Secretory phospholipase A2 induces dendritic cell maturation

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Abstract

High level of phospholipase A_2 (PLA_2) activity is found in serum and biological fluids during the acute phase response (APR). Extracellular PLA_2 in fluids of patients with inflammatory diseases such as sepsis, acute pancreatitis or rheumatoid arthritis is also associated with propagation of inflammation. PLA_2 activity is involved in the release of both pro- and anti-inflammatory lipid mediators from phospholipids of cellular membranes or circulating lipoproteins. PLA_2 may thus generate signals that influence immune responses. Here, group III secretory PLA_2s were tested for their ability to promote generation of functionally mature human dendritic cells (DC). PLA_2 treatment of differentiating monocytes in the presence of GM-CSF and IL-4 yielded cells with phenotypical and functional characteristics of mature DC. This maturation was dependent on the dose of PLA_2 and PLA_2-generated DC stimulated interferon gamma secretion by allogeneic T cells. The effects of PLA_2 on DC maturation was mainly dependent on enzyme activity and correlated with the activation of NF-κB, AP-1 and NFAT. The data suggest that transient increase in PLA_2 activity generates signals that promote transition of innate to adaptive immunity during the APR.

MESH Keywords Catalytic Domain ; Cell Differentiation ; immunology ; physiology ; Dendritic Cells ; enzymology ; immunology ; physiology ; Humans ; Phenotype ; Phospholipases A ; metabolism ; Phospholipases A2 ; Transcription Factors ; metabolism

Author Keywords dendritic cells ; acute-phase reactants ; lipid mediators ; inflammation ; immunomodulators

Introduction

The acute phase response (APR) is a non specific physiological response to aggression of the organism whose main function is to favor tissue repair and pathogen elimination. This alarm system can be triggered by different kinds of stress such as injury, physical trauma or infection and result in the release of inflammatory mediators that induce transient and drastic modifications of plasma composition [1]. The concentration of numerous plasma proteins called acute phase reactants can be increased up to a thousand fold while that of other proteins like albumin is drastically decreased [2]. This systemic response of APR has numerous consequences especially on lipid metabolism. It is accompanied by alterations in lipoprotein composition and result in accumulation of oxidized low density lipoproteins (LDL) and generation of modified phospholipids [3, 4]. Because phospholipase A_2 (PLA_2) activity increases following cell injury and during inflammatory conditions, secretory PLA_2 can be considered as an acute phase reactant [5].

PLA_2s are enzymes that hydrolyze phospholipids at the sn-2 position to produce lysophospholipids and free fatty acids. Mammalian PLA_2 isoenzymes are subdivided into four families, including cytosolic calcium-dependent and independent PLA_2s, secretory PLA_2s ($sPLA_2$) and PAF-acetylhydrolases [6]. $sPLA_2$s are low molecular weight enzymes that use calcium as cofactor. High amounts of $sPLA_2$s are also found in snake and bee venoms. Bee venom group III sPLA2 is the major allergen of hymenoptera venom and is largely used in desensitization treatments [7]. A human group III $sPLA_2$ (hGIII $sPLA_2$) with high homology to the bee venom enzyme has recently been described [8]. High level of $sPLA_2$ has been measured in synovial fluid of rheumatoid arthritis patients [9, 10], bronchoalveolar lavage of asthmatic patients [11] or in serum of individuals with systemic inflammatory disorders such as septic shock [12], acute pancreatitis [13] and autoimmune diseases [14]. Some $sPLA_2$s were characterized as acute phase reactants playing a role in atherosclerosis by altering high and low density lipoprotein catabolism and uptake [15].

The effects of $sPLA_2$s can be associated to their catalytic properties or to the engagement of cellular receptors [16, 17]. Different types of membrane receptors for $sPLA_2$s have been identified. N-type receptors are mostly expressed in brain and bind neurotoxic $sPLA_2$ with high affinity. M-type receptors that belong to the C-type lectin family are expressed in various tissues and display low affinity for the bee venom PLA_2 (for review see [18]). Binding of PLA_2 to the mannose receptor and glycosaminoglycans has also been reported and may trigger cellular activation and release of bioactive molecules like cytokines, leukotriene B4 and platelet-activating factor (PAF) [19–21].

PLA_2 hydrolysis of PC can generate bioactive lipids such as lysophosphatidylcholine (LPC) and non esterified poly-unsaturated fatty acids that exert various effects on immune cells. We have recently shown that LPC promotes mature DC generation from differentiating

monocytes [22, 23]. Non esterified poly-unsaturated fatty acids can modulate toll-like receptor (TLR) signaling, resulting in modified activation of NF-κB [24]. Furthermore, eicosanoids which are downstream metabolites of the PLA$_2$ reaction, are involved in the regulation of functional properties of dendritic cells (DCs) with diverse effects. For instance, lipoxin A4 strongly inhibits IL-12 production by mature DCs [25], and prostaglandin E2 regulates the migratory capacity of DCs [26] and their secretion of IL-12 [27].

PLA$_2$-mediated processing of PC can generate a number of bioactive molecules with opposite effects on immunity. Since the secretion of PLA$_2$s is strongly stimulated during the acute phase response, we asked whether an increased PLA$_2$ activity can generate signals identified by the innate immune system that would promote transition to an adaptive response. Here we describe the effect of group III sPLA$_2$s on the generation of functional human DC derived from monocytes.

Results

Phenotypic maturation induced by group III sPLA$_2$

We have previously shown that LPC can induce the differentiation of mature DC directly from monocytes when it is added for the last 24 h of monocyte differentiation in the presence of GM-CSF and IL-4 [22, 23]. LPC can be generated from PC by PLA$_2$ hydrolysis. Therefore, we asked whether sPLA$_2$ could exert the same effects on differentiating monocytes. As expected, monocytes incubated for 6 days with GM-CSF and IL-4 differentiated to immature DC (control) expressing high levels of CD1a but no CD14, low levels of HLA-DR and CD40 but no CD86, CD80 and CD83 (figure 1A). When bee venom sPLA$_2$ was introduced in the culture medium for the last 24 h of differentiation, cells obtained at day 6 had the phenotype of mature DC with enhanced expression of HLA-DR, CD86, CD80, CD83 and CD40. The maturation induced by this PLA$_2$ was weaker than that induced by LPS (figure 1A), especially for the up-regulation of CD83 and CD40. The addition of the endotoxin inhibitor polymixin B had no effect on PLA$_2$-induced maturation (figure 1A) whereas it strongly inhibited an important dose of LPS (10 ng/ml) (data not shown). The maturation was dependent on the dose of PLA$_2$ and maximal CD86 induction was obtained with 5 U/ml of PLA$_2$ (figure 1B). Further experiments with bee venom PLA$_2$ were therefore realized with 5 U/ml.

Functional mature DC promoted by group III sPLA$_2$

To analyze their functional properties, PLA$_2$-treated DC were washed and co-cultured with allogeneic T cells. We found that these DC were able to stimulate IFNγ secretion (figure 2A) whereas no IL-4 nor IL-5 secretion could be detected (data not shown). The concomitant addition of polymixin B with PLA$_2$ during DC differentiation did not affect the functional maturation induced by PLA$_2$ (data not shown). To confirm the Th1 polarization of T cells, intracellular IL-4 and IFNγ synthesis by T cells was analyzed after restimulation by IL-2. T cells co-cultured with immature control DC led to a low number of IFNγ-producing cells and no production of IL-4 (figure 2B). Although with less efficiency than cells treated with 1 μg/ml LPS, PLA$_2$-generated DC increased the percentage of IFNγ-secreting T cells but not that of IL-4-producing T cells (figure 2B). Therefore, bee venom PLA$_2$ was able to generate mature DC that have the ability to induce a Th1-oriented response in vitro. This polarization could not be explained by IL-12 secretion, since PLA$_2$-treated cells did not secrete IL-12p70 and secreted small amounts of IL-12p40 (43 ± 29 pg/ml) that were only slightly above that of untreated cells (13 ± 9 pg/ml).

The catalytic domain of human group III sPLA$_2$ induces DC maturation

The catalytic domain of the human homologue of group III bee-venom PLA$_2$ (hGIII sPLA$_2$), that was produced as a recombinant protein in S2 insect cells and purified to homogeneity [28] also induced the maturation of DC, enhancing the expression of presenting and costimulatory molecules (figure 3A). These cells were functionally mature since they also stimulated the secretion of IFNγ by allogeneic T cells (figure 3B). Because of the rarity of this purified human PLA$_2$, the following experiments were performed with the bee venom enzyme.

PLA$_2$ binding and internalization by DCs

Bee venom PLA$_2$ was labeled with fluorescent Alexa488 to follow its binding and internalization by cells. Differentiating monocytes were harvested at day 5 (before any treatment by PLA$_2$) and incubated on ice with increasing doses of fluorescent PLA$_2$. The binding of PLA$_2$ on cells was low, especially at the dose of 4 μg/ml, corresponding to the optimal active dose of 5 U/ml. Nevertheless, PLA$_2$ binding reached saturation at 8 μg/ml (~500 nM) for 10^6 cells (figure 4A). This binding could be inhibited by competition with nonlabeled PLA$_2$ and 80 % inhibition was observed with a ten-fold excess of non-labeled PLA$_2$ (figure 4B). The data suggest that PLA$_2$ binds to a specific receptor. The high concentration of bee venom PLA$_2$ (~500 nM) necessary to reach saturation suggests that this receptor may be of low affinity. Chelation of calcium by 2 mM EDTA and addition of 5 μg/ml of mannan inhibited the binding of Alexa-PLA$_2$ by 50 % and inhibitions by mannan and EDTA were not additive (data not shown), suggesting that at least one C-type lectin is involved in PLA$_2$ binding to differentiating monocytes. These results may be in line with those of Mukhopadhyay and Stahl showing that bee venom PLA$_2$ binds to the macrophage mannose receptor (CD206) [29], a C-type lectin that is expressed on immature DCs.

When the enzyme was incubated with cells at 37°C, the fluorescent PLA$_2$ was efficiently and rapidly internalized (figure 4C). Internalized PLA$_2$ could be visualized by a punctuated labeling in almost all cells (figure 4D). Binding/Internalization experiments revealed that the membrane receptor for PLA$_2$ could trigger internalization of its ligand (figure 4E). Therefore, during the 24 h treatment of DC, PLA$_2$ is likely to be internalized by both receptor-mediated endocytosis and constitutive pinocytosis which is highly efficient in immature DCs. The relative contribution of each pathway remains to be determined.

Mechanism of action of sPLA$_2$

The effect of PLA$_2$ on DCs may be due either to a direct enzymatic effect or to membrane signals induced by PLA$_2$ binding to surface receptors. The catalytic activity of the enzyme can be inactivated by progressive heating at 95°C, as measured by hydrolysis of arachidonoyl-thio-PC (figure 5A). After denaturation of PLA$_2$ for various periods of time (0 to 30 min), the same amount of enzyme (4 μg/ml) was added to the culture medium at day 5 of monocyte differentiation. The maturation state of the cells was estimated 24 hours later by analyzing their phenotype. We previously observed that CD86 is the most sensitive and reliable marker of activation, therefore CD86 expression was plotted according to the enzyme activity measured after heating (figure 5B). The induction of maturation correlated with the phospholipase activity, with a drastic decrease in CD86 induction when PLA$_2$ was heated for only 5 min. After heat-inactivation of the enzyme for 30 min, its binding to DCs was not affected (figure 5C), indicating that sPLA$_2$ binding is not involved or not sufficient by itself to induce DC activation. Thus, the generation of mature DC by PLA$_2$ appears to depend on the enzyme activity.

Transcription factors activated by sPLA$_2$

Activation signals of DC can induce maturation through several distinct pathways. Signals like those engaging Toll-Like Receptors (TLR) or inflammatory cytokine receptors result in the activation of NF-κB. Others like DC maturation triggered by FcR or LPC are independent of NF-κB. The role of nuclear factors was studied by electrophoretic mobility shift assays (EMSA) using specific DNA probes. As shown in figure 6 (A and C), NF-κB is activated by PLA$_2$ treatment. NF-κB binding activity is induced after 4 hours of treatment with PLA$_2$ and remains highly activated after 24 hours. PLA$_2$ treatment also induced the activation of AP-1 and NFAT (figure 6B–C). Peroxisome proliferator-activated receptors gamma (PPARγ) are ligand–dependent transcription factors that are inhibited by LPC and activated by lipids such as HODE and HETE derived from linoleic and arachidonic acid [30]. They are involved in the regulation of inflammation and lipid metabolism. Using a DNA probe containing a peroxisome proliferator response element from CD36 promoter, no significant variation of PPARγ could be observed (figure 6B–C).

Discussion

The aim of this work was to determine whether an increase in sPLA$_2$ activity resulted in the release of endogenous lipid signals that can be detected by the innate immune system. In this paper, it is shown that treatment of differentiating monocytes by the bee venom PLA$_2$ and the catalytic domain of hGIII sPLA$_2$ generates cells with phenotypic and functional characteristics of mature DCs. PLA$_2$-generated DC could activate a Th1 type response by allogeneic T cells, inducing the secretion of IFNγ but not that of IL-4. Although the bee venom PLA$_2$ binds to specific membrane receptors on DCs, its biological effects seem to be associated to its enzymatic activity. We could exclude PLA$_2$ contamination by endotoxins because: i, polymixin B did not affect PLA$_2$-induced phenotypic and functional maturation, ii, sPLA$_2$ did not induce important secretion of IL-12 and iii, heating of the enzyme completely abolished its effect. PLA$_2$ treatment leading to mature DC generation also activated transcriptional factors known to be involved in the activation and regulation of an immune response. The data supported and extended the notion recently proposed that lipid mediators, whose production is highly controlled during the APR, may play a central role in immunoregulation.

The biological effect of the bee venom PLA$_2$ on DCs appears dependent on its enzymatic activity. Although most of the study was performed with bee-venom PLA$_2$, similar data were obtained with the highly purified catalytic domain of hGIII sPLA$_2$. Several other PLA2 may also participate to DC maturation in vivo. For instance, the lipoprotein-associated plasmatic PLA$_2$ also called PAF-acetylhydrolase hydrolyzes oxidized phospholipids with shortened fatty acid in sn-2 position, increasing LPC content in oxLDL [31]. The human group IIA, V or X sPLA$_2$s produced under inflammatory conditions can also modify lipoproteins and generate high amounts of LPC in LDL [32–34]. Lipolytic modifications of LDL by bee venom PLA$_2$ increased the affinity of LDL for proteoglycans and glycosaminoglycans [35]. Under our experimental conditions, addition of purified LDL in the culture medium did not enhance PLA$_2$ effect on DC generation (data not shown). This may be due to the presence of albumin which is known to retain and inactivate fatty acids and lysophospholipids generated by PLA$_2$ hydrolysis of native lipoproteins. Therefore these lipid mediators are likely to be the most efficient when generated via PLA$_2$-mediated processing of membrane phospholipids. PLA$_2$ could also hydrolyze phospholipids from membranes of endocytic compartments following internalization of the enzyme. Human group II, V, X and XII as well as human and bee-venom group

III sPLA$_2$ have been reported to generate external lipid mediators and hydrolyze phospholipids from the outer membrane leaflet [28, 36]. Lipids generated at the cell membrane may be directly detected by membrane receptors or enter the cells to be metabolized or directly interact with nuclear receptors.

The treatment of DCs with the bee venom PLA$_2$ results in NF-κB, AP-1 and NFAT activation. These transcription factors control the expression of numerous genes involved in the regulation of immunity. The role of NF-κB in DC maturation has been extensively studied [37–39]. This nuclear factor regulates genes involved in inflammation such as inflammatory cytokines (IL-1β, TNFα, IL-12, etc…) and chemokines (IL-8, MCP, etc…). It is also implicated in LPS, CD40 or TLR-induced DC maturation. NFAT has been widely studied in T-cell activation where it plays a key role in antigen receptor-mediated responses by controlling the expression of a number of genes including cytokines such as IL-2, IL-4, TNFα, IFNγ and ligands such as CD40 and Fas ligand (reviewed by [40]). AP-1 proteins are regulated by PKC and Ras/Rac dependent pathways. AP-1 and NFAT transcription factors can form stable complexes that bind composite NFAT:AP-1 DNA sites. These composite sites have been identified in genes involved in the immune response such as IL-2, GM-CSF and IFNγ [41]. Activation of these transcription factors may reflect the diversity of bioactive molecules generated under PLA$_2$ treatment and may be an efficient way to integrate complex signals, enabling a fine tuning of biological responses. PLA$_2$-induced generation of mature DC probably results from the combined effects of several lipid mediators produced directly or indirectly by this enzyme. Among the various molecules resulting from PLA$_2$ activity, LPC was the best candidate to mediate PLA$_2$ effects on DC. Indeed, using the experimental procedures described above, we have shown previously that LPC is the major lipid mediator of oxidized LDL that can promote mature DC generation from differentiating monocytes by a G-protein coupled membrane receptor dependent pathway [22]. However, the transcription factors activated by LPC are different from those activated after bee venom PLA$_2$ treatment [30]. Therefore, LPC is unlikely to be directly responsible for the effects of PLA$_2$ on DC generation. Activation of NF-κB may be initiated by derivatives of both LPC and arachidonic acid. Further work is required to identify the lipid mediators and their signaling pathway.

Although bee venom sPLA$_2$ is a major allergen in humans, PLA$_2$-generated DC do not display a Th2-type function in vitro when cells are obtained from non-allergic donors. Accordingly, it is known for other allergens such as Der p 1, one of the major allergens of the house dust mite, that Th2 polarization of monocyte-derived DC is due to the allergic status of the donor [42]. It would therefore be interesting to compare the effects of PLA$_2$ on monocytes and DC from allergic versus non allergic individuals and to know whether environmental factors including histamine could reorient the function of PLA$_2$-generated DC toward a Th2-type as previously observed for LPS [43]. The overall data presented here suggest that sPLA$_2$ like bee venom or hGIII PLA$_2$ can generate lipid mediators with immunoregulatory functions in vitro. Increased PLA$_2$ activity during the APR may thus favor the development of the adaptive arm of immunity.

Material and methods

Differentiation of monocyte-derived dendritic cells

PBMC were isolated from human peripheral blood by density gradient centrifugation on Ficoll-Hypaque (Amersham Biosciences, Uppsala, Sweden). Mononuclear cells were separated from PBL by centrifugation on a 50 % Percoll solution. Monocytes were purified by immunomagnetic depletion (Dynal, Oslo, Norway) using a cocktail of monoclonal Abs anti-CD19 (4G7 hybridoma), anti-CD3 (OKT3, ATCC, Rockville, MD, USA) and anti-CD56 (NKH1, Beckman Coulter, Fullerton, CA, USA). Monocytes were more than 90 % pure as assessed by CD14 labeling. Monocytes were differentiated to immature DC during 6 days with 40 ng/ml human recombinant GM-CSF and 250 U/ml human recombinant IL-4 in RPMI 1640 (Life Technologies, Rockville, MD, USA) supplemented with 2 mM glutamine (Life Technologies), 10 mM Hepes (Life Technologies), 40 ng/ml gentamycin (Life Technologies) and 10 % lipoprotein-deficient fetal calf serum (LPDS, Sigma, St Quentin-Fallavier, France). At the end of the differentiation (day 6), cells were harvested and analyzed. Cells were CD14$^-$ CD1a$^+$ and viability was superior to 90 %.

PLA$_2$ treatment

Bee venom PLA$_2$ (Sigma; min. purity 87%; 1360 U/mg protein; one unit will hydrolyze 1.0 µmole of soybean L-α-phosphatidylcholine per min at pH 8.9 and 25°C) was dissolved in 100 mM Hepes buffer pH 8.5, aliquoted and stored at −20°C. The catalytic domain of the human group III sPLA$_2$ was produced in insect cells and purified as previously described [28]. A 50X solution of PLA$_2$ was prepared extemporaneously by dilution in 100 mM Hepes/5 mM CaCl$_2$ pH 8.5 buffer and 20 µl was added to 1 ml of differentiating DC at day 5. Cells were incubated for 24 h with the indicated doses of PLA$_2$ or LPS (1 µg/ml). Control cells were incubated with 20 µl of buffer alone. At day 6, cells and supernatants were harvested and analyzed. When indicated, polymixin B (10 µg/ml; Sigma) was added to the culture 10 min before sPLA$_2$ (5 U/ml) or LPS (10 ng/ml) addition.

PLA$_2$ inactivation

sPLA$_2$ (250 U/ml) in Hepes-CaCl$_2$ buffer was heated at 95°C for 5 to 30 min and the enzyme was kept on ice until the assay. Enzyme activity was assayed by arachidonoyl-thio-PC hydrolysis (Cayman Chemicals, Ann Arbor, MI, USA) as described [44]. 5 µl of buffer (150

mM NaCl/10 mM CaCl$_2$/80 mM Hepes/4 mM Triton X-100/30 % glycerol/1 mg/ml BSA pH 7.4) was added to 10 µl of heated PLA$_2$ and incubated for 60 min at room temperature with 200 µl of 1.5 mM arachidonoyl-thio-PC in the same buffer. After addition of 10 µl of DTNB/EGTA solution (25 mM DTNB/475 mM EGTA/0.5 M Tris-HCl pH 8) and incubation 5 min, the absorbance at 414 nm was measured against the blank without PLA$_2$. Enzymatic activity was measured in µmol of arachidonoyl-thio-PC hydrolyzed/min/ml.

Phenotype analysis

Phenotype was analyzed by flow cytometry on a FACSCalibur (Becton Dickinson, Franklin Lakes, NJ, USA) using FITC-conjugated anti-CD14, −HLA-DR, −CD80 and PE-conjugated anti-CD1a, −CD83, −CD86 all from Beckman Coulter.

Mixed leukocyte reaction (MLR)

PBMC were isolated by density gradient centrifugation on Ficoll-Hypaque. After depletion of monocytes on Percoll gradient, PBL were recovered in the dense fraction. T lymphocytes were purified by immunomagnetic depletion using a cocktail of monoclonal Abs anti-CD19 (4G7), anti-CD16 (3G8), anti-CD56 (NKH1), anti-glycophorin A (11E4B7.6) and anti-CD14 (RMO52) all from Beckman Coulter. T lymphocytes were more than 95 % pure as assessed by CD3 labeling. Primary MLRs were conducted in 96-well flat-bottom culture plates. DC were treated or not at day 5 with PLA$_2$, collected at day 6, extensively washed and resuspended in RPMI 1640 supplemented with 2 mM glutamine, 10 mM hepes, 40 ng/ml gentamycin and 10 % FCS (BioMedia, Boussens, France). Cells were then co-cultured with 2×10^5 allogeneic T cells in 200 µl complete culture medium at 1/5, 1/10, 1/20 or 1/40 DC/T cells ratio. After 4 days, culture supernatants were tested for the presence of IFNγ by ELISA. To detect intracellular IL-4 and IFNγ, 2.10^4 DC were co-cultured with 2.10^5 allogeneic T cells for 5 days. Cells were restimulated with 100 U/ml recombinant IL-2 (Chiron) for 7 days. Cells were washed and incubated with 10 ng/ml PMA and 1 µg/ml ionomycin for 5h. 10 µg/ml brefeldin A was added for the last 2h. Cells were washed, fixed and permeabilized with cytofix/cytoperm solution (Becton Dickinson) and labeled with anti-IFNγ-FITC and anti-IL-4-PE (Becton Dickinson).

Cytokine measurement

Culture supernatants were aliquoted and stored at −80°C. IL-12p40 and IFNγ levels were determined using ELISA kits from Biosource (Camarillo, CA, USA) and Endogen (Woburn, MA, USA) respectively. IL-12p70 was assayed using the human Th1/Th2 Cytometric Bead Array system (BD Biosciences).

PLA$_2$ binding and internalization

Bee venom sPLA$_2$ (2 mg/ml) was labeled with Alexa488-protein labeling kit (Molecular Probes, Leiden, The Netherlands). Free Alexa488 was removed by gel filtration and labeled protein was recovered in PBS at 1.18 mg/ml.

The binding of Alexa488-PLA2 was performed on differentiating cells harvested at day 5 and resuspended in culture medium. Alexa488-PLA$_2$ was incubated with cells (10^6/ml) for 20 min on ice. In competition experiments, non labeled PLA$_2$ was added into the medium 10 min prior to incubation with Alexa488-PLA$_2$ on ice.

Internalization was carried out at 37°C for 2 to 20 min in RPMI/10 % LPDS medium. To follow receptor-mediated endocytosis, cells were first incubated on ice for 20 min with 10 µg/ml Alexa488-PLA$_2$, washed twice at 4°C, and then incubated at 37°C for 10 min. Internalization was stopped on ice with cold PBS containing 0.1 % BSA and 0.05 % NaN$_3$. Cells were washed three times at 4°C in this buffer and analyzed by flow cytometry and fluorescence microscopy after cytospin and fixation. Slides were observed with the Leica DM IRB/E microscope or the Axioplan2 LSM510 Confocal microscope (Zeiss).

Electrophoretic Mobility Shift Assay (EMSA)

Differentiating cells were treated with 5 U/ml PLA$_2$ at day 5 for the indicated times (0, 2, 4, 8 or 24 h) as described above. After treatment, cells (4×10^6) were harvested and nuclear proteins were extracted: cells were washed twice with PBS, resuspended in 400 µl of ice-cold hypotonic buffer (10 mM Hepes (pH 7.9)/10 mM KCl/0.01M DTT/1.5mM MgCl$_2$/1X protease inhibitor cocktail (Sigma)), left on ice for 10 min, vortexed and centrifuged at 15,000 g for 1 min at 4°C. Sedimented nuclei were resuspended in 40 µl ice-cold saline buffer (20 mM Hepes (pH 7.9)/420 mM NaCl/0.2 mM EDTA/1.5 mM MgCl$_2$/25% glycerol/1X protease inhibitor mixture (Sigma)), left on ice for 20 min, vortexed and centrifuged at 15,000 g for 5 min at 4°C. Nuclear protein concentrations were determined by Micro-BCA Protein Assay Reagent (Pierce, Rockford, IL, USA). The binding activity of nuclear proteins was determined using specific DNA probes as described [30]. Sequences of the double-stranded oligonucleotide used for detection of NF-κB: 5′-AGTTGAGGGGACTTTCCCAGG-3′; PPAR: 5′-GGGGTCAGTAAGTCAGAGGCCAGGGA-3′; AP-1: 5′-GTGACTCATGACTCATGACTCATGACTC-3′; NFAT consensus: 5′-CGCCCAAAGAGGAAAATTTGTTTCATA-3′. Oligonucleotides were end-labeled with [γ-^{32}P]ATP (Amersham Biosciences) by T4 polynucleotide kinase (New England Biolab, Beverly, MA). For the binding reaction, 1 µg of nuclear extract was added to a reaction mixture containing 2 µg of poly (dI-dC) (Amersham Biosciences), 4 µl of 5X binding buffer (final concentration: 10 mM Tris (pH 7.5)/50

mM NaCl/1 mM DTT/1 mM EDTA/5% glycerol), and 50000 cpm of [^{32}P]-labeled oligonucleotide in a final volume of 20 μl and were incubated at room temperature for 20 min. Unlabeled competitor oligonucleotide was added in 50-fold excess to confirm the specificity of the binding reaction. The same amount of total protein was loaded on a 4% polyacrylamide non denaturing gel and DNA-protein complexes were separated from unbound DNA probe by electrophoresis in 0.5X Tris-glycine EDTA buffer. Gels were visualized using a Typhoon PhosphorImager (Molecular Dynamics, Sunnyvale, CA). Image Master software (Amersham Biosciences) was used for quantification of band intensities that were normalized to non specific background.

Ackowledgements:

Abbreviations

APR: acute phase response

LDL: low density lipoprotein

LPC: lysophosphatidylcholine

LPDS: lipoprotein deficient serum

oxLDL: oxidized low density lipoprotein

PAF: platelet-activating factor

PLA$_2$: phospholipase A$_2$

PC: phosphatidylcholine

PPAR: peroxisome proliferator-activated receptor

sPLA$_2$: secreted PLA$_2$, hGIII sPLA2, human group III sPLA2

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Fig. 1

Phenotypic maturation induced by bee venom PLA$_2$

Monocytes were differentiated in LPDS medium containing GM-CSF and IL-4 [22, 23]. Cells were treated or not at day 5 with PLA$_2$ or LPS and analyzed at day 6. A, Phenotype of cells treated with 5 U/ml PLA$_2$ (filled profile), 5 U/ml PLA$_2$ + polymixin (bold line), 10 ng/ml LPS (dotted line) or untreated control cells (thin line). B, Increasing concentrations of PLA$_2$ (0, 2, 5 or 10 U/ml) were added at day 5 and CD86 expression was analyzed at day 6. Data represent mean fluorescent intensities (mfi) normalized at 100 for control non-treated cells. Mean ± S.D. of three experiments.
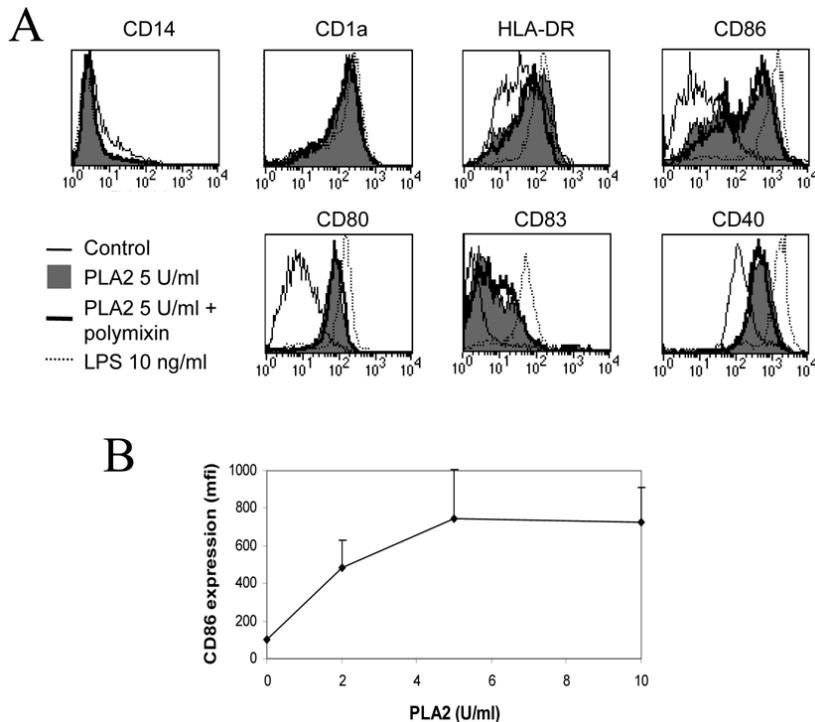
Fig. 2

Functional maturation induced by bee venom PLA$_2$

Monocytes were differentiated in LPDS medium containing GM-CSF and IL-4. Cells were treated or not at day 5 by addition of 5 U/ml PLA$_2$ or 1µg/ml LPS and harvested at day 6. A, Control immature DC or PLA$_2$-generated DC were harvested at day 6, washed and cultured for 4 days with allogeneic purified T cells (2×10^5/well) at DC/T cell ratios ranging between 1/5 and 1/40. The amount of IFNγ in the supernatants of the coculture was measured by ELISA. B, Control immature DC, PLA$_2$-generated DC or LPS-treated DC were harvested at day 6, washed and cultured for 5 days with allogeneic purified T cells (2×10^5/well) at 1/10 DC/T cell ratio. Cells were expanded with 100 U/ml IL-2 for 7 days, washed and restimulated with PMA and ionomycin for 5 hours. Brefeldin A was added for the last 2 hours and cells were processed for intracellular labeling with anti-IFNγ-FITC and anti-IL-4-PE.
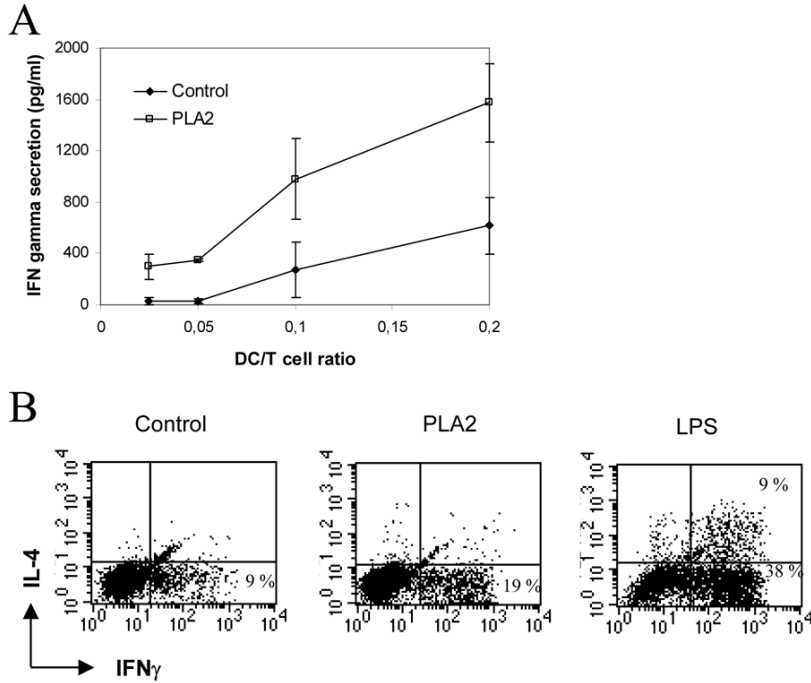
Fig. 3

Phenotypic and functional maturation induced by the catalytic domain of hGIII-sPLA$_2$

Monocytes were differentiated in LPDS medium containing GM-CSF and IL-4. Cells were treated or not at day 5 by addition of 700 nM hGIII sPLA$_2$ and analyzed at day 6. A, Phenotype of cells treated or not with hGIII sPLA$_2$. Data represent mean fluorescent intensities normalized at 100 % for control non-treated cells. B, 10^4 control immature DC or hGIII sPLA$_2$ treated DC were harvested at day 6, washed and cultured for 4 days with allogeneic purified T cells (2×10^5/well). The amount of IFNγ in the supernatants of the coculture was measured by ELISA.
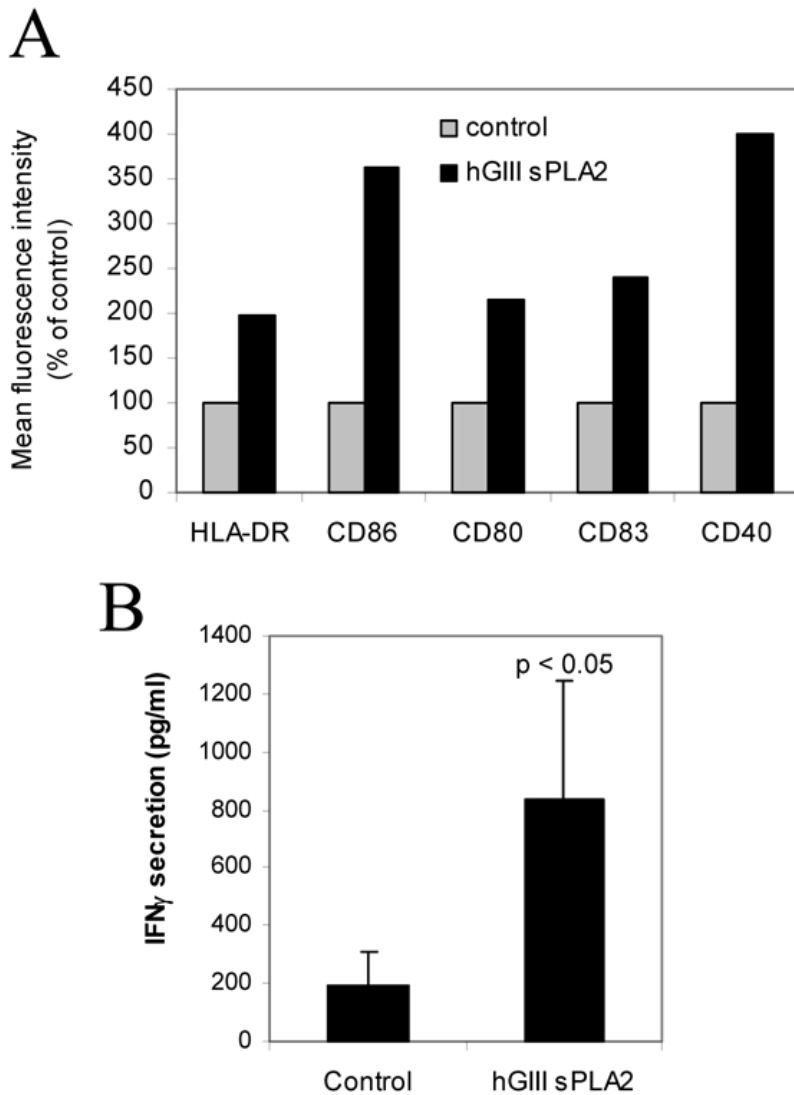
Fig. 4

Binding and internalization of PLA_2

Monocytes were differentiated in LPDS medium containing GM-CSF and IL-4 for 5 days. Cells were washed and resuspended in cold LPDS medium. A, Cells were incubated on ice for 20 min with increasing doses of Alexa488- PLA_2 (0, 4, 8, 16 or 32 µg/ml). After washings, the amount of bound fluorescent PLA_2 was measured by flow cytometry. Data represent mean ± S.D. from mean fluorescent intensities (mfi) of three experiments. B, Cells were incubated on ice for 20 min with increasing amounts of non labeled PLA_2 (20, 50, 100 or 200 µg/ml) and 20 µg/ml Alexa488-PLA_2. After washing, mean fluorescent intensity of cells was measured by flow cytometry. Data are expressed in percentage of PLA_2 binding without competitor. C, Cells were incubated with 2 µg/ml Alexa488-PLA_2 at 37°C or on ice, washed and analyzed by flow cytometry. D, Cells were incubated with 4 µg/ml Alexa488-PLA_2 on ice (up) or at 37°C (bottom), washed and observed in transmission (left) or fluorescence (right) microscopy. E, Receptor-mediated endocytosis: cells were incubated with 10 µg/ml Alexa488-PLA_2 on ice for 20 min, washed and incubated at 37°C for 10 min. Cells were washed and analyzed by confocal microscopy.
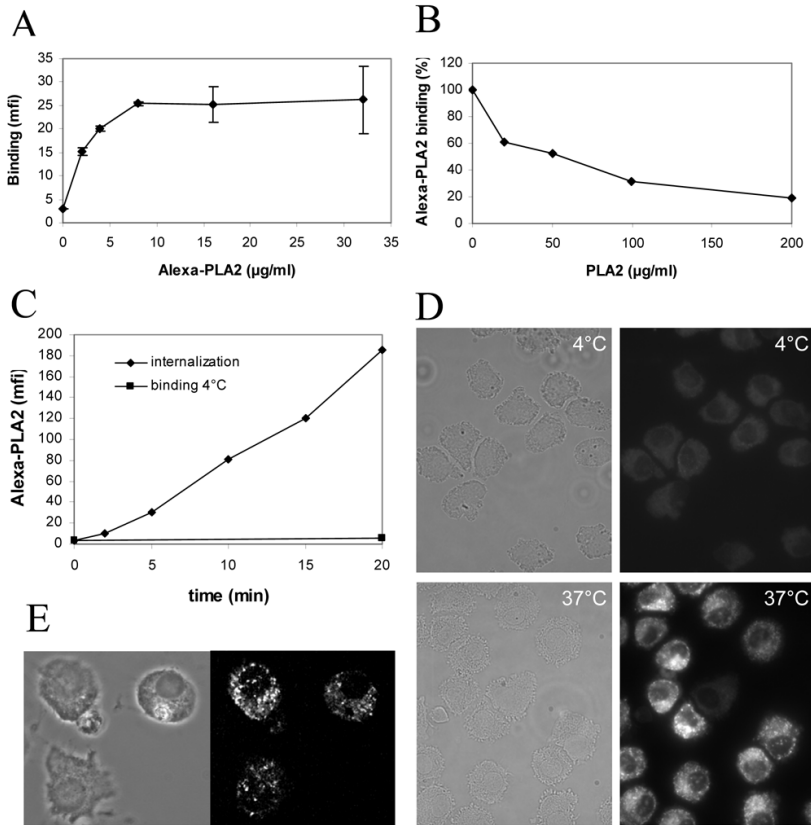
Fig. 5

Phospholipase activity is essential to induce DC maturation

PLA_2 in Hepes-$CaCl_2$ buffer was heated or not at 95°C for 5 to 30 min. A, Enzyme activity was assayed by arachidonoyl-thio-PC hydrolysis. B, Monocytes differentiating to DC were treated at day 5 with 4 µg/ml of PLA_2 heated for the indicated time. Cells were harvested at day 6 and their phenotype was analyzed. CD86 expression by PLA_2 treated cells was plotted against the heating time of PLA_2. C, Differentiating cells were washed at day 5, resuspended in cold LPDS medium and incubated for 20 min on ice with 4 µg/ml native PLA_2 or 4 µg/ml denatured PLA_2 (95°C for 30 min). Binding was measured as in figure 3.
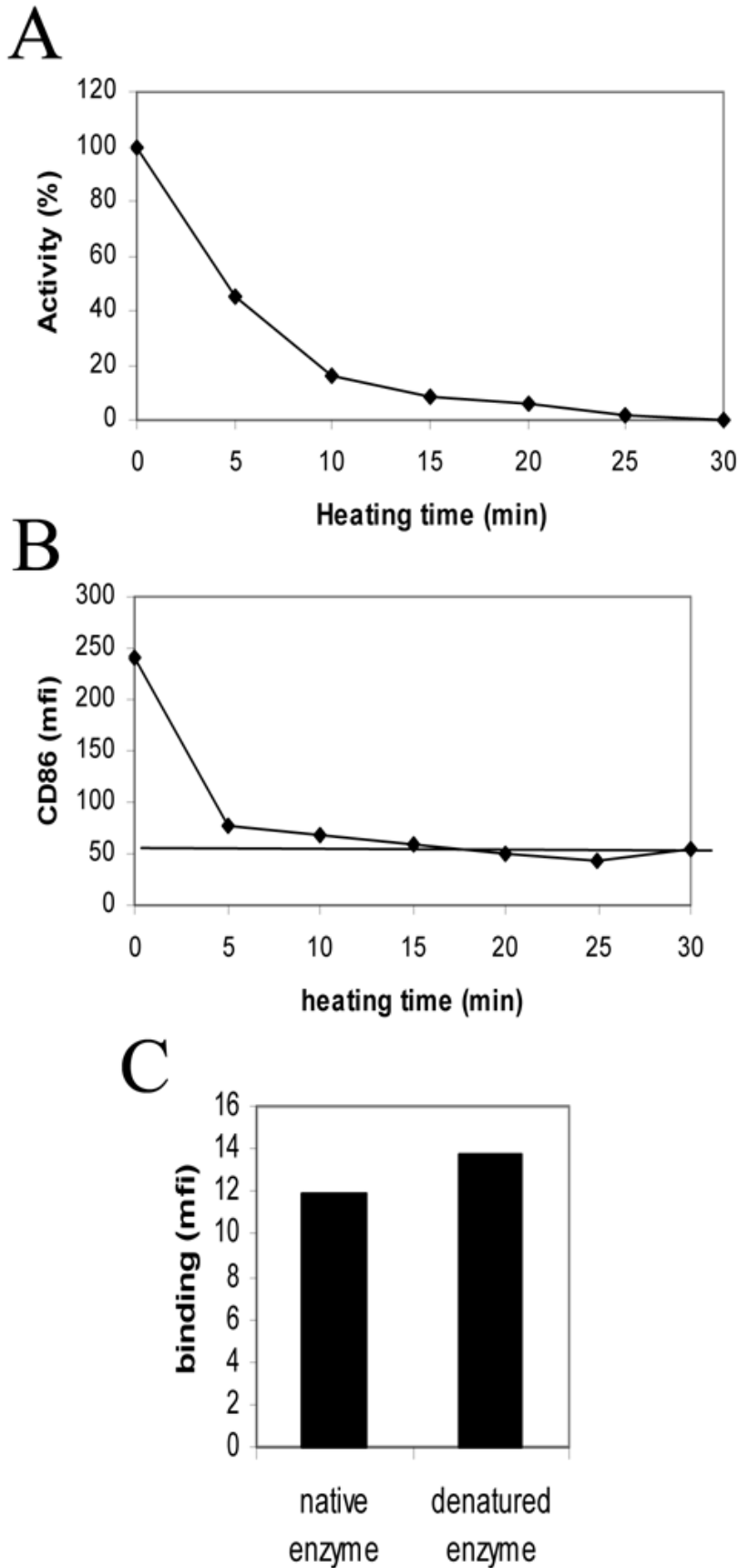
Fig. 6

EMSA on nuclear extracts from PLA$_2$-generated DC

Monocytes differentiating to DC were treated at day 5 with 5 U/ml PLA$_2$ for the indicated period of time. Cells were harvested and nuclear extracts prepared as described. Equal quantities of nuclear proteins were run for EMSA analysis, using ^{32}P-labeled DNA probes specific for NF-κB (A), AP-1, NFAT and PPARγ (B). The specificity of binding was shown by competition with non labeled probe in excess (lane C). C, Binding activity of the above transcription factors was determined by quantification of band intensities on gel shift assays using Image Master software.