Arteriosclerosis, Thrombosis, and Vascular Biology

JOURNAL OF THE AMERICAN HEART ASSOCIATION

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Arterioscler. Thromb. Vasc. Biol. 2007;27;587-593; originally published online Dec 28, 2006;

DOI: 10.1161/01.ATV.0000256467.25384.c6

Arteriosclerosis, Thrombosis, and Vascular Biology is published by the American Heart Association. 7272 Greenville Avenue, Dallas, TX 72514

 Print ISSN: 1079-5642. Online ISSN: 1524-4636

Phagocytic NADPH Oxidase-Dependent Superoxide Production Stimulates Matrix Metalloproteinase-9

Implications for Human Atherosclerosis

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Objective—Data suggest that matrix metalloproteinase-9 (MMP-9) has a role in atherosclerosis. The phagocytic NADPH oxidase has been also associated with atherosclerosis. This study aimed to investigate the association between phagocytic NADPH oxidase and MMP-9 in human atherosclerosis.

Methods and Results—In vitro experiments performed in human monocytes showed that NADPH oxidase activation enhanced MMP-9 secretion and activity, determined by enzyme-linked immunosorbent assay and zymography, respectively. Immunohistochemical study showed that phagocytic NADPH oxidase localized with MMP-9 in endarterectomies from patients with carotid stenosis. In addition, a positive relationship ($P<0.001$) was found between phagocytic NADPH oxidase-dependent superoxide production determined with lucigenin and plasma MMP-9 levels in 188 asymptomatic subjects free of overt clinical atherosclerosis. In multivariate analysis, this association remained significant after adjustment for cardiovascular risk factors. Interestingly, subjects in the upper quartile of superoxide production exhibited the highest values of MMP-9, oxidized low-density lipoprotein, nitrotyrosine, carotid intima media thickness, and an increased presence of carotid plaques.

Conclusions—Enhanced NADPH oxidase-dependent $\cdot O_2^-$ production stimulates MMP-9 in monocytes and this relationship may be relevant in the atherosclerotic process. Moreover, MMP-9 emerges as an important mediator of the phagocytic NADPH oxidase-dependent oxidative stress in atherosclerosis. **(*Arterioscler Thromb Vasc Biol*. 2007;27: 587-593.)**

Key Words: atherosclerosis ■ NADPH oxidase ■ superoxide ■ MMP

The NADPH oxidase systems, which constitute the most important sources of superoxide ($\cdot O_2^-$) in the vessel wall, are present in endothelial cells, smooth muscle cells (SMCs), fibroblasts, and infiltrated monocytes/macrophages.[1,2] The phagocytic NADPH oxidase consists of a membrane-associated cytochrome b_{558}, which comprises $gp91^{phox}$ and $p22^{phox}$ subunits, and cytosolic components $p47^{phox}$, $p67^{phox}$, and rac.[2]

Several studies have shown a key role for vascular NADPH oxidase isoforms in the development of human atherosclerosis.[3–7] Interestingly, phagocytic NADPH oxidase seems to play also a key role in the development and progression of atherosclerotic lesion.[5–7] Recently, enhanced phagocytic NADPH oxidase-dependent $\cdot O_2^-$ production has been correlated positively with carotid intima-media thickness (IMT), a surrogate marker of atherosclerosis.[8]

Metalloproteinases (MMPs) are a family of zinc-dependent endopeptidases capable as a class of degrading extracellular matrix components, which participate in the atherosclerotic process by remodeling the extracellular matrix.[9] Available evidence substantiates that plasma MMP-9 levels correlate with the presence of atherosclerosis[10] and represent an independent risk factor for atherothrombotic events (ie, coronary heart disease events and cerebrovascular disease).[11,12] Thus, plasma MMP-9 levels can provide a useful emerging plasma biomarker in the prediction of atherothrombotic events.[13] Whereas NADPH oxidase-mediated $\cdot O_2^-$ generation participates in MMP-2 and MMP-9 activation in cardiomyocytes, endothelial cells, and SMCs,[14–18] no data are available on its ability to regulate MMPs in blood phagocytic cells. We therefore hypothesized that an association may exist between phagocytic NADPH oxidase and MMP-9 in human atherosclerosis. To test this hypothesis, we performed the study at 3 levels; (1) we analyzed in vitro the ability of NADPH oxidase to regulate MMP-9 in human monocytes; (2) we studied the association between NADPH oxidase and MMP-9 in athero-

Original received July 27, 2006; final version accepted December 7, 2006.

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Arterioscler Thromb Vasc Biol. **is available at http://www.atvbaha.org** **DOI: 10.1161/01.ATV.0000256467.25384.c6**

sclerotic plaques from endarterectomy specimens; and (3) we explored the relationship of NADPH oxidase with plasma MMP-9 and carotid atherosclerosis in asymptomatic subjects.

Patients and Methods

Cell Culture Experiments

Human monocytes were isolated from peripheral blood mononuclear cells with the MACS Column Technology (Miltenyi Biotec) and maintained in RPMI 1640 supplemented with 0.2% fetal calf serum. Human THP-1 macrophagic cell line was obtained from ATCC, and was maintained in RPMI 1640 supplemented with 10% fetal calf serum. For experiments, cells (500000 cells/mL) were maintained in RPMI 1640 supplemented with 0.2% fetal calf serum for 24 hours. After this period of time, cells were incubated with phorbol myristate acetate (PMA, 6.4×10^{-8} mol/L) in the presence and the absence of apocynin, a specific intracellular inhibitor of NADPH oxidase assembly.

Detection In Vitro of $\cdot O_2^-$ Generation

We measured $\cdot O_2^-$ production in human monocytes in the presence of 5 μmol/L lucigenin. Luminescence was measured for 30 minutes in a plaque luminometer. A buffer blank was subtracted from each reading. Data were expressed as relative light units produced per second. In some experiments, the effects of apocynin, a NADPH oxidase inhibitor, was studied.

Determination In Vitro of MMP-9 Expression and Activity

A sandwich enzyme-linked immunosorbent assay (ELISA) (Amersham Biosciences), an assay that quantified both the precursor form and the active form complexed with the tissue inhibitor of metalloproteinase-1, was used to determine MMP-9 levels in cultured cell supernatants. MMP-9 gelatinolytic activity was assessed by zymography in supernatants from cells. Samples were prepared in nonreducing sample buffer (0.625 mmol/L Tris-HCl, 10% glycerol, 2% SDS, 2% bromphenol blue), and run through 10% zymogram gelatin gels.

Subjects

Two studies were performed. The first study was performed in 5 male patients (mean age, 67 years) undergoing carotid endarterectomy. Surgical intervention criteria were internal carotid stenosis >75%. The second study was performed in 188 consecutive apparently healthy subjects (80% men; mean age, 53 years). The criteria for defining the absence of atherosclerosis have been recently described (please see http://atvb.ahajournals.org).[8]

The studies were performed in subjects referred to our institution for global cardiovascular risk assessment. The presence of cardiovascular risk factors such as diabetes mellitus, arterial hypertension, dyslipidemia, obesity, metabolic syndrome, and smoking habits was assessed (please see http://atvb.ahajournals.org). Written informed consent was obtained from all subjects, the study was performed in accordance with the Declaration of Helsinki, and the local committee on human research approved of the study protocol.

Histochemistry

After endarterectomy, tissues were embedded in OCT in liquid N_2 and stored at −80°C. Serial sections of 7 μm were analyzed by immunohistochemistry. The primary antibodies were polyclonal antibodies anti MMP-9 (2 μg/mL, Neomarkers) and anti $p22^{phox}$, $gp91^{phox}$, $p47^{phox}$, and $p67^{phox}$ (0.4 μg/mL; Santa Cruz Biotechnology). Monoclonal anti CD-68 and anti α-actin (0.2 μg/mL; Dako) were used for detection of macrophages and SMCs, respectively. Sirius red staining was used to identify interstitial collagen on 3-μm sections as described.[19]

Detection In Situ of $\cdot O_2^-$ Generation

$\cdot O_2^-$ in atherectomies was detected by fluorescence with dihydroethidium (DHE). Unfixed frozen samples were cut into 10-μm-thick sections and placed on glass slides. DHE (10 μmol/L) was applied and incubated in a light-protected humidified chamber at 37°C for 30 minutes. The DHE image was obtained by a laser scanning confocal imaging system (Zeiss LSM-510 Meta) with a 585-nm long-pass filter. The specificity of DHE for $\cdot O_2^-$ was demonstrated by preincubating samples with CuZn-superoxide dismutase (SOD, 10 000 U/mL).

Determination In Vivo of MMP-9

A sandwich ELISA (Amersham Biosciences) was used to determine MMP-9 levels in plasma samples.

Determination In Vivo of $\cdot O_2^-$ Production

We measured $\cdot O_2^-$ production in peripheral mononuclear cells isolated from blood samples, in response to stimulation with PMA (3.2×10^{-6} mol/L), and using 5 μmol/L lucigenin as previously described (please see http://atvb.ahajournals.org).[8]

Determination of Circulating Markers of Oxidative Stress

ELISA was performed to determine plasma levels of protein-associated 3-nitrotyrosine (NT) (Hycult biotechnology) and oxidized low-density lipoprotein (Mercodia AB).

Measurement of Carotid IMT and Assessment of Carotid Plaques

Ultrasonography of the common carotid arteries was performed with a linear-array transducer (ATL 500 HDI) as previously reported.[8] Measurement of IMT was made 1 cm proximal to the carotid bulb of each common carotid artery at plaque-free sites. Atheroma plaques were defined as echogenic structures encroaching on the vessel's lumen with a distinct area 50% greater than the intimal plus media thickness of neighboring sites.

Statistical Analysis

Data are expressed as mean±SEM. The χ^2 analysis was used to search for differences for qualitative variables. Pearson correlation test was used to assess correlations between $\cdot O_2^-$ production and all continuous variables. Multivariate linear regression analysis was performed to evaluate factors related to MMP-9 levels and the possibility of interactions. For association studies, subjects were stratified according to quartiles of $\cdot O_2^-$ production (quartile 1, $\cdot O_2^-$ production <8 counts/second; quartile 2, $\cdot O_2^-$ production ≥8 and <16 counts/second; quartile 3, $\cdot O_2^-$ production ≥16 and <30 counts/second; quartile 4, $\cdot O_2^-$ production ≥30 counts/second). The cardiovascular medication intake (dichotomous: yes versus no) was tested, but revealed $P\geq0.05$. Likewise, if each class of cardiovascular medication were tested separately in the models, they were not significant covariates at the 5% test level. The linear trend of variables, according to $\cdot O_2^-$ production quartiles, was compared by use of ANOVA for continuous variables and the linear test of the χ^2 analysis for categorical variables.

Results

Study in Cultured Cells

To explore the ability of NADPH oxidase to regulate MMP-9, the effects of the NADPH oxidase-dependent $\cdot O_2^-$ production on the activity and secretion of MMP-9 were examined in fresh human monocytes isolated from five patients. First, incubation of monocytes with PMA immediately provoked a threefold enhanced $\cdot O_2^-$ generation ($P<0.01$) (Figure 1A). This effect was prevented in the presence of apocynin, in a dose-dependent way, thus supporting the notion that the

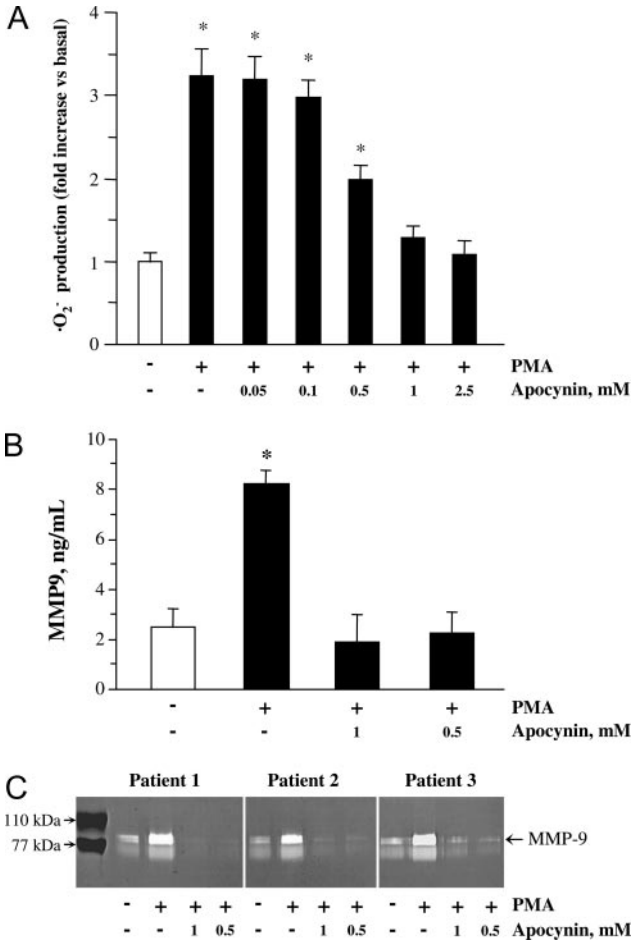

Figure 1. A, $\cdot O_2^-$ production of human monocytes. Monocytes were left untreated (baseline), or treated with PMA (6.4×10^{-8} mol/L) alone or in combination with different doses of apocynin (2.5 to 0.05 mmol/L). After stimulation, $\cdot O_2^-$ production was measured by luminescence 30 minutes in a plaque luminometer. MMP-9 (B) expression and gelatinolytic (C) activity of supernatants from human monocytes. Monocytes were left untreated (baseline), or treated with PMA (6.4×10^{-8} mol/L) alone or in combination with apocynin (1 or 0.5 mmol/L). After incubation for 24 hours, media samples were taken and analyzed by ELISA and gelatin zymography to assess MMP-9 expression and gelatinolytic activity,respectively. Experiments were performed by duplicate in monocytes isolated from 5 patients. *$P<0.01$ compared with baseline conditions.

NADPH oxidase has a key role in the PMA-induced $\cdot O_2^-$ generation. Second, incubation of human monocytes with PMA for 24 hours resulted in a 4-fold increase in secretion of MMP-9 protein ($P<0.01$) (Figure 1B). This enhanced MMP-9 secretion was associated with increased gelatinase MMP-9 activity (Figure 1C). These effects were also prevented in the presence of apocynin. These results were confirmed by similar experiments performed in THP-1 cells (supplemental Figure I, available online at http//atvb.ahajournals.org).

Study in Atherosclerotic Plaques

As shown in Figure 2 (also see supplemental Figure II), the pattern of expression of the phagocytic NADPH oxidase subunits ($p22^{phox}$, $gp91^{phox}$, $p47^{phox}$, and $p67^{phox}$) was similar to MMP-9 staining. It is noteworthy that NADPH oxidase expression was intense in the macrophage rich area and colocalized with MMP-9 staining (supplemental Figure III).

$\cdot O_2^-$ production in endarterectomies was detected by using DHE staining. $\cdot O_2^-$ was evident in all layers, although an intense area of $\cdot O_2^-$ production was observed throughout the macrophage-rich area (Figure 2). DHE fluorescence was abolished by preincubation with CuZn-SOD, demonstrating the specificity of the assay for $\cdot O_2^-$ (Figure 2). Interestingly, $\cdot O_2^-$ staining was similar to phagocytic NADPH oxidase staining.

The fibrous cap of the lesion was intensely stained for collagen fibers (Figure 2). The collagen staining was practically absent throughout the macrophage rich area. Besides, the diminished collagen staining coincided with enhanced MMP-9 expression.

These data suggest that infiltrated macrophages may favor the remodeling of atherosclerotic plaque by inducing the expression of activated MMP-9 through NADPH oxidase-dependent $\cdot O_2^-$ production.

Study in Asymptomatic Subjects

The clinical characteristics of the asymptomatic subjects are shown in Table 1. Whereas the cholesterol values were above the upper normal limit, the values of the remaining parameters tested were normal.

The values of phagocytic $\cdot O_2^-$ production and plasma MMP-9 in the whole population were 19.1 ± 1.2 counts/second and 14.8 ± 0.6 ng/mL, respectively. There was a significant positive bivariate correlation between phagocytic $\cdot O_2^-$ production and plasma levels of MMP-9 (Figure 3), which remained highly significant after controlling for age and sex (supplemental Table I). $\cdot O_2^-$ production was also significantly associated with triglycerides and body mass index, with the latter also remaining statistically significant after controlling for age and sex (supplemental Table I). When we analyzed only those subjects that were not receiving cardiovascular treatment, $\cdot O_2^-$ production was also associated with systolic blood pressure values, which remained significant after controlling for age and sex ($r=0.160$, $P=0.032$). However, plasma MMP-9 did not correlate with other analyzed variables.

In a multivariate analysis, the association between phagocytic $\cdot O_2^-$ production and MMP-9 remained statistically significant after adjusting for some potentially confounding cardiovascular risk factors (Table 2), with the $\cdot O_2^-$ production explaining up to 16% of the MMP-9 variance.

The classification of the subjects by quartiles of $\cdot O_2^-$ production showed a linear trend in MMP-9 levels ($P<0.05$) (Table 3). Furthermore, values of oxidized low-density lipoprotein and NT, 2 oxidative stress markers that have been associated with atherosclerosis, were enhanced in subjects in the fourth quartile compared with subjects in the other quartiles ($P<0.05$). Likewise, subjects in the fourth quartile exhibited higher frequency of carotid plaques and increased carotid IMT compared with subjects in the other quartiles ($P<0.05$) (Table 3). Interestingly, carotid IMT exhibited a positive bivariate correlation with $\cdot O_2^-$ production ($r=0.262$, $P=0.001$) and MMP-9 ($r=0.181$, $P=0.017$), after controlling for age and sex. Finally, subjects in the fourth quartile

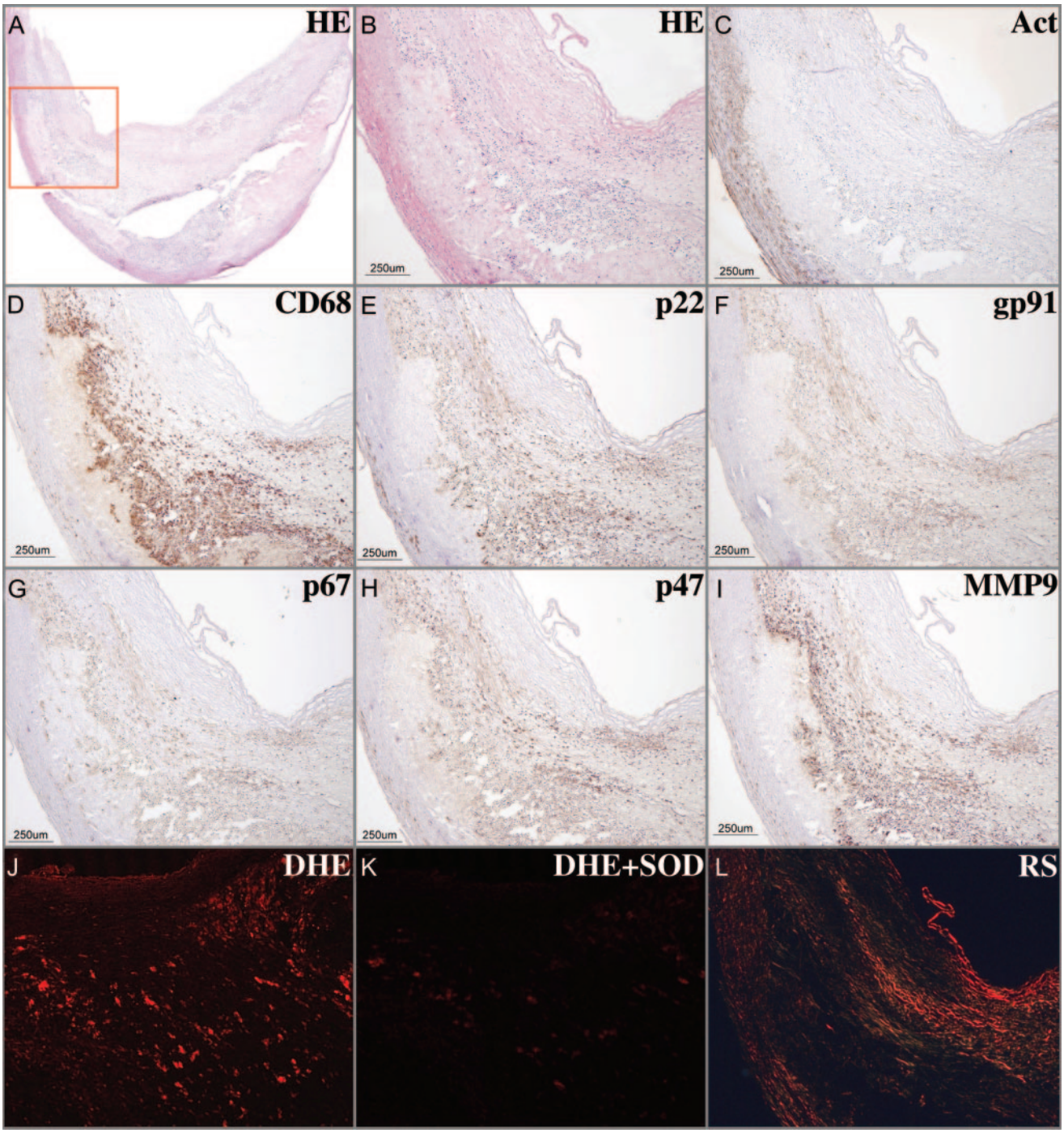

Figure 2. Histological analysis of human carotid endarterectomies. Micrograph (A) showing hematoxylin-eosin staining of atherectomy specimen. Inset (B) of the hematoxylin-eosin staining. Immunohistochemical staining (C) for SMCs with α-actin. Immunohistochemical staining (D) for macrophages with CD68. Immunohistochemical staining (E through H) for NADPH oxidase subunits. Immunohistochemical staining (I) for MMP-9. DHE staining (J) identified $\cdot O_2^-$ production in a higher magnification of the macrophage rich area. Effect (K) of CuZn-superoxide dismutase (CuZn-SOD, 10 000 U/mL) on DHE staining. Collagen staining (L) with Sirius red by polarized light. Analysis was performed in consecutive sections and is representative of 5 specimens. High-resolution images for each panel are available online (please see supplemental Figure II).

exhibited a higher prevalence of metabolic syndrome and obesity than subjects in the other quartiles ($P<0.05$).

Discussion

The main findings of this study are as follows: (1) enhanced phagocytic NADPH oxidase-dependent $\cdot O_2^-$ production stimulates MMP-9 in human monocytes; (2) phagocytic NADPH oxidase is associated with MMP-9 in plaques from atherosclerotic patients; and (3) enhanced phagocytic NADPH oxidase-dependent $\cdot O_2^-$ production is related to both plasma levels of MMP-9 and carotid atherosclerosis in asymptomatic subjects. This relationship is independent of confounding variables, including some conventional cardiovascular risk factors.

TABLE 1. Baseline Characteristics of the Studied Population

	n=188
Age, y	53±1
Sex, M/F	150/38
Body mass index, kg/m^2	28±1
Systolic blood pressure, mm Hg	131±1
Diastolic blood pressure, mm Hg	83±1
Glucose, mmol/L	5.77±0.11
Total cholesterol, mmol/L	5.84±0.08
HDL cholesterol, mmol/L	1.22±0.03
LDL cholesterol, mmol/L	3.98±0.08
Triglycerides, mmol/L	1.41±0.06
Smokers, %	33
Hypertensive, %	55
Diabetic, %	15
Obese, %	37
Metabolic syndrome, %	35
Medication	
Antihypertensives, %	31*
Statins, %	18
Oral hypoglycemics, %	10†

*Antihypertensives included angiotensin converting enzyme inhibitors (10%), angiotensin type 1 receptor antagonists (9%) and calcium channels blockers (12%).

†None of the diabetic patients was treated with insulin.

HDL indicates high-density lipoprotein; LDL, low-density lipoprotein.

In recent years, it has been demonstrated that reactive oxygen species (ROS) production may participate in MMP-9 activation.[9,20,21] In addition, results from several approaches using apocynin, a specific intracellular inhibitor of NADPH oxidase assembly, suggest that NADPH oxidase-mediated $\cdot O_2^-$ generation mediates the MMP-9 activation in different cell types, including cardiomyocytes,[16] endothelial cells,[17] and SMCs.[18] In this context, our finding showing that apocynin attenuated both MMP-9 secretion and activation in human blood monocytes, demonstrates for the first time that NADPH oxidase-mediated $\cdot O_2^-$ production stimulates

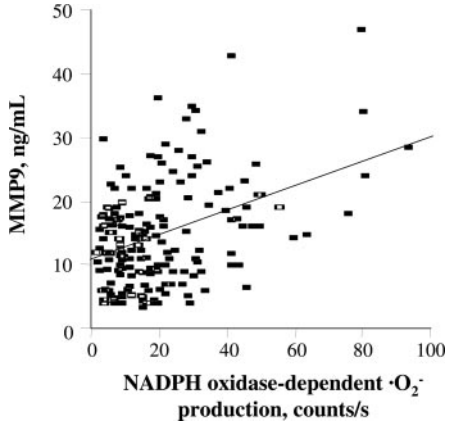

Figure 3. Positive correlation between NADPH oxidase-dependent $\cdot O_2^-$ production and plasma levels of MMP-9 (y=10.98+0.19x, r=0.411, P<0.001).

TABLE 2. Association of the MMP-9 with NADPH Oxidase-Dependent $\cdot O_2^-$ Production in Multiple Linear Regression Analysis

Independent Variables	β	P*	Partial r^2 (%)
$\cdot O_2^-$ production, counts/sec	0.386	0.001	16.0
Age, y	0.013	0.866	0.1
Sex, F/M	0.036	0.628	0.1
Body mass index, kg/m^2	0.025	0.745	0.1
Systolic blood pressure, mm Hg	−0.072	0.365	0.4
Glucose, mmol/L	0.005	0.258	0.5
Smokers, no/yes	0.033	0.659	0.2
Triglycerides, mmol/L	0.001	0.577	0.1

*Adjusted for age, sex, body mass index, systolic blood pressure, glucose, smoking, and triglycerides; r^2 for the total population was 17.4%

MMP-9 activity in these cells. We cannot discard other NADPH oxidase-dependent ROS effects on other MMPs in human monocytes. In fact, NADPH oxidase-dependent $\cdot O_2^-$ production may participate in MMP-2 activation in other cell types.[14–17,22]

The phagocytic NADPH oxidase plays a major role in human atherosclerosis. It has been reported that the severity of atherosclerotic lesion correlates with p22^{phox} overexpression in coronary arteries.[4] In addition, gp91^{phox} and p22^{phox} increase considerably along the progression of human atherosclerotic plaques, thus suggesting a causal link between the phagocytic NADPH oxidase and the development of lesions.[6] In fact, contribution of gp91^{phox} to lesion progression is caused almost entirely by infiltrated monocytes.[5,6] Finally, ROS production, mainly generated by infiltrated inflammatory cells, has been associated with p22^{phox} in atherosclerotic human coronary arteries.[7] Likewise, MMP-9 is involved in several stages of atherosclerosis through remodeling of the extracellular matrix.[9] In cell studies, degradation of the matrix by MMP-9 at the endothelial layer promotes recruitment of monocyte-derived cells into the subendothelial space.[23] In experimental models, degradation of the matrix surrounding SMCs promotes SMC migration,[24] whereas macrophage expression of active MMP-9 induces acute plaque disruption in apolipoprotein E$^{-/-}$ mice.[25] In this context, our finding showing that $\cdot O_2^-$ generation and NADPH oxidase components localized with MMP-9 in macrophage-rich areas in endarterectomy specimens from atherosclerotic patients confirms that the in vitro relationship between NADPH oxidase and MMP-9 in human monocytes is also present in plaques, and allows us to suggest that phagocytic NADPH oxidase-dependent ROS may promote MMP-9-dependent degradation of extracellular matrix and the development of atherosclerotic disease.

Phagocytic NADPH oxidase has been associated with subclinical atherosclerosis (ie, carotid IMT) in asymptomatic subjects,[8] thus suggesting that NADPH oxidase-mediated ROS production plays a crucial role in the initiation and development of atherosclerotic disease. It is thus likely that MMP-9 might be a potential mediator of the NADPH oxidase-dependent ROS production in the atherosclerotic process. In support of this possibility, we found a positive

TABLE 3. Phenotyping of Population According to Quartiles of $\cdot O_2^-$ Production

	Quartile 1 n=48	Quartile 2 n=49	Quartile 3 n=48	Quartile 4 n=43
Proatherosclerotic parameters				
$\cdot O_2^-$ production, counts/sec	4.8±0.3	12.1±0.4	21.7±1.6	40.1±2.7*
Plasma MMP-9, ng/mL	12.4±0.6	11.9±0.8	15.6±1.2	20.1±1.4*
Oxidized LDL, U/L	65.2±2.5	66.3±3.6	71.5±3.5	80.3±3.6*
Nitrotyrosine, nmol/L	2.2±0.5	3.5±1.1	3.4±0.9	6.4±1.1*
Carotid plaques, %	17	17	19	29*
Carotid IMT, mm	0.67±0.02	0.66±0.02	0.69±0.02	0.74±0.02*
Cardiovascular risk factors				
Hypertension, %	43	66	48	64
Diabetes, %	17	8	17	19
Obese, %	31	30	41	49*
Metabolic syndrome, %	26	32	32	53*
Smoking, %	29	34	36	34
Medication				
Antihypertensives, %	32	33	32	37
Statins, %	13	17	23	16
Oral hypoglycemics, %	11	7	11	14

*$P<0.05$ for lineal trend.

correlation between NADPH oxidase-dependent $\cdot O_2^-$ production and MMP-9 levels in asymptomatic subjects. In addition, findings showing that subjects in the upper quartile of $\cdot O_2^-$ production exhibited increased values of MMP-9, and were associated with high levels of oxidative stress markers and with enhanced carotid IMT and frequency of plaques, identifies a subgroup of subjects who might be prone to develop plaque rupture and/or ischemic events. In fact, it has been shown that MMP-9 levels provide a useful emerging biomarker in the prediction of atherothrombotic events.[13] Thus, epidemiologic studies suggest that MMP-9 expression correlates with lesion stability and clinical manifestations of atherosclerosis.[16,26–28] In addition, analysis of coronary atherectomies reveal active synthesis of MMP-9 by macrophages in lesions of patients with unstable versus stable angina.[29]

During the past decade, a significant number of studies support an essential role of vascular NADPH oxidase isoforms (Nox1 and Nox4) in vascular remodeling[30–33] and atherogenesis.[11–15] Because the present study does not provide direct evidence of the potential role of vascular NADPH oxidases, it is important to point out that the increased phagocytic NADPH oxidase-dependent $\cdot O_2^-$ production might not necessarily be the only factor responsible for the increased MMP-9 levels.[8] In fact, our findings showing that $\cdot O_2^-$ production explained up to 16% of the MMP-9 variance after adjusting for common risk factors, suggest that vascular NADPH oxidases may also be participating in the atherosclerotic process.[3–7] We should also take into account the fact that several enzymes have been proposed as sources of ROS in atherosclerosis other than NADPH oxidases, such as lipoxygenase, xanthine oxidase, and nitric oxide synthase.[34]

Cardiovascular treatment, including antihypertensive drugs,[35,36] statins,[37] and tiazolidinediones,[38] may reduce NADPH oxidase activity. In the current study, we found no association between $\cdot O_2^-$ production and blood pressure values in the whole population, which included 99 subjects using cardiovascular medication, contrary to results of a previous study.[39] Nevertheless, our results showed a positive association between $\cdot O_2^-$ production and systolic blood pressure in subjects who were not receiving cardiovascular medication, thus demonstrating a critical role of cardiovascular drugs on phagocytic NADPH oxidase activity.

In summary, we found that enhanced NADPH oxidase-dependent $\cdot O_2^-$ production stimulates MMP-9 in monocytes and that this relationship may be relevant in the atherosclerotic process. In fact, MMP-9 emerges as a potential mediator of the pro-atherosclerotic actions of phagocytic NADPH oxidase in both symptomatic and asymptomatic subjects.

Acknowledgments

We gratefully acknowledge technical assistance by Raquel Ros and Ana Montoya.

Sources of Funding

This project was funded through the agreement between FIMA and "UTE project CIMA," Foundation MMA, 25/2005 from Department of Health of Government of Navarra, SAF2004-07910 from Ministry of Science and Technology and RECAVA C03/01 from Fondo de Investigaciones Sanitarias, Instituto de Salud Carlos III, Ministry of Health, Spain.

Disclosures

None.

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