Chlamydia pneumoniae Binds to Platelets and Triggers P-Selectin Expression and Aggregation
A Causal Role in Cardiovascular Disease?

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Objective—Evidence linking Chlamydia pneumoniae to atherosclerotic cardiovascular disease is expanding. Platelets are considered to play an essential role in cardiovascular diseases; however, so far platelets have not been associated with an infectious cause of atherosclerosis. This study aims to clarify the interaction between C pneumoniae and platelets and possibly present a novel mechanism in the pathogenesis of atherosclerosis.

Methods and Results—The effects of C pneumoniae on platelet aggregation and secretion were assessed with lumiaggregometry, and the ability of C pneumoniae to bind to platelets and stimulate expression of P-selectin was analyzed with flow cytometry. We found that C pneumoniae, at a chlamydia:platelet ratio of 1:15, adheres to platelets and triggers P-selectin expression after 1 minute and causes an extensive aggregation and ATP secretion after 20 minutes of incubation. Inhibition of glycoprotein IIb/IIIa with Arg-Gly-Asp-Ser or abciximab markedly reduced C pneumoniae-induced platelet aggregation. Exposure of C pneumoniae to polymyxin B, but not elevated temperature, abolished the stimulatory effects on platelet activation, suggesting that chlamydial lipopolysaccharide has an active role. In contrast, other tested bacteria had no or only moderate effects on platelet functions.

Conclusion—Our findings demonstrate a new concept of how C pneumoniae activates platelets and thereby may cause atherosclerosis and thrombotic vascular occlusion. (Arterioscler Thromb Vasc Biol. 2003;23:1677-1683.)

Key Words: atherosclerosis ■ bacteria–cell interaction ■ LPS ■ thrombosis

Atherosclerosis and related diseases are a major cause of death in the industrialized world. Differences in the occurrence of typical cardiovascular risk factors, such as smoking, hypertension, and abnormalities of lipid and sugar metabolism, do not explain thoroughly temporal and geographical variations in the prevalence or severity of coronary artery disease. Over the last decade, the potential role of infectious agents in the pathogenesis and progression of atherosclerosis has attracted much attention. Among different microorganisms suspected, Chlamydia pneumoniae has arisen as the most plausible pathogen having a causal role.

Platelet rupture and thrombosis are the main mechanisms of acute arterial occlusion, leading to myocardial infarction. After taking into account conventional risk factors and genetic predisposition, at least one third of thrombotic incidents remain unclear. Several studies show an association between C pneumoniae and thrombosis in patients with carotid artery disease and venous thromboembolic disease.

C pneumoniae is an obligate intracellular bacterium responsible for a number of upper and lower respiratory tract diseases in humans, and ≈50% of adults worldwide have antibody evidence of previous infection by this bacterium. An association between C pneumoniae infections and atherosclerosis has been demonstrated in a number of epidemiological, serological, immunohistochemical, and molecular biological investigations. Furthermore, in vitro studies have revealed that C pneumoniae is able to infect and replicate in the major cell types found within the atherosclerotic lesion, such as macrophages, endothelial cells, and smooth muscle cells. However, the interaction between C pneumoniae and platelets, other important actors in atherogenesis, has to our knowledge not been investigated.

Platelets are specialized in the processes of hemostasis and thrombus formation after an endothelial injury but are also considered to be involved in inflammatory reactions and the development of atherosclerosis. We have previously reported inflammatory properties of platelets by demonstrating their regulatory effects on leukocyte function. The α-granule constituent P-selectin is considered as a reliable marker of platelet activation and as a predictor of acute coronary heart disease. Several studies indicate that P-selectin mediates adhesion and recruitment of leukocytes to activated platelets, exerts procoagulant activity, and facilitates atherosclerotic development.
In this study, we evaluated the interaction between C pneumoniae and human platelets and found that C pneumoniae binds to platelets and effectively stimulates aggregation, secretion, and surface expression of P-selectin. These observations introduce new possible mechanisms involved in the development of cardiovascular diseases.

**Methods**

**Cells and Bacteria**

*C. pneumoniae* (strain T45) was cultured in HEp2 cells essentially as described by Redecke et al. The bacteria and cells were tested for mycoplasma contamination by using mycoplasma-specific polymerase chain reaction essentially according to van Kuppeveld et al. Platelets and neutrophils were isolated from human blood as previously described. For a detailed description of the preparation of cells and bacteria, please see http://atvb.ahajournals.org.

**Platelet Aggregation and ATP Secretion**

Aggregation and ATP secretion were analyzed under stirring conditions by using a calibrated two-sample Lumi-Aggrometer model 560 (ChronoLog Corp). Aggregation was measured as the change in light transmission, where the unstimulated platelet suspension was set to 0% and the buffer (KRG) to 100%. ATP secretion was measured in parallel as change in bioluminescence when ATP interacts with a luciferin–luciferase mixture (1.6 μg/mL luciferin and 176 U/mL luciferase; ChronoLog Corp). Calibration was performed for each test by adding a known amount of ATP.

**Flow Cytometry**

*C. pneumoniae–Platelet Interaction*

Platelets (2 × 10^5/mL) were preincubated for 5 minutes at 37°C under stirring conditions in a 24-well plate (Nunc) before being mixed with various concentrations of *C. pneumoniae*. Samples were taken immediately before, and 1 minute, 5 minutes, 10 minutes, and 20 minutes after adding *C. pneumoniae* to the platelet suspension. In some experiments, viable *C. pneumoniae* was replaced with heat-inactivated (70°C, 30 minutes) *C. pneumoniae*, HEp2 debris, or collagen (2 μg/mL). The role of platelet adhesion proteins was tested by preincubating the platelets with blocking antibodies against CD42b (3.6 μg/mL) and CD41 (4.3 μg/mL). The involvement of chlamydial lipopolysaccharide (LPS) was evaluated by treating *C. pneumoniae* with polymyxin B (100 μg/mL) for 30 minutes at room temperature. Unspecific effects of polymyxin B on platelet activity were tested during collagen-induced activation.

Immunofluorescence staining of platelets and *C. pneumoniae* was performed by incubation with saturating concentrations of monoclonal fluorescein isothiocyanate (FITC)-conjugated anti P-selectin (CD62p; BD Biosciences, Pharmigen) or phycoerythrin-conjugated anti-GpIb (CD42b; Dakopatts) and monoclonal FITC-labeled anti-chlamydia LPS (Boyle Diagnostics). At room temperature for 10 minutes in the dark, samples were then fixed with Optilyse (with 2.5% formaldehyde; Immunotech) under the same conditions and diluted in distilled H2O. Phycoerythrin- or FITC-labeled irrelevant isotype-matched monoclonal antibodies were used as controls for nonspecific staining. Immediately after staining, the samples were analyzed with flow cytometry in a Becton Dickinson FACS Calibur. The platelet population was identified by means of its light-scatter characteristics and by confirming that more than 99% of analyzed platelet particles in each sample were GpIb positive. Events stained positive for both platelet and *C. pneumoniae* antigens (GpIb and LPS, respectively) were considered to represent platelet–chlamydia complexes. Figure 2B illustrates a time-dependent increase in bound chlamydiae as revealed by elevated FITC fluorescence in the platelet gate. Approximately 10% of the platelet population bound to *C. pneumoniae* (C/p 1:10) after 1 minute, 20% after 5 minutes, 40% after 10 minutes, and 45% after 20 minutes of coincubation (Fig. 2B). Control experiments did not reveal any unspecific binding of anti-LPS antibodies to platelets and only a negligible binding of irrelevant isotype control antibodies. The wide distribution in size and fluorescence intensity indicates that platelets and platelet aggregates bound varying numbers of chlamydiae. The chlamydiae themselves did not form aggregates during incubation at 37°C under stirring conditions (data not shown).

**Binding of C pneumoniae to Neutrophils**

Neutrophils were preincubated for 5 minutes at 37°C and then mixed with *C. pneumoniae* at a *C. pneumoniae*:neutrophil ratio of 1:5. After 5 minutes of coincubation, the samples were stained with monoclonal phycoerythrin–conjugated anti CD11b (Dakopatts) and monoclonal FITC–labeled anti-chlamydia LPS antibodies. Neutrophil events stained positive for *C. pneumoniae* LPS were considered to represent neutrophil–chlamydia complexes. Unspecific binding of the FITC-labeled anti-chlamydia LPS antibody to the neutrophil control was subtracted from the fluorescence value of neutrophils incubated with *C. pneumoniae*.

**Results**

*C. pneumoniae* Triggers Platelet Aggregation and分泌

The interaction between *C. pneumoniae* and platelets was assessed by using lumiaagrometry, which enables a simultaneous analysis of platelet aggregation and ATP secretion. We found that the addition of *C. pneumoniae* to a pure platelet suspension (2×10^9 platelets/mL) induced aggregation (Fig. 1A and 1B) and ATP secretion (Fig. 1C) in a dose- and time-dependent manner. The responses were triggered at an infection forming unit chlamydia:platelet (C/p) ratio of 1:30. The chlamydia-induced platelet aggregation occurred in an all-or-nothing manner and increases in the bacteria concentration affected the lag period (time between addition of bacteria and onset of aggregation) but not the extent of aggregation (Fig. 1A and 1B). Once begun, the aggregation proceeded at about the same rate when using different C/p ratios, as indicated by the slope of the tracings (Fig. 1A). The *C. pneumoniae*-induced platelet aggregation and secretion were comparable with the responses triggered by collagen (Fig. 1C). No aggregation or ATP secretion was observed in stirred, unstimulated platelet suspensions or in samples with platelets incubated with cell debris of uninfected HEp2 cells (data not shown).

*C. pneumoniae* Binds to Platelets

The capacity of *C. pneumoniae* to bind and activate platelets was studied by using flow cytometry. Platelet events positive for FITC-conjugated antichlamydia LPS represent platelets with bound chlamydiae. We found that exposing platelets to *C. pneumoniae* caused a rapid and pronounced increase in platelet-associated FITC fluorescence. Scatterplots on platelets (Fig. 2A) with or without chlamydiae illustrated a change in size distribution, proposing the formation of platelet–chlamydia complexes. Figure 2B illustrates a time-dependent increase in bound chlamydiae as revealed by elevated FITC fluorescence in the platelet gate. Approximately 10% of the platelet population bound to *C. pneumoniae* (C/p 1:10) after 1 minute, 20% after 5 minutes, 40% after 10 minutes, and 45% after 20 minutes of coincubation (Fig. 2B). Control experiments did not reveal any unspecific binding of anti-LPS antibodies to platelets and only a negligible binding of irrelevant isotype control antibodies. The wide distribution in size and fluorescence intensity indicates that platelets and platelet aggregates bound varying numbers of chlamydiae. The chlamydiae themselves did not form aggregates during incubation at 37°C under stirring conditions (data not shown).
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We found that C pneumoniae at a C/p ratio of 1:15 markedly increased the expression of P-selectin, whereas no effects were detected on platelets incubated with uninfected HEp2 cell debris or 2-sp buffer. The P-selectin expression increased dramatically already after 1 minute and reached a maximum after 10 minutes of coincubation (Fig. 3A and 3B). We found a chlamydial-induced increase in platelet P-selectin at C/p ratios as low as 1:60, and the effects of C pneumoniae were comparable with those induced by collagen (2 μg/mL; Fig. 3C).

Effects of Other Bacteria on Platelet Activity
The ability of a number of other bacteria to induce platelet aggregation and secretion was tested. Neither Staphylococcus aureus, Staphylococcus epidermidis, Salmonella typhimurium, nor Escherichia coli stimulated platelet aggregation, ATP secretion, or P-selectin expression when using similar bacteria:platelet ratios as in the experiments of C pneumoniae. An irreversible, incomplete aggregation was triggered by S. aureus at a considerable higher bacteria:platelet ratio (2:1).

Role of Chlamydial LPS in Platelet Activation
To determine whether platelet activation required viable bacteria, an active release of chlamydial cell components, and/or binding to heat-labile chlamydial surface structures, experiments by using heat-inactivated C pneumoniae were performed. We found that heat treatment of C pneumoniae did not change the platelet binding capacity nor the stimulatory effects on platelet aggregation and P-selectin expression. To study the role of LPS in the interaction between C pneumoniae and platelets, C pneumoniae was preincubated with polymyxin B (100 μg/mL) for 30 minutes at room temperature. Figure 4 shows that polymyxin B–treated C pneumoniae was unable to stimulate platelet P-selectin expression (C/p 1:20). To elucidate whether polymyxin B unspecifically affected platelet activation, we studied the surface expression of P-selectin on platelets exposed to a mixture of polymyxin B (100 μg/mL) and collagen (2 μg/mL). We found that polymyxin B only slightly reduced the collagen-triggered increase of P-selectin (not shown).

Role of Platelet Surface Structures in the Interaction with C pneumoniae
Experiments were also performed to search for the platelet surface components involved in the interaction with C pneumoniae. Neither monoclonal antibodies directed against GpIb or P-selectin nor the peptide glycocalicin (blocking the von Willenbrand factor binding site on GpIb) antagonized the effects of C pneumoniae on platelet activity (data not shown). However, preincubation of platelets with Arg-Gly-Asp-Ser (RGDS; 1 mg/mL) or the monoclonal Gp IIb/IIIa antibody F(ab)2 fragment abciximab (Reopro; 40 μg/mL) significantly inhibited platelet aggregation triggered by C pneumoniae (Fig. 5).

Discussion
A growing amount of evidence suggests that C pneumoniae has a role in the development of atherosclerosis. However, it is uncertain whether a C pneumoniae infection is a triggering event of atherosclerosis or a secondary infectious

Figure 1. C pneumoniae triggers platelet aggregation and secretion. Platelets (2×10^7/mL) were monitored for aggregation (% light transmission) and ATP secretion during interaction with various infection-forming units of C pneumoniae (1×10^7/mL [C/p 1:10], 1.3×10^7/mL [1:20], 2×10^7/mL [1:15], 4×10^7/mL [1:5]). A, Representative traces of platelet aggregation triggered by C pneumoniae. B, Effects of different C/p ratios on the lag period, that is, the time between addition of C pneumoniae and the onset of platelet aggregation. C, ATP secretion from platelets triggered by C pneumoniae or collagen (2 μg/mL). The data in panels B and C represent the mean ± SD from 3 to 6 different experiments run in duplicate.

Binding of C pneumoniae to Neutrophils
Binding of C pneumoniae to neutrophils was studied with flow cytometry. Neutrophil events stained positive for FITC-conjugated antichlamydia LPS were calculated. Incubation of C pneumoniae with neutrophils at a ratio of 1:5 for 5 minutes resulted in a considerably lower binding of C pneumoniae to the neutrophils compared with the binding of C pneumoniae to platelets (Fig. 2C).

C pneumoniae Increases Platelet Expression of P-Selectin
The effects of C pneumoniae on platelet activity were further evaluated by studying P-selectin expression by flow cytometry.
complication of an already-formed atherosclerotic plaque. Several studies have investigated *C. pneumoniae* interaction with different cell types involved in the atherosclerotic process, for example, monocytes/macrophages, smooth muscle cells, and endothelial cells. However, it is not known whether *C. pneumoniae* affects platelets. In this study, we evaluated *C. pneumoniae* interaction with platelets by studying binding, aggregation, secretion, and surface expression of P-selectin.

We found that *C. pneumoniae* was highly adhesive to platelets and triggered aggregation and secretion in a time- and concentration-dependent manner. An extensive *C. pneumoniae*-platelet binding was observed already after 1 minute of coincubation and increased significantly during 10 to 25 minutes, whereupon an irreversible complete aggregation was obtained. Flow cytometric analysis shows a continuous increase in the size distribution of the platelet microaggregates during the lag period. The low number of *C. pneumoniae* elementary bodies in relation to the platelet concentration (C/p 1:20) and the kinetics of the chlamydia-induced lumiaaggregometry response with a lag period of 20 to 25 minutes suggest a cascade effect, where the chlamydiae initially stimulate few platelets, which activate neighboring cells through paracrine-signaling mechanisms. The ability of *C. pneumoniae* to cross-link platelets and support formation of microaggregates may constitute a mechanism by which *C. pneumoniae* relocalizes from the infected lung epithelium into the circulation. Earlier studies have demonstrated that bacteria can survive inside platelet aggregates, which protect the bacteria from the host defense and spread the bacteria in the circulation.

Several studies implicate an important role of P-selectin in atherosclerosis and thrombosis, shown by elevated levels of P-selectin in patients with congestive heart failure, stroke, peripheral artery disease, and acute coronary syndromes. Furthermore, ongoing *C. pneumoniae* infection and the occur-
rence of myocardial infarction is related to increased plasma levels of soluble P-selectin. In this study, we demonstrated that C pneumon...
have a role in infective endocarditis by activating platelets,\textsuperscript{30} \textit{E. coli} aggregation. The fact that \textit{C. pneumoniae} infections and strengthens the pathogenic property linking activates platelets underlies the tropism of chlamydial inflammatory effects of \textit{C pneumoniae} with atherosclerosis.

The most effectively needed for a complete platelet aggregation stimulated by \textit{C. pneumoniae}.\textsuperscript{30} S. epidermidis, S. typhimurium, \textit{S. aureus}, \textit{C. pneumoniae}--induced aggregation at a considerably higher bacteria:platelet ratio (2:1) compared with the low number of \textit{C pneumoniae} needed for a complete platelet aggregation. The fact that \textit{C pneumoniae} most effectively activates platelets underlies the tropism of chlamydial infections and strengthens the pathogenic property linking \textit{C pneumoniae} with atherosclerosis.

Our finding that heat treatment did not change the stimulatory effects of \textit{C pneumoniae} on platelet activation suggests an involvement of a heat-stable surface structure. Exposure of \textit{C pneumoniae} to polymyxin B abolished the effects on platelets, which indicates that LPS has a crucial role in platelet activation. The low number of elementary bodies of \textit{C pneumoniae} required for platelet activation may be caused by an extensive release of chlamydial LPS, which activates the major part of the platelet population in an aggregatory and secretory response. The finding that \textit{C pneumoniae} but no other tested Gram-negative bacteria (\textit{E. coli} and \textit{S. typhimurium}) activates platelets suggests that differences in the chemical structure of LPS are essential. Chlamydial LPS contains a unique lipid A, lacks an O-chain, and exposes a genus-specific highly immunogenic epitope on the polysaccharide core.\textsuperscript{31} Similar LPS has also been identified in \textit{Porphyromonas gingivalis}.\textsuperscript{32} Interestingly, it has been shown that platelets are directly stimulated by lipid A through an activation of protein kinase C and that bacteria with modified LPS, for example, \textit{P. gingivalis}, are much more potent activators of platelets than classic Gram-negative bacteria.\textsuperscript{33,34} \textit{P. gingivalis} is a major pathogen of periodontal diseases and has also been associated with atherosclerosis.\textsuperscript{35} A role for chlamydial LPS in atherogenesis has previously been reported by its ability to induce foam cell formation.\textsuperscript{36}

\textit{C pneumoniae} has considerably larger affinity to platelets than to neutrophils, which suggests recognition of specific receptors on the platelet surface. The counter receptors on the platelet surface involved in the interaction with \textit{C pneumoniae} were studied by using specific blocking antibodies and peptides. We found that inhibition of Gp Iib/IIa, with RGDS or with the monoclonal fab fragment abciximab, significantly lowered the aggregation induced by \textit{C pneumoniae}, whereas blocking of Gpib or P-selectin had no effects. Abciximab is used worldwide in patients with acute coronary syndromes and in those undergoing percutaneous coronary intervention.\textsuperscript{37} The rapid upregulation of platelet P-selectin induced by \textit{C pneumoniae} reflects an early release of \alpha-granule constituents, including fibrinogen. We suggest that the extensive delay (15 to 20 minutes) between \alpha-granule secretion and platelet aggregation constitutes a period of transformation of GpIb/IIa into a competent fibrinogen receptor. This process, supported by generation of intercellular mediators (eg, eicosanoids), engages more and more platelets forming microaggregates and leads finally to a complete aggregation.

\textit{C pneumoniae} infection is very common among the human population, occurs early and several times in life, and the bacteria persist for long periods in tissues. Thus, there are probably several opportunities for bacteria–platelet interaction, which may stimulate both the early proliferative phases of atherosclerosis and the late thrombotic vascular occlusion. A crucial role for \textit{C pneumoniae}-induced platelet aggregation in atherogenesis is supported by findings suggesting that recurrent thrombus incorporation into atherosclerotic lesions is fundamental in the pathogenesis and progression of atherosclerotic plaques.\textsuperscript{38}

This study supports the concept that \textit{C pneumoniae} plays a major causative role in atherosclerosis and suggests that platelets are susceptible target cells. Antibiotics and vaccines against \textit{C pneumoniae} infections might in the future be
complementary to, or even replace, classic antiplatelet and antiatherogenic drugs. We believe that an approach to specifically prevent C. pneumoniae binding to platelets and C. pneumoniae-induced activation of platelets can be a novel therapeutic tool for cardiovascular diseases.

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Preparation of cells and *Chlamydia pneumoniae*

**Cell culture**

HEp2 cells were grown and maintained in RPMI 1640 medium supplemented with 10% heat-inactivated fetal bovine serum (FBS), 10 mg/L gentamicin, and 2 mmol/L L-glutamine (Gibco, BRL, Life Technologies, Paisley, Scotland). The cells were incubated at 37°C and 5% CO₂ in 75 cm² culture flasks, and then subcultured in 6-well plates at a density of 0.7 x 10⁶ cells/well prior of infection with chlamydiae.

**Chlamydia pneumoniae propagation**

*Chlamydia pneumoniae* (strain T45) was cultured in HEp2 cells, grown and maintained in RPMI 1640, essentially as described by Redecke *et al.* (18). The bacteria were added to subconfluent monolayers of HEp2 cells in 6-well plates. The plates were centrifuged at 3000 x g for 45 min at 25°C, and incubated for 2 h at 37°C and 5% CO₂. Nonadherent bacteria were removed and infected cells were incubated in fresh RPMI 1640, supplemented with 1 µg/mL cyclohexamide (ICN Biomedicals Inc, Aurora, OH). Infected cells were incubated for 72 h as mentioned above to allow development of characteristic chlamydial inclusions. The chlamydiae were harvested by disrupting HEp2 cells with glass beads followed by sonication and centrifugation at 900 x g for 10 min at 4°C to remove cellular debris. Supernatants were centrifuged at 12 000 x g for 30 min at 4°C, and the bacteria were suspended in sucrose-phosphate buffer, supplemented with FBS (10 %) (sp-2-buffer), counted by immunofluorescence staining and then stored at -70°C until use. The chlamydiae are expressed as inclusion forming units (IFU) throughout the study. Uninfected HEp2 cells (HEp2 cell debris) were handled exactly as chlamydia-infected cells and used as a control. To
study the involvement of heat-lable structures, \textit{C. pneumoniae} was incubated at 70°C for 30 min.

The bacteria and cells were tested for mycoplasma contamination by using mycoplasma specific PCR essentially according to van Kuppeveld \textit{et al.} (19). The nucleotide sequences of primers used in the Mycoplasma group-specific PCR assay were as follows: upstream primer GPO-3 5’-GGGAGCAAACAGGATTAGATACCCCT-3’ and downstream primer MGSO 5’-TGCACCATCTGTACACTCTGTAACCTC-3’ (SGS AB, Köping, Sweden). In short, the cells were centrifuged at 300 x g at 5 min and the DNA of the cells and \textit{C. pneumoniae} culture was extracted by using QIAamp® DNA Mini Kit according to QIAgen Blood & Body fluid Protocol. Sample (1 µL) was added to 25 µL of the following PCR mixture: 1.5 units of Taq DNA polymerase, 10 mmol/L Tris-HCL (pH 9.0 at room temperature), 50 mmol/L KKL, 1.5 mmol/L MgCl$_2$, 200 µmol/L of each dNTP and stabilizers, including BSA, 0.8 µmol/L upstream primer GPO-3, and 0.8 µmol/L downstream primer MGSO. The PCR protocol used in a PTC-100™ (SDS, Falkenberg, Sweden) was as follows: denaturation at 94 °C for 40 seconds, annealing temperature at 55 °C for 40 seconds, extension at 72 °C for 1 min at 25 cycles.

**Preparation of platelets and neutrophils**

Platelets and neutrophils were isolated from freshly drawn heparinized human peripheral blood, donated by apparently healthy and drug free adult volunteers at the blood bank at Linköping University Hospital, Linköping, as previously described (13). Five parts of blood were mixed with one part of an acid citrate/dextrose solution (85 mmol/L trisodium citrate dihydrate, 71 mmol/L citric acid hydrate and 111 mmol/L D-glucose), followed by centrifugation at room temperature for 20 min at 220 x g to obtain platelet rich plasma (PRP).
The PRP was centrifuged for 20 min at 480 x g, and the platelets were then gently washed and resuspended in calcium-free buffer (final cell density $2 \times 10^8$/mL) and stored in plastic tubes at room temperature before use. To obtain functional but non-activated platelets, the isolation was performed without any specific platelet inhibitors, and, due to this, extra care was taken when handling the cells. Morphological studies showed discoid, solitary platelets displaying no signs of activation due to the preparation procedure. The contamination of other blood cells was negligible. The extracellular calcium concentration was adjusted to 1 mmol/L immediately before each experiment.

In short, neutrophils were isolated by layering one part of fresh whole blood on one part of lymphoprep over four parts of Polymorphprep (Nycomed Pharma AS, Olso, Norway) followed by centrifugation for 40 min at 480 x g. The resulting band of neutrophils was harvested and washed, and remaining red blood cells were eliminated by brief hypotonic lysis at 4°C followed by washing in calcium-free buffer.