromboglobulin and an increased prostaglandin (PG) and thromboxane (TXA₂) metabolism.⁵ Moreover, activated platelets have been found in the circulation of FH patients⁶ and high concentrations of oxLDL stimulate platelet adhesion and aggregation via suppression of endothelial production of nitric oxide and stimulation of the synthesis of PG precursors and prostaglandins.⁷ These observations suggest that LDL enhances platelet responsiveness.

Native LDL (nLDL) is a mild activator of platelets via TXA₂-dependent and TXA₂-independent pathways.⁸⁻¹¹ Activation is mediated via a specific LDL receptor, which differs from the classical apoB/E receptor because a similar response is observed after LDL stimulation of platelets from healthy subjects, platelets from FH patients, and platelets that were treated with apoB/E receptor–blocking antibodies.¹² We recently identified apolipoprotein E receptor 2’ (apoER2’) as a possible candidate for LDL binding to platelets.¹³ apoER2’ is a splice variant of apoER2 that has been identified in platelets and megakaryocytic cell lines.¹⁴ At physiological concentrations (0.6 to 0.9 g/L), nLDL increases the sensitivity of platelets for α-thrombin, collagen, and ADP but fails to independently induce platelet functions.⁸⁻¹⁰,¹¹,¹⁵ At higher concentrations (3 g/L), nLDL becomes an independent initiator of platelet activation triggering aggregation and secretion.¹⁶ nLDL-induced platelet sensitization is mediated via the activation of p38 mitogen-activated protein kinase.

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Lysophosphatidic acid (LPA), generated during oxidation. LPA has platelet-activating properties of oxLDL have been attributed to LPA2, and LPA3. Selective antagonists of LPA1 and LPA3 block LPA-induced platelet activation, indicating that these receptors respond to LPA. At low concentrations (EC50 ~18 nmol/L), LPA activates Rho and Rho-kinase via G12/13, causing phosphorylation of myosin light chain and changes of the actin cytoskeleton that underlie platelet shape change. At higher concentrations (EC50 ~1.6 μmol/L), LPA increases intracellular Ca2+ levels ([Ca2+]i) and induces platelet aggregation.

The large variation in oxidizing procedures, the interindividual variation in susceptibility to oxidation of LDL and the lack in quantification of the degree of LDL oxidation have concealed the insight in the role of oxidation in LDL–platelet interactions. The present study was initiated to compare platelet activation by nLDL and by oxLDL. To this end, we prepared LDL preparations oxidized to well-defined extents varying between 0% and 60% oxidation and characterized their platelet-activating properties.

Figure 1. OxLDL-induced p38MAPK phosphorylation and Ca2+ mobilization. A, Platelets were stimulated with LDL (1.0 g/L, 5 minutes, 37°C) and fixed with 1% formaldehyde. After centrifugation (30 seconds, 9000g, 20°C), pellets were taken up in Laemmli sample buffer and analyzed by SDS-PAGE to identify dual-phosphorylated and total p38MAPK phosphorylation using a phospho-specific anti-p38MAPK polyclonal antibody (upper panel) or an antibody against p38MAPK as a control for equal lane loading (lower panel). The bars show the semiquantification of dual-phosphorylated p38MAPK. B, Ca2+ mobilization was measured in Ca2+-free buffer on addition of LDL (0.2 g/L, 37°C) to Fura-2/AM-loaded platelets. Inset, Representative traces for Ca2+ mobilization. C, Platelets were incubated with vehicle, L-NASPA, or SB203580 (10 μmol/L, 10 minutes, 37°C), and p38MAPK phosphorylation or Ca2+ mobilization induced by oxLDL (31% to 60%) were measured as described. Data are expressed as fold increase compared with untreated suspensions (ctrl) (means ± SEM, n = 3, *P < 0.05 vs control).

Methods

For a detailed Methods section, please see http://atvb.ahajournals.org.

Results

Lipoprotein Modification

Table I (available online at http://atvb.ahajournals.org) summarizes the amount of conjugated dienes and relative electrophoretic mobility (REM) of the different oxLDL preparations, defining the extent of lipid and protein modification of the LDL preparations used in this study.

OxLDL-Induced Signaling Via p38MAPK Activation and Via Ca2+ Mobilization

To understand how oxidation changes the p38MAPK-activating properties of nLDL, platelets were treated with LDL oxidized to different extents. Incubation with nLDL induced p38MAPK phosphorylation, confirming earlier observations. There was little change between 0% and 15% oxidation, but at >15% p38MAPK phosphorylation increased to an almost 6-fold increase at >60% oxidation (Figure 1A). A similar p38MAPK phosphorylation was found in the presence of L-NASPA (Figure 1C), which blocks binding of LPA to its receptor, thereby antagonizing platelet functions induced by LPA, such as shape change and aggregation. These results indicate that LPA formed during LDL oxidation did not contribute to p38MAPK phosphorylation. As expected, oxLDL-induced p38MAPK phosphorylation was inhibited in the presence of the p38MAPK inhibitor SB203580 (Figure 1C).

To investigate the contribution of LPA in oxLDL-induced platelet activation, the mobilization of intracellular Ca2+ was measured because this is a sensitive marker for LPA-induced signaling. Between 0% and 30% oxidation, there was no...
significant change in $[\text{Ca}^{2+}]$, but further oxidation strongly increased $\text{Ca}^{2+}$ mobilization to a 2-fold increase at >60% oxidation (Figure 1B). The increase in $[\text{Ca}^{2+}]$ was completely blocked by l-NASPA (Figure 1C), indicating that LPA caused the $\text{Ca}^{2+}$ mobilization by oxLDL. OxLDL-induced $\text{Ca}^{2+}$ mobilization was not inhibited by SB203580 (Figure 1C). Thus, both p38MAPK phosphorylation and $\text{Ca}^{2+}$ mobilization increased at increasing oxidation of LDL with a threshold of 15% to 30% oxidation, below which there was little difference with nLDL. In addition, the findings with l-NASPA and SB203580 suggest that oxLDL activates 2 independent pathways.

**OxLDL-Dependent Regulation of cAMP**

Platelet agonists initiate aggregation and secretion via $\text{G}_{\text{i}}$-mediated pathways while concurrently suppressing cAMP formation via ADP release and P2Y$_{12}$-mediated activation of the inhibitory G-protein, $\text{G}_{\text{i}}$. Because p38MAPK activation and $\text{Ca}^{2+}$ mobilization sense changes in cAMP, we investigated whether the higher activation observed at more oxidation resulted from suppression of cAMP. Platelets had a basal cAMP concentration of 3.87±1.41 ng/10$^{11}$ cells, which was not disturbed by nLDL or oxLDL (data not shown). Prostacyclin ($\text{PGI}_{2}$) induced a 2.6-fold increase in cAMP, which was not changed by LDL preparations oxidized up to 30%. At >30% oxidation, oxLDL reduced the increase in cAMP by 30% to 40% (Table II, available online at http://atvb.ahajournals.org). Similar results were observed in the presence of l-NASPA, indicating that the reduction was independent of LPA. As expected, $\alpha$-thrombin reduced the PGI$_{2}$-induced cAMP accumulation amounting to a decline of 70%, an effect that was independent of LPA. Assuming that the inhibition of PGI$_{2}$-induced cAMP accumulation by oxLDL reflects a similar effect on the basal level of cAMP, which is difficult to measure, the platelet-activating properties of oxLDL were enhanced by suppression of cAMP in an LPA-independent manner.

**The Effects of oxLDL on Aggregation**

nLDL-induced p38MAPK phosphorylation is an early and rapid step in a slow process that after 5 minutes or more synergistically increases agonist-induced fibrinogen binding, aggregation, and secretion. In contrast, LPA independently raises $[\text{Ca}^{2+}]$, inducing shape change, aggregation, and secretion within seconds. Because oxLDL was a more potent activator of p38MAPK phosphorylation than nLDL, and LPA-mediated $\text{Ca}^{2+}$ signaling is especially evident at high stages of oxidation, we investigated the functional responses initiated by the 2 pathways. After 5 minutes of pre-incubation, nLDL enhanced thrombin receptor (PAR-1)-activating peptide (TRAP)-induced aggregation (Figure 2A). Surprisingly, this property disappeared on oxidation and at high oxidation oxLDL became an inhibitor of TRAP-induced platelet aggregation (Figure 2A). The inhibition was independent of LPA, because similar results were observed in the presence of l-NASPA (data not shown). In contrast, oxLDL induced aggregation within seconds (Figure 2B). This finding was in agreement with the rapid LPA-dependent mobilization of $\text{Ca}^{2+}$ by oxLDL (Figure 1). Aggregation was inhibited in the presence of l-NASPA, indicating that LPA was responsible (data not shown).

We further investigated the inhibition of aggregation by oxLDL via the p38MAPK pathway and measured TRAP-induced fibrinogen binding to integrin $\alpha$II$\beta$3, in the presence of oxLDL. In unstimred platelet suspensions, LDL alone failed to induce fibrinogen binding at any oxidation stage (data not shown). In contrast, after 5 minutes of pre-incubation, nLDL enhanced TRAP-induced fibrinogen binding (Figure 2C). Oxidation to <15% preserved the synergistic properties of nLDL, but further oxidation reduced this property and, at high oxidation, oxLDL inhibited TRAP-induced fibrinogen binding (Figure 2C). Inhibition was already observed at a concentrations of 750 mg/L oxLDL ($P=0.0329$) and increased at higher concentrations of oxLDL (1.0 g/L; $P=0.0220$) (Figure 2D). nLDL enhances TRAP-induced fibrinogen binding at this concentration, which indicates that the inhibition by oxLDL was not caused by changes in lipid composition of the medium. The inhibition of TRAP-induced fibrinogen binding was independent of LPA (data not shown).

**Inhibition of Platelet Functions by oxLDL**

CD36 is a scavenger receptor that is present on platelets and binds oxLDL with high affinity. To determine whether
binding of oxLDL to CD36 is involved in oxLDL-induced inhibition of platelet aggregation, platelets were treated with the antibody FA6.152 to block binding of oxLDL to CD36, before addition of oxLDL and TRAP. Inhibition of oxLDL binding to CD36 by FA6.152 abolished the reduction of TRAP-induced fibrinogen binding by oxLDL in a dose-dependent manner (Figure 3A).

CD36 is known to associate with αvβ3 on the plasma membrane of resting platelets. Binding of oxLDL to CD36 might therefore inhibit ligand binding to αvβ3, or inhibit αvβ3 activation. We investigated the association of CD36 with CD61 (the β3 subunit of αvβ3) in the presence of LDL. CD36 associated with CD61 on resting platelets confirming earlier observations. No change in the association was observed on incubation up to 30 minutes with either nLDL or oxLDL (Figure 3B). Immunoprecipitation experiments with a nonspecific antibody failed to immunoprecipitate both CD61 and CD36 (Figure 3B).

To determine whether binding of oxLDL to CD36 might block ligand-binding to or activation of αvβ3, platelets were treated with nLDL or oxLDL, apoB100 was immunoprecipitated, and the communoprecipitation with CD36 was determined. Immunoprecipitation of the lipoproteins was associated with the precipitation of the 88-kDa scavenger receptor, CD36 (Figure 3C). Binding of nLDL to CD36 was transient, leading to dissociation after 5 minutes. In contrast, in platelet lysates stimulated with oxLDL, the coassociation between apoB100 and CD36 was persistent, indicating that oxLDL was still bound to CD36 after 5 minutes of oxLDL–platelet interaction. Collectively, these results indicate that the persistent binding of oxLDL to CD36 but not of nLDL is sufficient to block ligand binding to or activation of αvβ3.

OxLDL inhibits ligand binding to αvβ3. A, Platelets were pretreated with FA6.152 (30 minutes, 37°C) at the indicated concentrations before incubation with oxLDL (31% to 60%) and aggregation was stimulated with suboptimal concentration TRAP (2 μmol/L, 900 revelations per minute, 37°C) in the presence of fibrinogen (1 μmol/L). The tracings are representative for 3 similar experiments. B, Platelets were stimulated with nLDL or oxLDL (31% to 60%) and lysed at the indicated time points. CD36 was immunoprecipitated from platelet lysates with FA6.152 and association with CD61 was analyzed by SDS-PAGE with antibody S221 (upper panel). The antibody 131.2 against CD36 was used as a control for equal lane loading (lower panel). A CD11b antibody was used as a nonspecific control compared with CD36. C, Platelets were stimulated with nLDL or oxLDL (31% to 60%) and lysed at the indicated time points. apoB100 was immunoprecipitated from platelet lysates with 1D2, and coprecipitation of CD36 was analyzed by SDS-PAGE using antibody 131.2. The graphs show the semiquantification of the association of apoB100 with CD36. Data are expressed as percentage of the association of apoB100 with CD36 after 3 minutes incubation with oxLDL (100%).

nLDL sensitizes platelets to stimulation by collagen and TRAP via ligand-induced outside-in signaling through αvβ3.18 Inhibition of ligand-binding to αvβ3 caused by binding of oxLDL to CD36 might impede outside-in signaling through αvβ3 and thus inhibit platelet function. To investigate whether outside-in signaling through αvβ3 was inhibited, platelets were incubated with LDL and TRAP-induced P-selectin expression was determined as a marker for α-granule secretion. Pre-incubation with nLDL for 5 minutes did not influence TRAP-induced P-selectin expression. In contrast, oxLDL inhibited TRAP-induced α-granule secretion (Figure 4). This observation indicates that on oxidation, LDL becomes an inhibitor of platelet functions by inhibition of ligand-induced outside-in signaling through αvβ3.
Discussion

nLDL increases the responsiveness of platelets to activating agents, resulting in faster aggregation and secretion after stimulation with thrombin, ADP, and collagen. This sensitization process is slow,8,18 requiring 5 minutes or more (37°C), and starts with the rapid activation of p38MAPK, which via cPLA2-mediated arachidonic acid release17 triggers the formation of TXA2.9,17 TXA2 further activates platelets by stimulating the TXA2 receptor, leading to activation of integrin αIIbβ3 and αIIbβ3-mediated ligand-induced outside-in signaling.18 Blockade of TXA2 formation by indomethacin sharply reduces secretion.15

Oxidation increases the platelet-activating properties of nLDL via 2 mechanisms, which depend on the degree of oxidation and the duration of platelet–LDL contact. The first mechanism involves p38MAPK activation. In this mechanism, a further increase in nLDL-induced p38MAPK activation on LDL oxidation leads to a 6-fold increase at >60% oxidation. This increase in the activating pathway, concurrent fibrinogen binding remains constant and even decreases at 16% oxidation or more. The second mechanism is LPA-mediated platelet activation, which is insignificant at low oxidation but becomes a potent activation pathway at >30% oxidation, inducing Ca2+ mobilization and aggregation. The observations that LPA is unable to activate p38MAPK (Figure 1C)17 and that p38MAPK-mediated functions are insensitive to extensive oxidation stages (data not shown). However, when PECAM-1 activation was mimicked by treatment with the antibody PECAM-1.3 and cross-linking with F(ab’)2-fragments, there was little interference with TRAP-induced fibrinogen binding, suggesting that PECAM-1 does not mediate platelet inhibition by oxLDL (data not shown).

Treatment of platelets with nLDL or oxLDL and immunoprecipitation with an antibody directed against the apoB100-moiety of LDL showed a clear association of an 88-kDa protein that was identified as CD36, a scavenger receptor that binds nLDL and oxLDL.34 The association of CD36 with nLDL was transient and disappeared after 5 minutes, but with oxLDL a persistent association between apoB100 and CD36 was found. CD36 associates with αmβ3 on intact platelets and plasma membrane preparations36,42 and colocalizes with fibrinogen and αmβ3 on immuno-electron micrographs.43 We demonstrated a strong association of CD36 with CD61 on resting platelets, which did not change in the presence of nLDL and oxLDL. Inhibition of oxLDL binding to CD36 abolished the inhibition of TRAP-induced aggregation by oxLDL. Hence, binding of oxLDL to CD36 blocks ligand-binding to αmβ3, thereby interfering with outside-in signaling and further platelet activation in a similar way as antibodies directed against αmβ3.18 A similar inhibition is observed with peptides that block ligand binding to αmβ3 and thereby block the stimulation of secretion by nLDL.18 The inhibition of TRAP-induced α-granule secretion by oxLDL supports this conclusion. Whether the inhibition of fibrinogen binding, aggregation, and αmβ3-mediated outside-in signaling was caused by steric hindrance by oxLDL or inhibited activation of αmβ3 remains to be clarified. Collectively, these data suggest that oxLDL directly interferes with fibrinogen binding to αmβ3, thereby abolishing outside-in signaling and the stimulation of aggregation and secretion observed with nLDL and LDL preparations oxidized at <15%.

In conclusion, the present study describes distinct mechanisms by which LDL modulates platelets. Between 0% and 15% oxidation, LDL sensitizes platelets to TRAP-induced fibrinogen binding and aggregation through activation of a slow sensitization process mediated by p38MAPK. At >30% oxidation, the LPA-mediated pathway induces the rapid activation of Ca2+ mobilization, leading to immediate aggregation. At >15% oxidation, platelet sensitization via p38MAPK is abolished and oxLDL inhibits TRAP-induced aggregation and secretion. This mechanism is independent of activation of PECAM-1 but is caused by binding to CD36 and interference with αmβ3-mediated ligand-induced outside-in signaling.
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THE EFFECT OF OXIDATION ON THE PLATELET-ACTIVATING PROPERTIES OF LOW-DENSITY LIPOPROTEIN

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Methods

Materials
The following agents were used: 1-oleoyl-L-α-lysophosphatidic acid (LPA, dissolved in the presence of BSA) and Brij-35 (Sigma, St.Louis, MO, USA); human α-thrombin (Kordia Life Sciences, Leiden, the Netherlands); N-palmitoyl-L-serine-phosphoric acid (L-NASPA) (Biomol, Plymouth, PA, USA); prostacyclin (PGI2) (Cayman Chemical, Ann Arbor, MI, USA); FITC-conjugated anti-human fibrinogen (WAK-Chemie, Bad Soden, Germany); RPE-conjugated anti-human P-selectin (DAKO, Glostrup, Denmark); monoclonal antibody 1D2 directed against apoB_{100} (Yamasa Corporation, Tokyo, Japan); monoclonal antibody SZ21 directed against the β3-subunit of α_{III}β_{3} (CD61); anti-CD36 antibody FA6.152 (Immunotech, Marseille, France); and anti-CD11b clone ICRF44 (BD Pharmingen, San Diego, CA, USA). Thrombin receptor (PAR1)–activating peptide (TRAP) was synthesized with a semi-automatic peptide synthesizer (Labortec AG SP650, Switzerland\textsuperscript{1}). Antibody 131.2 against CD36 was a gift from Dr. N.N. Tandon (Otsuka American Pharmaceuticals, Inc, Rockville, USA). All other chemicals were as defined in the cited articles.

Isolation of LDL and oxidation
Fresh plasma from 3 donors, each containing less than 100 mg lipoprotein(a)/L, was pooled and LDL was isolated by sequential flotation\textsuperscript{2}. The concentration of LDL was expressed as g apoB\textsubscript{100}/L as determined on a Behring Nephelometer 100 (Dade Behring, Marburg, Germany). The quality of these preparations has been described\textsuperscript{2}. Prior to each experiment, nLDL was dialyzed overnight against 10\textsuperscript{4} volumes of 150 mmol/L NaCl. LDL (5 g/L) was oxidized to different extents by dialysis against 5 μmol/L FeSO\textsubscript{4}-7H\textsubscript{2}O in phosphate-buffered saline (PBS) and 150 mmol/L NaCl containing 1 mmol/L NaN\textsubscript{3}, pH 7.2, for 24, 48 or 72 hrs (22°C\textsuperscript{3}). After modification, oxLDL was dialyzed against 10\textsuperscript{3} volumes of 150 mmol/L NaCl containing 1 mmol/L EDTA and 1 mmol/L NaN\textsubscript{3}. The degree of lipid modification was inferred from the formation of conjugated dienes at 234 nm and expressed as % oxidation compared to nLDL. Protein modification was assessed by agarose gel electrophoresis (Beckman Coulter, Fullerton, CA, USA).

Platelet isolation and incubations
Washed human platelets were prepared as described\textsuperscript{4} and resuspended in HEPES-Tyrode buffer (145 mmol/L NaCl, 5 mmol/L KCl, 0.5 mmol/L Na\textsubscript{2}HPO\textsubscript{4}, 1 mmol/L MgSO\textsubscript{4}, 10 mmol/L HEPES, 5 mmol/L D-glucose, pH 7.2). Platelet count was adjusted to 2.0 x 10\textsuperscript{11} platelets/L. Platelets were incubated with LDL (1.0 g/L, 5 minutes, 37°C) oxidized to different extents, unless stated otherwise. To address the role of LPA-signaling, experiments were performed without and with a pre-incubation with L-NASPA (10 μmol/L, 5 minutes, 37°C), which is an inhibitor of LPA binding to the LPA-receptors\textsuperscript{5,6}. Ca\textsuperscript{2+} mobilization and aggregation were measured in stirred platelet suspensions (900 rev.p.m.). The other measurements were performed in unstirred suspensions to avoid pre-activation of signaling molecules.
**Phosphorylation and immunoprecipitation studies**

The phosphorylation of p38^{MAPK} was measured as reported \(^7,8\). For co-immunoprecipitation studies of apoB100, CD36 and \(\alpha_{IIB}^b\beta_3\), platelets were lysed with ice-cold lysis buffer (1% (v/v) Brij-35, 250 mmol/L NaCl, 25 mmol/L Tris-HCl, 5 mmol/L EDTA), supplemented with 1% (v/v) protease inhibitor cocktail and 1 mmol/L NaVO\(_3\). ApoB100 and CD36 were immunoprecipitated (16 hours, 4°C) with antibody 1D2 (1 µg/mL) and FA6.152 (2.5 µg/mL), respectively, and protein G-sepharose (60 minutes, 20°C). An antibody against CD11b, which is not expressed on platelets, was used as a non-specific control. After washing, samples were taken up in Laemmli sample buffer and proteins were analyzed by SDS-PAGE and Western blotting. After blocking, membranes were incubated with the appropriate antibody (16 hours, 4°C). Antibody binding was detected using peroxidase-linked secondary antibodies, and visualized by the enhanced chemiluminescence reaction. For semi-quantitative determination, the bands were analyzed using ImageQuant software (Molecular Dynamics).

**Ca\(^{2+}\) mobilization and measurement of cAMP**

Ca\(^{2+}\) mobilization was measured in Fura-2/AM-labeled platelets upon addition of a low concentration of LDL (0.2 g/L) to avoid quenching of the fluorescent signal \(^9\). To investigate whether LDL interfered with the accumulation of cAMP, platelets were incubated with LDL and PGI\(_2\) (10 ng/mL, 5 minutes, 22°C). Incubation with \(\alpha\)-thrombin (0.5 U/mL, 5 minutes, 22°C) was used as a control as it is known to suppress the formation of cAMP through the P2Y\(_{12}\) receptor \(^10\). Samples on ice were lysed with perchloric acid, centrifuged (11.000 \(\times\) g, 10 minutes, 4°C) and cAMP was measured in the supernatant with a [\(^3\)H]-based immuno-assay (Amersham Pharmacia Biotech, Buckinghamshire, England).

**Flow cytometry**

TRAP-induced fibrinogen binding to integrin \(\alpha_{IIB}^b\beta_3\) after treatment with LDL was determined as reported \(^5\). For P-selectin expression, platelets were incubated with LDL and thereafter stimulated with TRAP (15 µmol/L, 5 minutes, 22°C). After addition of an excess of HEPES-Tyrode buffer, samples were incubated with RPE-conjugated anti-human P-selectin (5 µg/mL), fixed in 1% formaldehyde and analyzed by flow cytometry (FACScalibur, Becton Dickinson, Mountain View, CA, USA).

**Platelet aggregation**

Platelet suspensions were stimulated with LDL alone or a suboptimal concentration of TRAP (2 µmol/L) without or with pre-incubation with LDL in the presence of fibrinogen (1 µmol/L) at a stirring speed of 900 rev.p.min.. Optical aggregation was monitored in a Chrono-Log lumiaggregometer (Chrono-Log Corporation, Havertown, PA, USA).

**Statistical analysis**

Results are expressed as means±SEM with number of observations n, and analyzed with the Student’s t-test for unpaired observations.
**Table I.** Assessment of oxidative modification of LDL

The degree of lipid modification was inferred from the amount of conjugated dienes of LDL. The electrophoretic mobility was assessed by agarose gel electrophoresis. REM is defined as $R_{f\text{ oxLDL}}/R_{f\text{ nLDL}}$.

<table>
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<th>Type of lipoprotein</th>
<th>Conjugated dienes (AU)</th>
<th>Lipid oxidation range (%)</th>
<th>Protein modification REM</th>
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<tr>
<td>nLDL</td>
<td>0.338±0.005</td>
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<td>1</td>
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<td>oxLDL (24 hrs)</td>
<td>0.358±0.019</td>
<td>0-27</td>
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<td>0.485±0.029</td>
<td>0-72</td>
<td>1.17±0.04</td>
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<tr>
<td>oxLDL (72 hrs)</td>
<td>0.704±0.023</td>
<td>20-94</td>
<td>1.40±0.08</td>
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Table II. OxLDL-induced suppression of cAMP levels is LPA-independent

Platelets were pretreated at 37°C with vehicle or L-NASPA (10 µM, 5 minutes), incubated with LDL and treated with PGI$_2$ (10 ng/mL, 5 minutes, 22°C). As a positive control, PGI$_2$-induced cAMP accumulation was suppressed by α-thrombin (0.5 U/mL, 5 minutes, 22°C). After lysis, the amount of cAMP in the cAMP-rich supernatant was measured with a [3H]-based immuno-assay. (means±SEM, n=5, ‡ P<0.05 versus control)

<table>
<thead>
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<th>Agonist</th>
<th>Vehicle cAMP (% of control without L-NASPA)</th>
<th>L-NASPA cAMP (% of control without L-NASPA)</th>
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<td>Control</td>
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<td>nLDL</td>
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<td>82±8</td>
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<td>oxLDL (1-15%)</td>
<td>93±8</td>
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<td>oxLDL (31-60%)</td>
<td>66±3‡</td>
<td>86±10</td>
</tr>
<tr>
<td>oxLDL (&gt;60%)</td>
<td>60±6‡</td>
<td>68±9‡</td>
</tr>
<tr>
<td>α-thrombin</td>
<td>30±9‡</td>
<td>29±6‡</td>
</tr>
</tbody>
</table>
References


