



(12) **DEMANDE DE BREVET CANADIEN
CANADIAN PATENT APPLICATION**

(13) **A1**

(86) Date de dépôt PCT/PCT Filing Date: 2018/08/22
(87) Date publication PCT/PCT Publication Date: 2019/02/28
(85) Entrée phase nationale/National Entry: 2020/02/24
(86) N° demande PCT/PCT Application No.: IL 2018/050924
(87) N° publication PCT/PCT Publication No.: 2019/038764
(30) Priorités/Priorities: 2017/08/23 (US62/549,058);
2018/01/24 (US62/621,261)

(51) Cl.Int./Int.Cl. *C07C 229/10* (2006.01),
A61K 31/14 (2006.01), *A61K 31/164* (2006.01),
A61K 31/221 (2006.01), *A61K 31/23* (2006.01),
A61K 31/231 (2006.01), *A61K 31/232* (2006.01),
A61P 9/10 (2006.01), *C07C 211/63* (2006.01),
C07C 229/12 (2006.01), *C07C 229/30* (2006.01),
C07C 233/20 (2006.01), *C07C 233/34* (2006.01),
C07C 233/45 (2006.01), *C07C 69/22* (2006.01),
C07C 69/52 (2006.01)

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(54) Titre : COMPOSITIONS ET METHODES DE TRAITEMENT D'UNE MALADIE CARDIOVASCULAIRE
ATHEROSCLEREUSE

(54) Title: COMPOSITIONS AND METHODS FOR TREATING ATHEROSCLEROTIC CARDIOVASCULAR DISEASE

(57) **Abrégé/Abstract:**

The present invention relates to lyso-diacylglyceryltrimethylhomoserine (lyso- DGTS) or derivatives thereof for use in the treatment of atherosclerotic cardiovascular disease, and further provides particular such lyso-DGTS derivatives.

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(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property
Organization
International Bureau(10) International Publication Number
WO 2019/038764 A1(43) International Publication Date
28 February 2019 (28.02.2019)**(51) International Patent Classification:**

<i>C07C 229/10</i> (2006.01)	<i>A61K 31/221</i> (2006.01)
<i>C07C 233/20</i> (2006.01)	<i>A61K 31/23</i> (2006.01)
<i>C07C 233/34</i> (2006.01)	<i>A61K 31/231</i> (2006.01)
<i>C07C 229/30</i> (2006.01)	<i>A61K 31/232</i> (2006.01)
<i>C07C 233/45</i> (2006.01)	<i>A61P 9/10</i> (2006.01)
<i>C07C 69/52</i> (2006.01)	<i>C07C 229/12</i> (2006.01)
<i>A61K 31/14</i> (2006.01)	<i>C07C 211/63</i> (2006.01)
<i>A61K 31/164</i> (2006.01)	<i>C07C 69/22</i> (2006.01)

Published:

— with international search report (Art. 21(3))

(21) International Application Number:

PCT/IL2018/050924

(22) International Filing Date:

22 August 2018 (22.08.2018)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

62/549,058	23 August 2017 (23.08.2017)	US
62/621,261	24 January 2018 (24.01.2018)	US

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WO 2019/038764 A1

COMPOSITIONS AND METHODS FOR TREATING ATHEROSCLEROTIC CARDIOVASCULAR DISEASE

TECHNICAL FIELD

[0001] The present invention provides pharmaceutical compositions and methods for treatment of atherosclerotic cardiovascular disease.

BACKGROUND ART

[0002] Atherosclerosis is a multifactorial disease and the usual cause of heart attacks, strokes, and peripheral vascular disease, together referred to as "cardiovascular disease" (CVD). Atherosclerotic CVD is a pathological process characterized by the deposition of lipids and compounds within the arterial wall, and is considered the major cause of morbidity and mortality in the western world.

[0003] Lowering of low density lipoprotein (LDL)-cholesterol using 3-hydroxy-3-methylglutaryl coenzyme A reductase inhibitors (statins) has become an integral component of strategies to reduce cardiovascular risk; however, statins reduce CVD risk by no more than 40%, and they have some side effects such as muscle pain and damage, liver problems, digestive problems, rash or flushing, blood glucose elevation, and memory loss or confusion. Modulation of high density lipoprotein (HDL) become to be an alternative strategy for reducing CVD risk due to its antiatherogenic properties such as reverse cholesterol transport (Khera *et al.*, 2011; Miller *et al.*, 1985), antioxidant, anti-inflammatory (Barter *et al.*, 2007), anti-apoptotic, vasodilatory and cytoprotective effects, and endothelial function improvement (Nofer *et al.*, 2005; Yuhanna *et al.*, 2001). In the last several years, there is growing evidence from epidemiological data, animal studies, and clinical trials supporting HDL as the next target to reduce residual cardiovascular risk in statin-treated, high-risk patients (Zakiev *et al.*, 2017). However, the hypothesis that raising HDL-cholesterol (HDL-C) levels will result in reduction of CVD risk has never been really confirmed. Methods developed to increase blood HDL levels failed to reduce CVD risk. For example, clinical trials using cholesteryl ester transfer protein inhibitors were terminated due to excess adverse events and futility despite a 72% increase in blood HDL cholesterol levels. Nicotinic acid and fabric acid derivatives increased HDL cholesterol levels, but linking these increases to clinical risk reduction has been questionable. Instead, recent studies indicate that the focus should be on improving HDL

functions (HDL “quality”), which truly reflect and are responsible for the actual beneficial effects of HDL, rather than increasing HDL-C levels (HDL-C “quantity”) (Santos-Gallego *et al.*, 2015; Zheng *et al.*, 2012; Pirillo *et al.*, 2013).

[0004] HDL comprises a heterogeneous family of lipoprotein species, differing in surface charge, size, and lipid and protein compositions (Hafiane *et al.*, 2015). A lipid such as sphingosine-1-phosphate (S1P) has been recently discovered to be both a mechanistic cause and a therapeutic target for HDL dysfunction (Sattler *et al.*, 2009). Coronary artery disease (CAD) patients exhibited lower HDL-bound S1P than healthy volunteers, while CAD-HDL was found dysfunctional, demonstrating lower endothelial signaling activation and vasodilatation induction. Supplementation of S1P to animals with HDL dysfunction reversed HDL quality (Levkau *et al.*, 2015; Poti *et al.*, 2014; Sattler *et al.*, 2015).

[0005] Most of the HDL functional and atheroprotective effects are also attributed to its associated enzyme paraoxonase 1 (PON1; EC 3.1.8.1) (Gu *et al.*, 2016). PON1-deficient mice were found susceptible to the development of atherosclerosis, while overexpression of human PON1 in mice inhibits its development (Shih *et al.*, 1995; 2000). PON1 activity has been inversely correlated with carotid intima-media thickness (Gur *et al.*, 2014), attenuates oxidized-LDL uptake by macrophage, inhibits macrophage cholesterol biosynthesis rate, and stimulates HDL-mediated cholesterol efflux from macrophage (Cohen *et al.*, 2014; Tavori *et al.*, 2009, 2011a, 2011b). Epidemiological evidence demonstrates that low PON1 activity is associated with increased risk of cardiovascular events and CVD (Gugliucci *et al.*, 2015). PON1 has many activities towards organophosphate triesters, arylesters, cyclic carbamates, glucuronides, oestrogen esters and thiolactones, whereas the “natural” substrates of PON1 assume to be lactones (Tavori *et al.*, 2008). As an antioxidant enzyme carried by HDL, PON1 can hydrolyze lipid peroxide in lipoproteins through its lipolactonase activity which, thus decreases oxidative stress in serum lipoproteins, macrophages, and atherosclerotic lesions (Rosenblat *et al.*, 2006; Ben-David *et al.*, 2012).

[0006] Microalgae are used as food source and as addible feed in aquaculture for production of mollusks and some fish species. Microalgae have been recognized as potentially good sources for biofuel production because of their high oil content and rapid biomass production. Components of algae are frequently used in cosmetics as thickening agents, water-binding agents, and antioxidants. Microalgae extracts are widely used as therapeutic and food supplements due to their high content of carotenoids, phenolic

compounds including polyphenols, and lipids such as phospholipids, whole and unhydrolyzed glycolipids, lysolipids, free fatty acids, waxes, and sterols and sterols esters.

[0007] Several microalgae, including *Nannochloropsis sp.* and *Nannochloropsis salina*, have been described as potential sources of omega-3 fatty acids such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA).

SUMMARY OF INVENTION

[0008] In one aspect, the present invention provides a pharmaceutical composition for treatment of atherosclerotic cardiovascular disease, comprising a pharmaceutically acceptable carrier and a compound of the formula I:



wherein

R₁ is (C₁₅-C₂₁)alkyl, (C₁₅-C₂₁)alkenyl, or (C₁₅-C₂₁)alkynyl;

R₂ is -O-CH₂-CHR₄-CH₂-O-, -NH-CH₂-CHR₄-CH₂-O-, -O-, or -NH-;

R₃ is (C₁-C₈)alkylene substituted with a group of the formula -N⁺(R₅)₃, and optionally further substituted with one or more -OH groups;

R₄ is -OH, -O-C(O)-R₆, or -NH-C(O)-R₆;

R₅ each independently is (C₁-C₈)alkyl; and

R₆ is (C₁₅-C₂₁)alkyl, (C₁₅-C₂₁)alkenyl, or (C₁₅-C₂₁)alkynyl,

or a pharmaceutically acceptable salt or solvate thereof.

[0009] In another aspect, the present invention relates to a compound of the formula I as defined above, or a pharmaceutically acceptable salt or solvate thereof, for use in the treatment of atherosclerotic cardiovascular disease.

[0010] In yet another aspect, the present invention relates to use of a compound of the formula I as defined above, or a pharmaceutically acceptable salt or solvate thereof, for the preparation of a pharmaceutical medicament for treatment of atherosclerotic cardiovascular disease.

[0011] In still another aspect, the present invention relates to a method for treatment of atherosclerotic cardiovascular disease in a subject in need thereof, comprising administering to said subject a therapeutically effective amount of a compound of the formula I as defined above, or a pharmaceutically acceptable salt or solvate thereof.

[0012] In a further aspect, the present invention provides a compound of the formula I as defined above, but excluding the compounds wherein R_2 is $-O-CH_2-CHR_4-CH_2-O-$, i.e., a compound of the formula I wherein R_2 is $-NH-CH_2-CHR_4-CH_2-O-$, $-O-$, or $-NH-$.

[0013] In yet a further aspect, the present invention provides a pharmaceutical composition comprising a compound of the formula I as defined above but excluding the compounds wherein R_2 is $-O-CH_2-CHR_4-CH_2-O-$, or a pharmaceutically acceptable salt or solvate thereof, and a pharmaceutically acceptable carrier.

BRIEF DESCRIPTION OF DRAWINGS

[0014] **Figs. 1A-1B** show lactonase activity of rePON1 after incubation with lyso-DGTS at concentrations of 0, 1, 5, 10, 50, and 100 $\mu\text{g/ml}$ for 2, 4, 24, or 48 h at 37°C in Tris buffer $\text{pH}=8.4$ (**1A**); and arylesterase activity of rePON1 after incubation with lyso-DGTS at concentrations of 0, 1, 5, 10, 50, and 100 $\mu\text{g/ml}$ for 2 or 4 h at 37°C in Tris buffer $\text{pH}=8.4$ (**1B**). Each experiment was repeated separately at least three times. $*p<0.05$, $***p<0.0001$ related to the control (rePON1 without lyso-DGTS). Statistics were analyzed using one-way ANOVA and Graphpad prism 5 software.

[0015] **Fig. 2** shows human serum PON1 lactonase activity. Human serum was diluted by 20 with PBS and incubated with lyso-DGTS at a concentration of 0, 1, 5, 10, or 50 $\mu\text{g/ml}$ for 4 h at 37°C in Tris buffer $\text{pH}=8.0$, and PON1 lactonase activity was measured using dihydrocumarine assay. Each experiment was repeated separately at least three times. $*p<0.05$, $***p<0.0001$ related to the control (serum without lyso-DGTS). Statistics were analyzed using one-way ANOVA and Graphpad prism 5 software.

[0016] **Figs. 3A-3B** show tryptophan fluorescence spectra of rePON1 (50 $\mu\text{g/ml}$; 1.16 μM) incubated with/without lyso-DGTS at concentrations of 1, 5, 10, 25, 50, 75, and 100 $\mu\text{g/ml}$ in black 96-well plates for 2 h at 25°C (**3A**) or 37°C (**3B**). Fluorescence was measured at excitation of 290 nm and emission of 320-450 nm. Each experiment was repeated separately at least three times.

[0017] **Figs. 4A-4D** show Stern-Volmer plot of the fluorescence quenching of rePON1 by lyso-DGTS at 37°C (**4A**) and 25°C (**4B**); and double-log plot of the fluorescence quenching of rePON1 by lyso-DGTS at 37°C (**4C**) and 25°C (**4D**). Each experiment was repeated separately three times. Results are presented as $\text{mean}\pm\text{SD}$. $R^2 >0.99$ and $p<0.0001$ for all linear plots.

[0018] **Figs. 5A-5B** show orientation of lyso-DGTS within the potential rePON1 binding site. Molecular surface of rePON1 showing hydrophilic (red) and hydrophobic (blue) zones docked with lyso-DGTS (**5A**); and location of the lyso-DGTS within the rePON1 binding site showing interaction with the amino acid in the binding groove (red, oxygen; blue, nitrogen; gray, carbon) (**5B**).

[0019] **Figs. 6A-6B** show the effect of lyso-DGTS on rePON1 influx to macrophage cells. rePON1 was labeled with FITC and incubated with different concentrations of lyso-DGTS (10, 20, 50, and 100 $\mu\text{g/ml}$) for 2 h; and each solution was then added to J774A.1 cells, incubated at 37°C for 16 h, and analyzed by FACS analysis. **Fig. 6A** shows a histogram showing the shift of mean fluorescence intensity (MFI) of a representative experiment in cells incubated with rePON1 without FITC (negative control), cells incubated with FITC-rePON1; and cells incubated with FITC-rePON1 incubated with lyso-DGTS at 10, 20, 50, and 100 $\mu\text{g/ml}$. The average of the MFI is shown in **Fig. 6B**. *** $p < 0.0001$ related to the control (cells incubated with FITC-rePON1 alone; $n=3$). Statistic was analyzed using one-way ANOVA Graphpad prism 5 software (FL1-H - relative FITC fluorescence intensity (height) in the FL1 channel).

[0020] **Figs. 7A-7B** show the effect of lyso-DGTS-rePON1 interaction on ox-LDL-induced foam cell formation in J774A.1 macrophage cells. RePON1 (50 $\mu\text{g/ml}$), rePON1 with lyso-DGTS (50 or 100 $\mu\text{g/ml}$) and lyso-DGTS (50 $\mu\text{g/ml}$) were incubated for 2 h, added to cells and incubated for 24 h, and the cells were then treated with ox-LDL (25 $\mu\text{g/ml}$) for another 24 h. Oil red O staining was performed to analyze foam cell formation, and representative images are shown in **Fig. 7A**. Intensity of lipid accumulation into cells was quantified by alcohol extraction, and absorbance was measured at 514 nm as shown in **Fig. 7B**. # $p < 0.05$ related to control (untreated cells), * $p < 0.05$, and ** $p < 0.01$ related to cells treated with ox-LDL alone. Statistics was analyzed using one-way ANOVA and Graphpad prism 5 software. Data are the means \pm SD from 3 experiments.

[0021] **Fig. 8** shows the effect of lyso-DGTS on HDL-mediated cholesterol efflux from macrophage cells. J774A.1 cells were incubated for 16 h with 50 μl fluorescently-labeled cholesterol and 50 μl equilibration buffer. The cells were washed and further incubated for 4 h with RPMI_buffer (media), HDL (25 μg protein) incubated with 2 μl DMSO, or HDL (25 μg protein) incubated with 2 μl lyso-DGTS dissolved in DMSO at a final concentration of 10, 20, 50, and 100 $\mu\text{g/ml}$ for 4 h. Fluorescence was measured in the media and the cells at excitation/emission 482/515 nm. The cholesterol efflux was expressed as % efflux

elicited by cells. Each experiment was repeated separately at least three times. $*p < 0.05$, $***p < 0.0001$ related to the control (HDL incubated with DMSO). $n=3$. Statistics were analyzed using one-way ANOVA and Graphpad prism 5 software.

[0022] Fig. 9 shows the effect of lyso-DGTS on APOA1-mediated cholesterol efflux from macrophage cells. J774A.1 cells were incubated for 4 h with RPMI buffer (media), APOA1 (10 μg) preincubated with DMSO or with lyso-DGTS (at final concentration of 10, 20, 50, and 100 $\mu\text{g}/\text{ml}$) for 2 h. Fluorescence was measured in media and cells at excitation/emission 482/515 nm. The cholesterol efflux was expressed as % efflux elicited by cells. Each experiment was repeated separately at least three times. $*p < 0.05$, $***p < 0.0001$ relative to the control (APOA1 incubated with DMSO; $n=3$). Statistical analysis by one-way ANOVA and Graphpad prism 5 software.

[0023] Figs. 10A-10B show tryptophan fluorescence spectra of HDL (0.03 mg/ml) incubated with/without lyso-DGTS at various concentrations (1, 5, 10, 25, 50, 75, and 100 $\mu\text{g}/\text{ml}$) in black 96-well plates for 4 h at 37°C (**10A**) or 25°C (**10B**). The fluorescence was measured at excitation/emission 290/320-340 nm. The ability of lyso-DGTS to elevate HDL activity correlates with its binding affinity to HDL. Each experiment repeated separately at least three times.

[0024] Fig. 11A-11D show Stern-Volmer plot of the fluorescence quenching of HDL by lyso-DGTS at 37°C (**11A**) and 25°C (**11B**); and double-log plot of the fluorescence quenching of HDL by lyso-DGTS at 37°C (**11C**) and 25°C (**11D**). Each experiment was repeated separately at least three times. Results are presented as mean \pm SD. $R^2 > 0.99$ and $p < 0.0001$ for all linear plots.

[0025] Fig. 12 shows General Polarization (Gp) values of Laurdan incorporated in HDL (100 $\mu\text{g}/\text{ml}$) incubated with lyso-DGTS at various concentrations (0, 10, 20, 50, and 100 $\mu\text{g}/\text{ml}$). The fluorescence emission spectra of Laurdan were obtained using at excitation/emission 340/400-520 nm. The value of Gp of Laurdan was calculated using the formula: $Gp = (I_{435} - I_{490}) / (I_{435} + I_{490})$. Each experiment was repeated separately at least three times. $*p < 0.05$, $***p < 0.0001$ related to the control (HDL without lyso-DGTS). Statistics were analyzed using T-test Graphpad prism 5 software.

[0026] Fig. 13 shows human umbilical vein endothelial cell (HUVEC) nitric oxide (NO) production detected by the DAN assay after reducing culture media with nitrate reductase. HUVECs were stimulated for 2 h with HDL (50 $\mu\text{g}/\text{ml}$) preincubated with DMSO, lyso-DGTS and S1P at final concentrations of 10, 20, and 50 $\mu\text{g}/\text{ml}$ for 3 h. Media were then

collected and treated with nitrate reductase followed by analysis using the DAN assay. Data are expressed as NO concentration (μM) released by the cells. Each experiment was repeated separately at least three times. $*p<0.05$, $***p<0.0001$ related to the control (HDL without lyso-DGTS or S1P). Statistics were analyzed using one-way annova Graphpad prism 5 software.

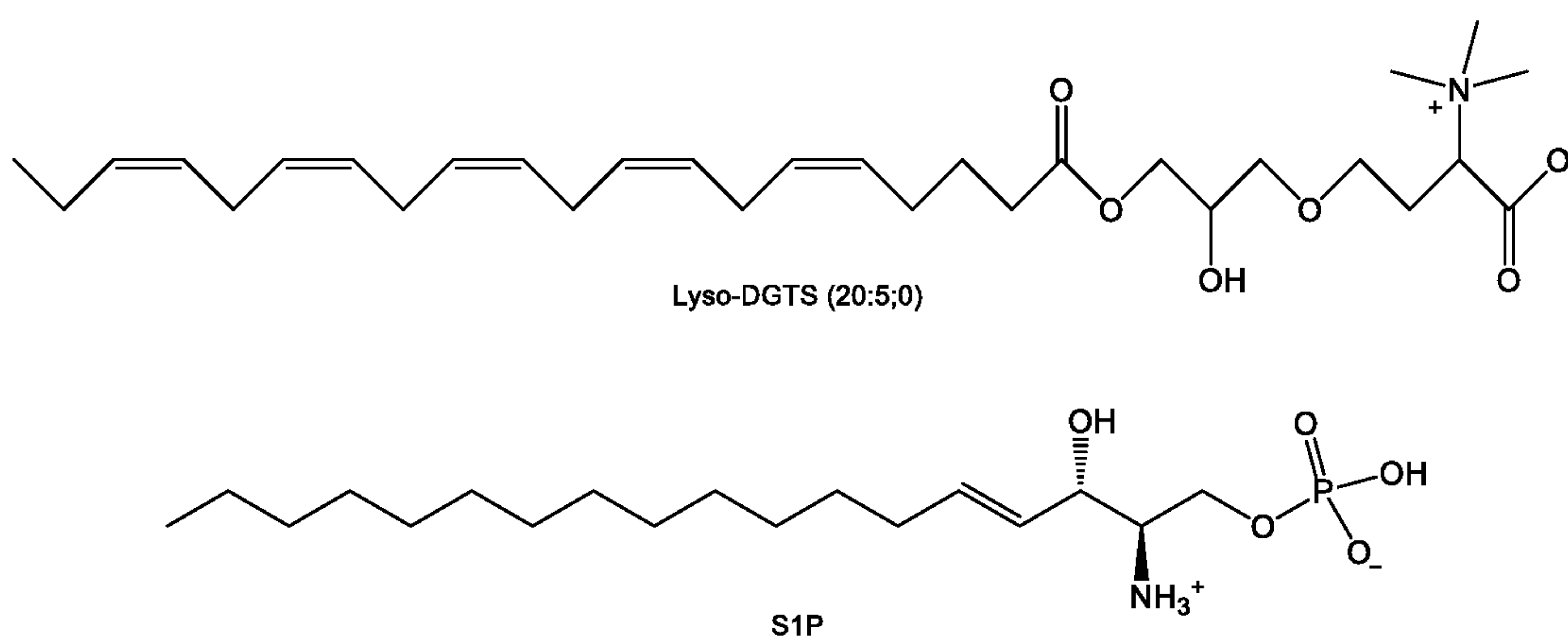
[0027] **Fig. 14** shows the effect of lyso-DGTS on serum PON1 lactonase activity of Balb/c mice. Balb/c mice were fed with either normal rodent diet (the "non" group; $n=11$) or high-fat diet (HFD), and received treatment administered via subcutaneously implanted osmotic mini-pumps: 1) vehicle group injected with DDW+2% Tween 80 ($n=9$); 2) lyso-DGTS group injected with lyso-DGTS (1.43 mg/ml in DDW+2% Tween 80; $n=11$). At the end of the protocol, serum was produced and diluted by 20 with PBS, and PON1 lactonase activity was measured using dihydrocumarine assay. Statistics was analyzed using one-way ANOVA and Graphpad prism 5 software. $\#p<0.05$ related to the "non" group and $*p<0.05$ related to the vehicle group.

[0028] **Fig. 15** shows the effect of lyso-DGTS on the pro-inflammatory/anti-inflammatory properties of HDL isolated from Balb/c mice. Balb/c mice fed with normal rodent diet (the "non" group; $n=11$) or HFD received treatment administered via subcutaneously implanted osmotic mini-pumps: 1) vehicle group injected with DDW+2% Tween 80 ($n=9$); 2) lyso-DGTS group injected with lyso-DGTS (1.43 mg/ml in DDW+2% Tween 80; $n=11$). At the end of the protocol, serum was obtained, HDL was isolated, and its pro-inflammatory/anti-inflammatory properties were determined using cell free assay (CFA). Fluorescence in the absence of HDL was normalized to 1.0. Values > 1.0 , after addition of the tested HDL, indicated pro-inflammatory activity; and values < 1.0 indicated anti-inflammatory activity. ($*p<0.05$).

DETAILED DESCRIPTION

[0029] As found in accordance with the present invention, extracts of the microalgae *Nannochloropsis salina* and *Nannochloropsis oculata* contain an active substance that protects PON1 from oxidation and increases its lactonase and arylesterase activities, and inhibits LDL and macrophage oxidation. As particularly found, an ethanol water (70:30%) extract of the microalgae *Nannochloropsis salina* and *Nannochloropsis oculata* increased recombinant PON1 (rePON1) activities in a dose-dependent manner, and stabilized and preserved rePON1 activity for at least 48 hours.

[0030] Analysis of said ethanol water extract using LC-MS and NMR methods has revealed that the active substance comprised within said extract is lyso-diacylglyceryltrimethylhomoserine (lyso-DGTS, herein identified compound **Ia-12**, when n is 2; and R_5 is methyl), a betaine lipid derivative, abundant in the membranes of many algae, lower plants and fungi, and composed of EPA (C20:5) fatty acid connected to glyceryl-trimethyl-homoserine (C20:5 lyso-DGTS lipid). This compound resembles S1P structure, as both contain a hydrophobic element (the C:15:1(Δ^2) in the sphingosine and EPA in the lyso-DGTS), and a polar element in the other side of the molecule (phosphoric acid vs. trimethyl homoserine).



[0031] As stated above, the beneficial effects of HDL have been partly attributed to its antioxidant properties mediated by PON1. According to the literature, the hydrolytic lactonase, arylesterase, and paraoxonase activities of PON1 are all inactivated under oxidative stress, and epidemiological evidences demonstrate that low serum PON1 lactonase activity is associated with increased risk of coronary heart disease and diabetes (Mackness *et al.*, 2003 and 2015; Fuhrman *et al.*, 2006). Moreover, lower serum arylesterase provided incremental prognostic value and clinical reclassification of stable subjects at risk of cardiovascular events (Tang *et al.*, 2012).

[0032] Based on the above, pharmacological and nutritional modulation of PON1 activity and/or gene expression could constitute a useful approach for improving HDL functions and prevention of cardiovascular diseases (Hernaes *et al.*, 2017; Lou-Bonafonte *et al.*, 2017). As previously shown, various endogenous and exogenous molecules, e.g., nutrients, can non-covalently interact with PON1 and affect its properties (increase or decrease its activity/stability, prevent its free thiol oxidation, affect its influx into cells, and affect

cytosolic triglyceride accumulation). Lipids such as phosphatidylcholines interact with PON1 and increase its activity (Atrahimovich *et al.*, 2012; Cohen *et al.*, 2014).

[0033] As shown herein, lyso-DGTS increases rePON1 lactonase and arylesterase activities in a dose and time dependent manner, and stabilizes and preserves rePON1 lactonase activity for at least 48 hours. Moreover, increase in the PON1 lactonase activity in a dose dependent manner was also observed following incubation of lyso-DGTS with the whole human serum.

[0034] Protein activities can be affected and may be altered by their interaction with small molecules in their milieu. In order to understand the mechanism by which lyso-DGTS affects PON1 activities, a tryptophan (Trp) fluorescence quenching assay was carried out to indicate possible interaction between lyso-DGTS and rePON1. PON1 contains four Trp amino acid residues and the Trp fluorescence quenching assay measures the affinity of the interaction between the protein and lyso-DGTS that results in changes in PON1 3D structure, and consequently in alteration in the protein Trp fluorescence. As shown herein, increasing lyso-DGTS concentrations decreased the intensity of rePON1 fluorescence in a dose dependent manner at both 25°C and 37°C.

[0035] Stern-Volmer plot did not show any deviation from linearity toward the y axis at the reported lyso-DGTS concentrations, and the K_{sv} values obtained indicated a static quenching process initiated by lyso-DGTS, suggesting a specific interaction between rePON1 and lyso-DGTS. Binding constant (K_a) and thermodynamic parameters calculations revealed decrease in binding constant with increasing temperature (the best association appeared to be at 298°K). The values obtained for the number of binding sites per rePON1 (n) were not affected by the temperature and were found to be ~ 1 , indicating the existence of a single binding site for lyso-DGTS in rePON1. Thermodynamic parameters were calculated to elucidate the lyso-DGTS-PON1 interaction. A negative ΔG was observed, indicating that the interaction is spontaneous, and negative values for both ΔH and ΔS indicated that the dominating force is a van der Waals or/and hydrogen bond (Sun *et al.*, 2010).

[0036] In accordance with the fluorescence analysis, docking analysis has shown that lyso-DGTS binds to PON1 with a negative binding energy, indicating a spontaneous interaction dominated by van der Waals and hydrogen bonds forces.

[0037] The interaction site of phosphatidylcholines (PCs) with PON1, obtained from the molecular docking analysis, was near the α -helix H2, which together with α -helix H1

forms a hydrophobic patch that binds the protein to the HDL surface. This interaction interrupts the ability of PON1 to bind to the HDL particle at the expense to its binding to PC. PC 16:0 18:2, demonstrated the highest affinity to PON1 relative to other PCs examined, and decreased the ratio between HDL-PON1 and free-PON1 by 50%. The interaction affinity of rePON1 with lyso-DGTS was found to be higher in one-fold order than that of PC 16:0 18:2 (Cohen *et al.*, 2014). The K_a of lyso-DGTS at 25°C and 37°C was 1.052×10^4 (M^{-1}) and 2.377×10^3 (M^{-1}), respectively, while the K_a for PC 16:0 18:2 was 1.68×10^3 (M^{-1}) at 25°C. As shown herein, lyso-DGTS interacts with PON1 in a different site than PC 16:0 18:2, far from H1 and H2, and therefore in contrast to PC, does not affect PON1 binding to HDL. The ratio between HDLbound-PON1 vs. free-PON1 did not change (data not shown).

[0038] As previously shown, PON1 specifically internalized into the cytoplasm of macrophage cells through endocytosis and may thus protect these cells from oxidation and prevent foam cell formation. As further shown, phosphatidylcholine lipids, and particularly PC 16:0 18:2, enhance PON1 uptake by macrophage cells. As shown herein, lyso-DGTS lipid significantly increases rePON1 internalization into macrophage cells in a dose dependent manner, which can be a useful mechanism for macrophage defense, considering that PON1 protects macrophage cells from oxidative stress (Rozañberg *et al.*, 2003) and from plaque triglyceride damage (Tavori *et al.*, 2011b; 2009), and decreases macrophage cholesterol biosynthesis (Rozañberg *et al.*, 2003).

[0039] Macrophage cells uptake of ox-LDL forming foam cell is the hallmark for atherosclerosis. Macrophage cells via their scavenger receptors take up ox-LDL and other lipids, undergo activation, produce cytokines and reactive oxygen species (ROS), and differentiate into foam cells to form the early lesions stage. Incubation of macrophage cells with ox-LDL resulted in lipid deposition in the cells and foam cell formation. The quantitative analysis of oil red staining intensity showed that pre-incubation of cells with lyso-DGTS alone significantly reduced oil red staining intensity. Pre-incubation of the cells with rePON1 or rePON1 incubated with lyso-DGTS also significantly decreased oil red staining intensity, confirming that lyso-DGTS alone, and lyso-DGTS incubated with rePON1, can inhibit ox-LDL-induced foam cell formation.

[0040] HDL removes cholesterol from cells including macrophage cells, and this is considered to represent a major atheroprotective function of HDL particles. A link between the *in vitro* efflux of cholesterol from macrophage cells and atherosclerosis has recently

been established by studies demonstrating a negative correlation between cholesterol efflux from J774 mouse cells and coronary artery disease. HDL removes excess cholesterol from arterial cells, including macrophage foam cells, via the scavenger receptor B1 (SR-BI,) and the ATP binding cassette transporter A1 (ABCA1,) (Jian *et al.*, 1998; Oram *et al.*, 2003). Previous studies have shown that PON1 enhances HDL-mediated macrophage cholesterol efflux via the ABCA1 transporter in association with increased HDL binding to the cells (Rosenblat *et al.*, 2005). As demonstrated herein, lyso-DGTS enhanced HDL-mediated macrophage cholesterol efflux, and significantly increased the ability of HDL to take out cholesterol from macrophages in a dose dependent manner.

[0041] The effect of lyso-DGTS on PON1 activity and clinical parameters was examined using *in vivo* experiments. Balb/c mice were fed with a high fat diet (HFD) for 12 weeks, and during the last 4 weeks they were supplemented with lyso-DGTS. The administration of lyso-DGTS to the circulation was carried via subcutaneously implanted osmotic mini-pumps. This technique ensures continuous exposure of the tested compound at a desired concentrations and period. At the end of the treatment period, the mice were sacrificed, and clinical parameters were analyzed. Serum lactonase PON1 activity was significantly decreased in mice fed with high fat diet while administration of lyso-DGTS significantly increased serum lactonase activity to the level of the control (mice fed with normal diet). Studies with different ethnic groups have shown that lower PON1 activities are associated with type 2 and type 1 diabetes (Hatzihidioglou *et al.*, 2016; Jamuna Rani *et al.*, 2014; Noack *et al.*, 2013; Gupta *et al.*, 2011; Juretic *et al.*, 2006; Cracium *et al.*, 2016). A non-significant increase in serum glucose concentrations was observed in the mice group treated with HFD compared to the non-treated group, whereas their lactonase PON1 activity decreased significantly. Interestingly, the group treated with lyso-DGTS showed decrease in serum glucose concentrations in parallel to increase of serum lactonase activity (both statistically significant), demonstrating values similar to those shown by the non-treated group (mice fed with normal diet). These findings demonstrate a correlation between PON1 lactonase activity and serum glucose levels.

[0042] In conclusion, the studies described herein demonstrate that lyso-DGTS interacts with rePON1 and increases its lactonase and aryl esterase activity in a dose dependent manner; increases human serum PON1 lactonase activity in a dose dependent manner; enhances rePON1 influx into macrophage cells in a dose dependent manner; decreases the deposition of lipids induced by ox-LDL; and increases HDL mediated cholesterol efflux,

and may thus protect macrophage cells from oxidation and prevent foam formation. In addition, serum taken from mice fed with HFD and treated with lyso-DGTS shows increased lactonase PON1 activity and decreased glucose concentration that is, in fact, similar to that of mice fed with regular diet. These findings suggest that lyso-DGTS has a potential to decrease atherosclerosis risk by enhancing PON1 activity, improving HDL quality, protecting macrophages, and preventing foam cells formation, and may thus decrease CVD.

[0043] In one aspect, the present invention thus provides a pharmaceutical composition for treatment of atherosclerotic cardiovascular disease, comprising a pharmaceutically acceptable carrier and a compound of the formula I as defined above, herein referred to as the “*active agent*”.

[0044] The compound of the formula I may have one of the four sub-structures referred to herein as formulas Ia, Ib, Ic and Id, and shown in **Table 1**. A compound of the formula Ia consists of a saturated or unsaturated fatty acid residue linked via ester bond to one of the terminal carbon atoms of glyceryl (-O-CH₂-CHR₄-CH₂O-), wherein the other terminal carbon atom of the glyceryl is linked via ether bond to a terminal carbon atom of the side chain of an alpha amino acid having a quaternary ammonium. The compound of the formula Ib has a structure similar to that of Ia, wherein the glyceryl nuclei is replaced with a ceramide-like nuclei having an amino group on one of the terminal carbon atoms (-NH-CH₂-CHR₄-CH₂O-). Such a compound thus consists of a saturated or unsaturated fatty acid residue linked via amide bond to the terminal carbon atom of the ceramide-like nuclei, wherein the other terminal carbon atom of the ceramide-like nuclei is linked via ether bond to a terminal carbon atom of the side chain of an alpha amino acid having a quaternary ammonium. The compound of the formula Ic has neither glyceryl nor ceramide-like nuclei, and it consists of a saturated or unsaturated fatty acid residue linked directly, via ester bond, to a terminal carbon atom of the side chain of an alpha amino acid having a quaternary ammonium. The compound of the formula Id has a structure similar to that of Ic, wherein the ester bond is replaced with an amide bond, and it thus consists of a saturated or unsaturated fatty acid residue linked directly, via amide bond, to a terminal carbon atom of the side chain of an alpha amino acid having a quaternary ammonium. Specific compounds of the formulas Ia, Ib, Ic and Id described herein are herein identified compounds **Ia-1 to Ia-14**, **Ib-1 to Ib-14**, **Ic-1 to Ic-14**, and **Id-1 to Id-14**, and are shown in **Tables 2-3**.

Table 1: General structures of formulas Ia, Ib, Ic and Id

Ia	Ib	Ic	Id

* R₁, R₃ and R₄ are each as defined above.

[0045] The term "alkyl" as used herein typically means a linear or branched saturated hydrocarbon radical. The term (C₁-C₈)alkyl denotes such a radical having 1-8 carbon atoms and includes, e.g., methyl, ethyl, *n*-propyl, isopropyl, *n*-butyl, sec-butyl, isobutyl, *tert*-butyl, 2-methylpropyl, *n*-pentyl, isopentyl, neopentyl, 2-methylbutyl, 1,1-dimethylpropyl, 2,2-dimethylpropyl, *n*-hexyl, isohexyl, 2-methylpentyl, 3-methylpentyl, 1,1-dimethylbutyl, 2,2-dimethylbutyl, 2-ethylbutyl, *n*-heptyl, 2-methylhexyl, 1,1-dimethylpentyl, 1,2-dimethylpentyl, 1,1,2-trimethylbutyl, *n*-octyl, 2-methylheptyl, 1,1-dimethylhexyl, 1,2-dimethylhexyl, 1,1,2-trimethylpentyl, and the like, wherein preferred are (C₁-C₆)alkyl or (C₁-C₄)alkyl groups such as methyl, ethyl, *n*-propyl, isopropyl, or *n*-butyl. The term "(C₁₅-C₂₁)alkyl" denotes such a radical having 15-21 carbon atoms, i.e., (C₁₅)alkyl, (C₁₆)alkyl, (C₁₇)alkyl, (C₁₈)alkyl, (C₁₉)alkyl, (C₂₀)alkyl, or (C₂₁)alkyl, wherein preferred are (C₁₅)alkyl, (C₁₇)alkyl, (C₁₉)alkyl, and (C₂₁)alkyl groups, more specifically linear (C₁₅)alkyl, (C₁₇)alkyl, (C₁₉)alkyl, and (C₂₁)alkyl groups.

[0046] The terms "alkenyl" and "alkynyl" typically mean linear or branched hydrocarbon radicals having at least one, e.g., one, two, three, four, five, or six, double bond or triple bond, respectively. The terms "(C₁₅-C₂₁)alkenyl" and "(C₁₅-C₂₁)alkynyl" denote such hydrocarbon radicals having 15-21 carbon atoms. Examples of such alkenyls include, without being limited to, (C₁₅)alkenyl, (C₁₆)alkenyl, (C₁₇)alkenyl, (C₁₈)alkenyl, (C₁₉)alkenyl, (C₂₀)alkenyl, or (C₂₁)alkenyl, having at least one double bond, wherein preferred are (C₁₇)alkenyl, (C₁₉)alkenyl, or (C₂₁)alkenyl. Examples of such alkynyls include, without limitation, (C₁₅)alkynyl, (C₁₆)alkynyl, (C₁₇)alkynyl, (C₁₈)alkynyl, (C₁₉)alkynyl, (C₂₀)alkynyl, or (C₂₁)alkynyl, having at least one triple bond.

[0047] The term "alkylene" typically means a divalent linear or branched hydrocarbon radical. The term "(C₁-C₈)alkylene" denotes such a divalent hydrocarbon radical having 1-8 carbon atoms and includes, e.g., methylene, ethylene, propylene, butylene, 2-methylpropylene, pentylene, 2-methylbutylene, hexylene, 2-methylpentylene, 3-

methylpentylene, 2,3-dimethylbutylene, heptylene, octylene, and the like. Preferred are (C₁-C₆)alkylenes or (C₁-C₄)alkylenes such as methylene, ethylene, propylene, or butylene.

[0048] The term "amino acid" as used herein refers to an organic compound comprising both quaternary ammonium and carboxylic acid functional groups. The term "alpha amino acid" as used herein denotes such a compound, wherein the quaternary ammonium is bonded directly to the alpha carbon, that is further substituted with a side chain consisting of an alkyl optionally substituted with one or more hydroxyl groups. Particular such alpha amino acids are those wherein the side chain is a linear (C₁-C₈)alkyl, such as methyl, ethyl, *n*-propyl and *n*-butyl, optionally substituted with one or more -OH groups.

[0049] In certain embodiments, the active agent comprised within the pharmaceutical composition of the present invention is a compound of the formula I, wherein R₁ is (C₁₅-C₂₁)alkyl, or (C₁₅-C₂₁)alkenyl having one or more, e.g., two, three, four, five or six, double bonds. Particular such embodiments are those wherein R₁ is a linear (C₁₅)alkyl, (C₁₇)alkenyl, (C₁₉)alkenyl, or (C₂₁)alkenyl. In more particular such embodiments, R₁ is CH₃-(CH₂)₁₄-, CH₃-(CH₂)₇-CH=CH-(CH₂)₇-, CH₃-(CH₂)₄-(CH=CH-CH₂)₂-(CH₂)₆-, CH₃-(CH₂-CH=CH)₃-(CH₂)₇-, CH₃-(CH₂)₄-(CH=CH-CH₂)₄-(CH₂)₂-, CH₃-(CH₂-CH=CH)₅-(CH₂)₃-, or CH₃-(CH₂-CH=CH)₆-(CH₂)₂-, and together with the carbonyl group attached thereto forms a palmitic acid residue, oleic acid residue, linoleic acid residue, linolenic acid residue, arachidonic acid residue, EPA residue, or DHA residue, respectively.

[0050] In certain embodiments, the active agent comprised within the pharmaceutical composition of the present invention is a compound of the formula I, wherein R₂ is -O-CH₂-CHR₄-CH₂-O-, -NH-CH₂-CHR₄-CH₂-O-, -O-, or -NH-, wherein R₄ is -OH, or -O-C(O)-R₆. Particular such embodiments are those wherein R₄ is -OH.

[0051] In certain embodiments, the active agent comprised within the pharmaceutical composition of the present invention is a compound of the formula I, wherein R₃ is a linear (C₁-C₈)alkylene substituted, preferably at the carbon atom attached to the carboxyl group, with a group of the formula -N⁺(R₅)₃, i.e., -(CH₂)₁₋₇-CH(N⁺(R₅)₃)-, that is optionally further substituted with one or more -OH groups.

[0052] In certain embodiments, the active agent comprised within the pharmaceutical composition of the present invention is a compound of the formula I, wherein R₅ each independently is (C₁-C₄)alkyl, e.g., methyl, ethyl, *n*-propyl, or isopropyl.

[0053] In certain embodiments, the active agent comprised within the pharmaceutical composition of the present invention is a compound of the formula I, wherein R₆ is (C₁₅-

C₂₁)alkyl, or (C₁₅-C₂₁)alkenyl having one or more, e.g., two, three, four, five or six, double bonds. Particular such embodiments are those wherein R₆ is a linear (C₁₅)alkyl, (C₁₇)alkenyl, (C₁₉)alkenyl, or (C₂₁)alkenyl. In more particular such embodiments, R₆ is CH₃-(CH₂)₁₄-, CH₃-(CH₂)₇-CH=CH-(CH₂)₇-, CH₃-(CH₂)₄-(CH=CH-CH₂)₂-(CH₂)₆-, CH₃-(CH₂-CH=CH)₃-(CH₂)₇-, CH₃-(CH₂)₄-(CH=CH-CH₂)₄-(CH₂)₂-, CH₃-(CH₂-CH=CH)₅-(CH₂)₃-, or CH₃-(CH₂-CH=CH)₆-(CH₂)₂-, and together with the carbonyl group attached thereto forms a palmitic acid residue, oleic acid residue, linoleic acid residue, linolenic acid residue, arachidonic acid residue, EPA residue, or DHA residue, respectively.

[0054] In certain embodiments, the active agent comprised within the pharmaceutical composition of the present invention is a compound of the formula I, wherein R₁ is (C₁₅-C₂₁)alkyl, or (C₁₅-C₂₁)alkenyl having one or more double bonds, preferably a linear (C₁₅)alkyl, (C₁₇)alkenyl, (C₁₉)alkenyl, or (C₂₁)alkenyl; R₂ is -O-CH₂-CHR₄-CH₂-O-, -NH-CH₂-CHR₄-CH₂-O-, -O-, or -NH-; R₃ is -(CH₂)₁₋₇-CH(N⁺(R₅)₃)-, optionally further substituted with one or more -OH groups; R₄ is -OH, or -O-C(O)-R₆; R₅ each independently is (C₁-C₄)alkyl such as methyl, ethyl, *n*-propyl, or isopropyl; and R₆ is (C₁₅-C₂₁)alkyl, or (C₁₅-C₂₁)alkenyl having one or more double bonds, preferably a linear (C₁₅)alkyl, (C₁₇)alkenyl, (C₁₉)alkenyl, or (C₂₁)alkenyl. In particular such embodiments, R₁ is CH₃-(CH₂)₁₄-, CH₃-(CH₂)₇-CH=CH-(CH₂)₇-, CH₃-(CH₂)₇-CH=CH-(CH₂)₇-, CH₃-(CH₂)₄-(CH=CH-CH₂)₂-(CH₂)₆-, CH₃-(CH₂-CH=CH)₃-(CH₂)₇-, CH₃-(CH₂)₄-(CH=CH-CH₂)₄-(CH₂)₂-, CH₃-(CH₂-CH=CH)₅-(CH₂)₃-, or CH₃-(CH₂-CH=CH)₆-(CH₂)₂-. More particular such embodiments are those wherein (i) R₂ is -O-CH₂-CHOH-CH₂-O-, R₃ is -CH₂-CH(N⁺(R₅)₃)-, or -(CH₂)₂-CH(N⁺(R₅)₃)-, forming together with the -O- and carboxyl group linked thereto either a serine or homoserine residue, respectively, in which the amino group is replaced by an ammonium cation; and R₅ each is methyl, ethyl, *n*-propyl, or isopropyl; (ii) R₂ is -NH-CH₂-CHOH-CH₂-O-; R₃ is -CH₂-CH(N⁺(R₅)₃)-, or -(CH₂)₂-CH(N⁺(R₅)₃)-, forming together with the -O- and carboxyl group linked thereto either a serine or homoserine residue, respectively, in which the amino group is replaced by an ammonium cation; and R₅ each is methyl, ethyl, *n*-propyl, or isopropyl; (iii) R₂ is -O-; R₃ is -CH₂-CH(N⁺(R₅)₃)-, or -(CH₂)₂-CH(N⁺(R₅)₃)-, forming together with the -O- and carboxyl group linked thereto either a serine or homoserine residue, respectively, in which the amino group is replaced by an ammonium cation; and R₅ each is methyl, ethyl, *n*-propyl, or isopropyl; or (iv) R₂ is -NH-; R₃ is -CH₂-CH(N⁺(R₅)₃)-, or -(CH₂)₂-CH(N⁺(R₅)₃)-, forming together with the -NH- and carboxyl group linked thereto, a 2,3-diaminopropanoic acid or

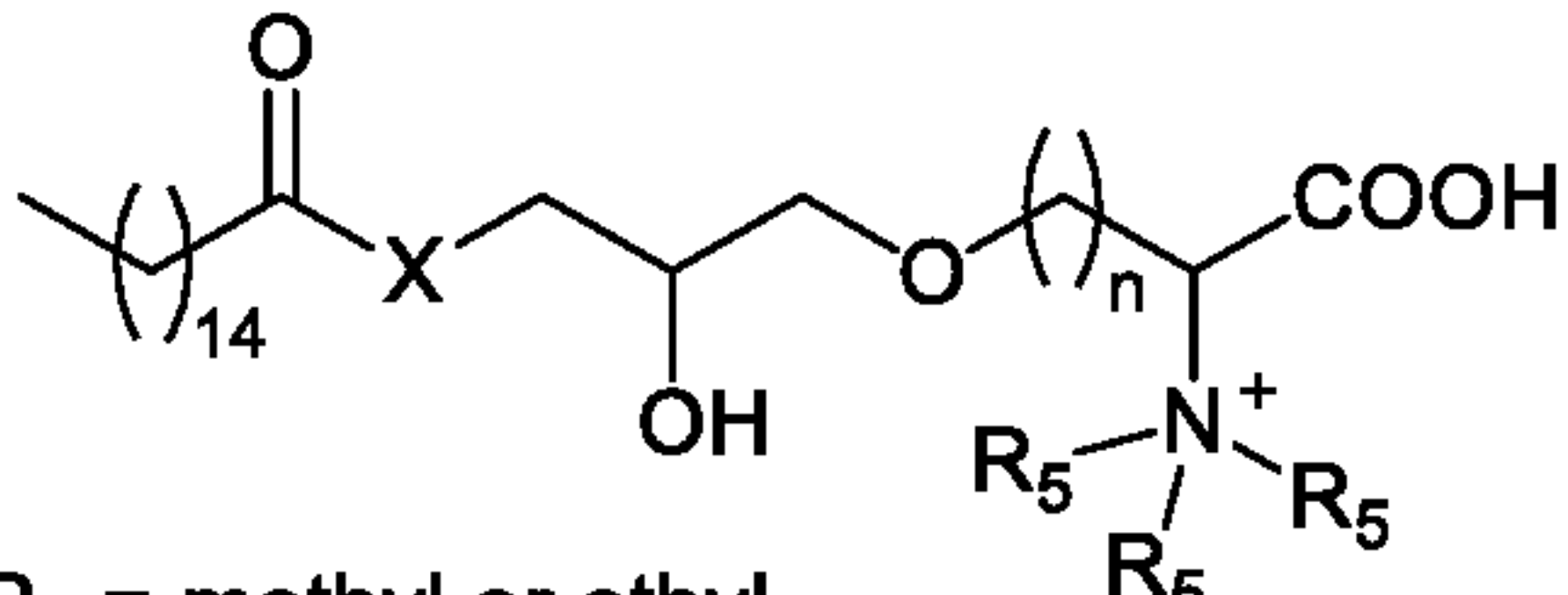
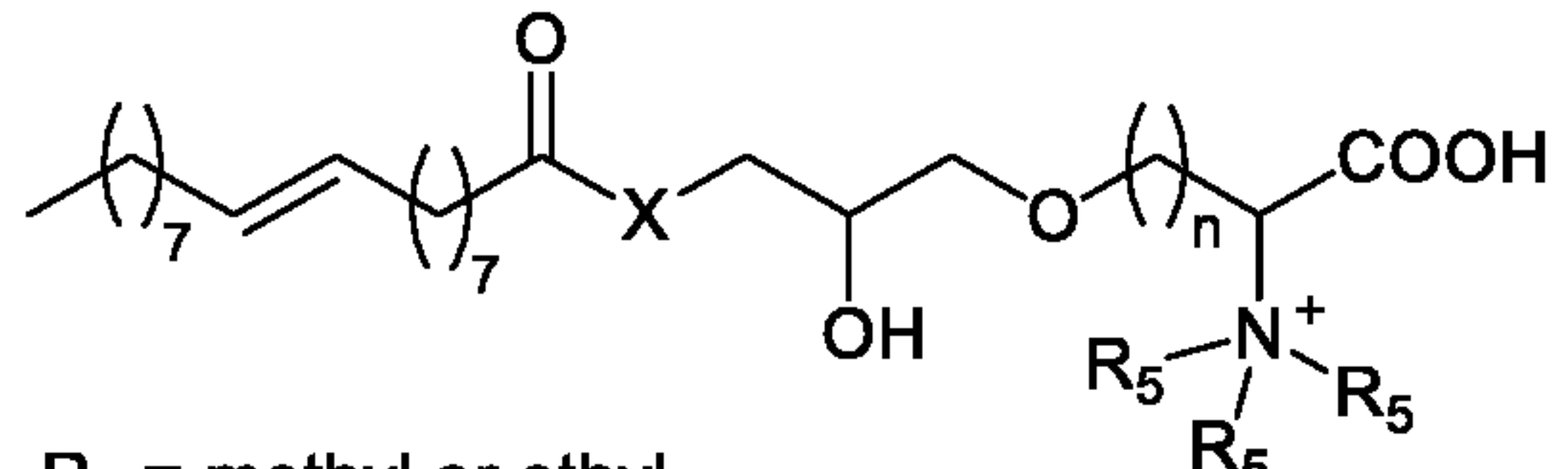
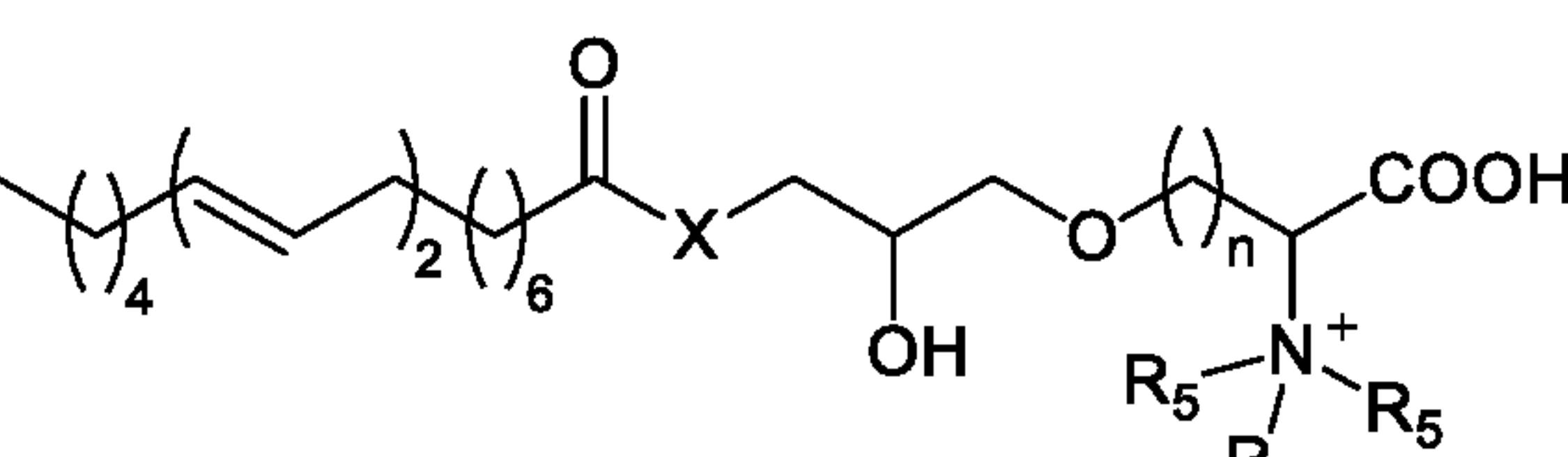
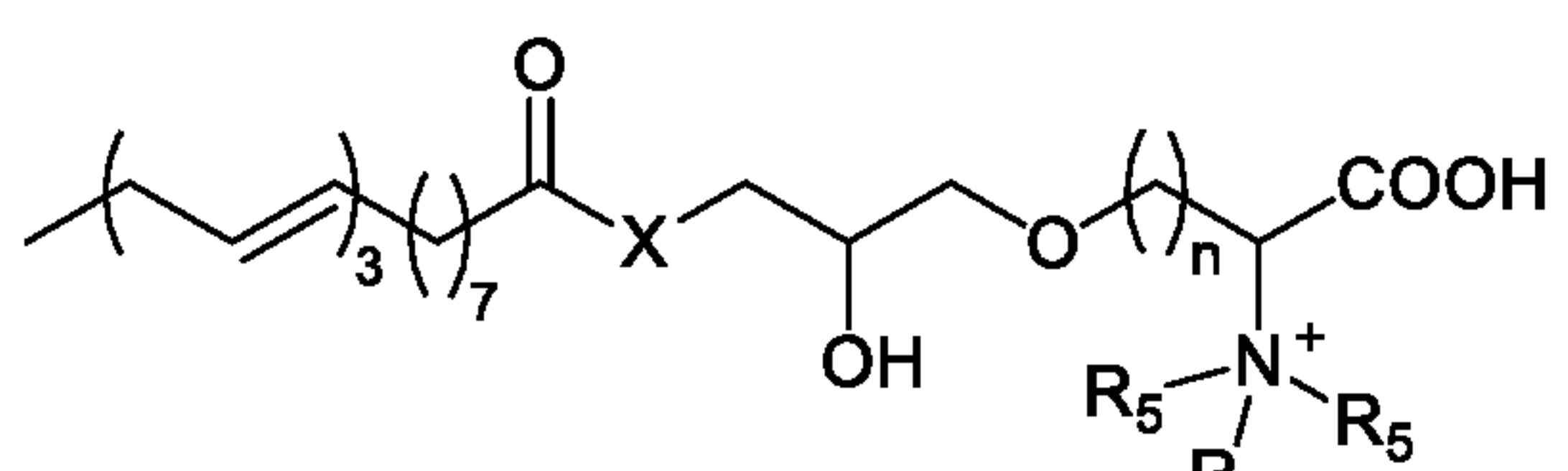
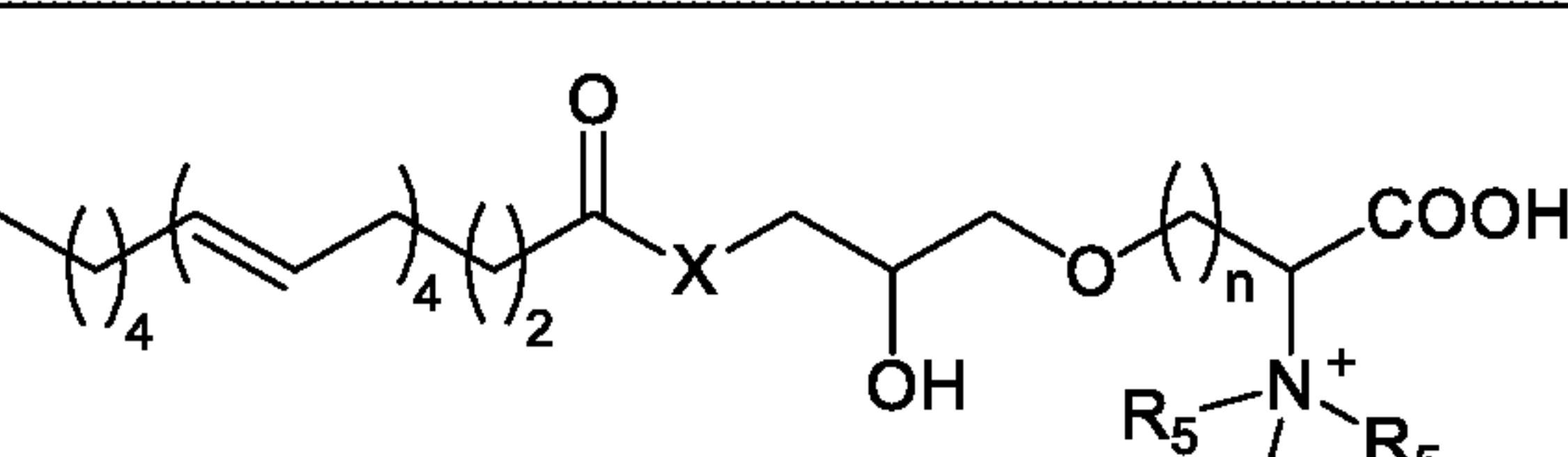
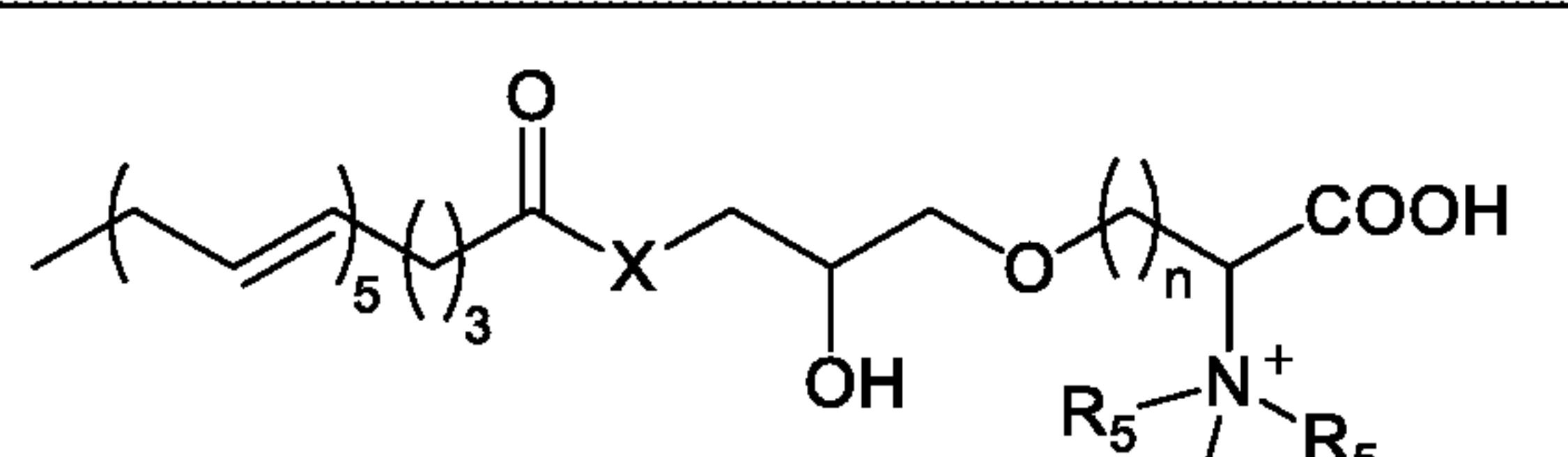
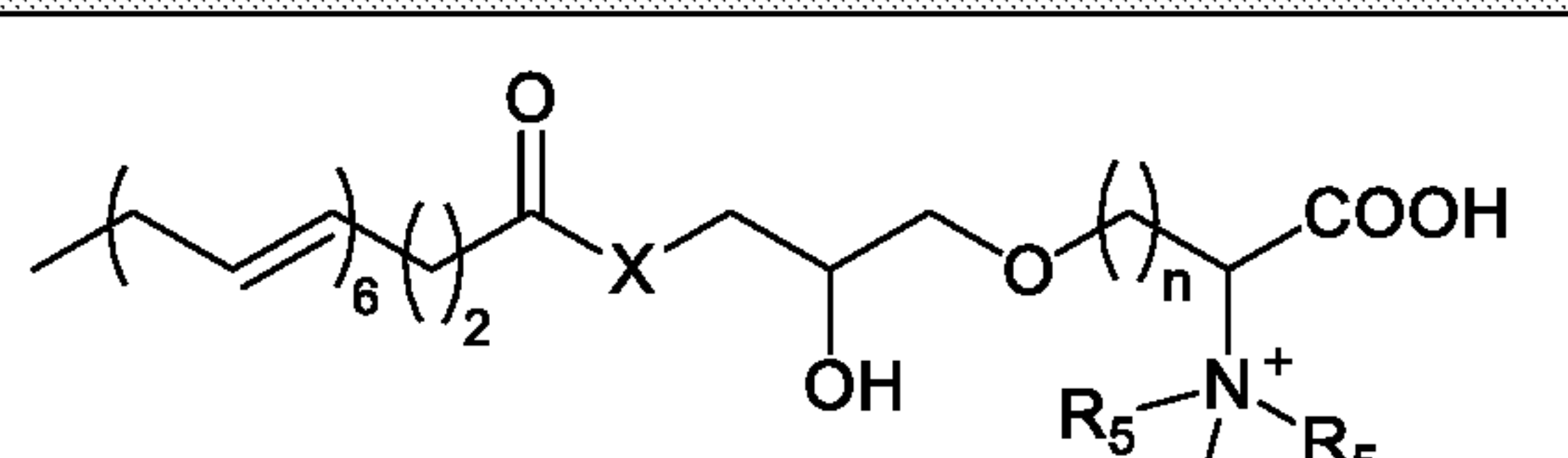
2,3-diaminobutyric acid residue, respectively, in which the amino group linked to the carbon atom at position 2 is replaced by an ammonium cation; and R_5 each is methyl, ethyl, *n*-propyl, or isopropyl.

[0055] In certain specific such embodiments, the active agent comprised within the pharmaceutical composition of the present invention is a compound of the formula Ia, wherein (i) R_1 is $\text{CH}_3\text{-(CH}_2\text{)}_{14}\text{-}$; R_2 is $\text{-O-CH}_2\text{-CHOH-CH}_2\text{-O-}$; and R_3 is $\text{-CH}_2\text{-CH(N}^+(\text{R}_5\text{)}_3\text{-}$ or $\text{-(CH}_2\text{)}_2\text{-CH(N}^+(\text{R}_5\text{)}_3\text{-}$, herein identified compound **Ia-1** and **Ia-2**, respectively; (ii) R_1 is $\text{CH}_3\text{-(CH}_2\text{)}_7\text{-CH=CH-(CH}_2\text{)}_7\text{-}$; R_2 is $\text{-O-CH}_2\text{-CHOH-CH}_2\text{-O-}$; and R_3 is $\text{-CH}_2\text{-CH(N}^+(\text{R}_5\text{)}_3\text{-}$ or $\text{-(CH}_2\text{)}_2\text{-CH(N}^+(\text{R}_5\text{)}_3\text{-}$, herein identified compound **Ia-3** and **Ia-4**, respectively; (iii) R_1 is $\text{CH}_3\text{-(CH}_2\text{)}_4\text{-(CH=CH-CH}_2\text{)}_2\text{-(CH}_2\text{)}_6\text{-}$; R_2 is $\text{-O-CH}_2\text{-CHOH-CH}_2\text{-O-}$; and R_3 is $\text{-CH}_2\text{-CH(N}^+(\text{R}_5\text{)}_3\text{-}$ or $\text{-(CH}_2\text{)}_2\text{-CH(N}^+(\text{R}_5\text{)}_3\text{-}$, herein identified compound **Ia-5** and **Ia-6**, respectively; (iv) R_1 is $\text{CH}_3\text{-(CH}_2\text{-CH=CH)}_3\text{-(CH}_2\text{)}_7\text{-}$; R_2 is $\text{-O-CH}_2\text{-CHOH-CH}_2\text{-O-}$; and R_3 is $\text{-CH}_2\text{-CH(N}^+(\text{R}_5\text{)}_3\text{-}$ or $\text{-(CH}_2\text{)}_2\text{-CH(N}^+(\text{R}_5\text{)}_3\text{-}$, herein identified compound **Ia-7** and **Ia-8**, respectively; (v) R_1 is $\text{CH}_3\text{-(CH}_2\text{)}_4\text{-(CH=CH-CH}_2\text{)}_4\text{-(CH}_2\text{)}_2\text{-}$; R_2 is $\text{-O-CH}_2\text{-CHOH-CH}_2\text{-O-}$; and R_3 is $\text{-CH}_2\text{-CH(N}^+(\text{R}_5\text{)}_3\text{-}$ or $\text{-(CH}_2\text{)}_2\text{-CH(N}^+(\text{R}_5\text{)}_3\text{-}$, herein identified compound **Ia-9** and **Ia-10**, respectively; (vi) R_1 is $\text{CH}_3\text{-(CH}_2\text{-CH=CH)}_5\text{-(CH}_2\text{)}_3\text{-}$; R_2 is $\text{-O-CH}_2\text{-CHOH-CH}_2\text{-O-}$; and R_3 is $\text{-CH}_2\text{-CH(N}^+(\text{R}_5\text{)}_3\text{-}$ or $\text{-(CH}_2\text{)}_2\text{-CH(N}^+(\text{R}_5\text{)}_3\text{-}$, herein identified compound **Ia-11** and **Ia-12** (lyso-DGTS, when *n* is 2; and R_5 is methyl), respectively; or (vii) R_1 is $\text{CH}_3\text{-(CH}_2\text{-CH=CH)}_6\text{-(CH}_2\text{)}_2\text{-}$; R_2 is $\text{-O-CH}_2\text{-CHOH-CH}_2\text{-O-}$; and R_3 is $\text{-CH}_2\text{-CH(N}^+(\text{R}_5\text{)}_3\text{-}$ or $\text{-(CH}_2\text{)}_2\text{-CH(N}^+(\text{R}_5\text{)}_3\text{-}$, herein identified compound **Ia-13** and **Ia-14**, respectively. In all these compounds, R_5 can be either methyl or ethyl (**Table 2**).

[0056] In other specific such embodiments, the active agent comprised within the pharmaceutical composition of the present invention is a compound of the formula Ib, wherein (i) R_1 is $\text{CH}_3\text{-(CH}_2\text{)}_{14}\text{-}$; R_2 is $\text{-NH-CH}_2\text{-CHOH-CH}_2\text{-O-}$; and R_3 is $\text{-CH}_2\text{-CH(N}^+(\text{R}_5\text{)}_3\text{-}$ or $\text{-(CH}_2\text{)}_2\text{-CH(N}^+(\text{R}_5\text{)}_3\text{-}$, herein identified compound **Ib-1** and **Ib-2**, respectively; (ii) R_1 is $\text{CH}_3\text{-(CH}_2\text{)}_7\text{-CH=CH-(CH}_2\text{)}_7\text{-}$; R_2 is $\text{-NH-CH}_2\text{-CHOH-CH}_2\text{-O-}$; and R_3 is $\text{-CH}_2\text{-CH(N}^+(\text{R}_5\text{)}_3\text{-}$ or $\text{-(CH}_2\text{)}_2\text{-CH(N}^+(\text{R}_5\text{)}_3\text{-}$, herein identified compound **Ib-3** and **Ib-4**, respectively; (iii) R_1 is $\text{CH}_3\text{-(CH}_2\text{)}_4\text{-(CH=CH-CH}_2\text{)}_2\text{-(CH}_2\text{)}_6\text{-}$; R_2 is $\text{-NH-CH}_2\text{-CHOH-CH}_2\text{-O-}$; and R_3 is $\text{-CH}_2\text{-CH(N}^+(\text{R}_5\text{)}_3\text{-}$ or $\text{-(CH}_2\text{)}_2\text{-CH(N}^+(\text{R}_5\text{)}_3\text{-}$, herein identified compound **Ib-5** and **Ib-6**, respectively; (iv) R_1 is $\text{CH}_3\text{-(CH}_2\text{-CH=CH)}_3\text{-(CH}_2\text{)}_7\text{-}$; R_2 is $\text{-NH-CH}_2\text{-CHOH-CH}_2\text{-O-}$; and R_3 is $\text{-CH}_2\text{-CH(N}^+(\text{R}_5\text{)}_3\text{-}$ or $\text{-(CH}_2\text{)}_2\text{-CH(N}^+(\text{R}_5\text{)}_3\text{-}$, herein identified compound **Ib-7** and **Ib-8**, respectively; (v) R_1 is $\text{CH}_3\text{-(CH}_2\text{)}_4\text{-(CH=CH-CH}_2\text{)}_4\text{-(CH}_2\text{)}_2\text{-}$; R_2 is $\text{-NH-CH}_2\text{-CHOH-CH}_2\text{-O-}$; and R_3 is $\text{-CH}_2\text{-CH(N}^+(\text{R}_5\text{)}_3\text{-}$ or $\text{-(CH}_2\text{)}_2\text{-}$

CH(N⁺(R₅)₃)-, herein identified compound **Ib-9** and **Ib-10**, respectively; (vi) R₁ is CH₃-(CH₂-CH=CH)₅-(CH₂)₃-; R₂ is -NH-CH₂-CHOH-CH₂-O-; and R₃ is -CH₂-CH(N⁺(R₅)₃)- or -(CH₂)₂-CH(N⁺(R₅)₃)-, herein identified compound **Ib-11** and **Ib-12**, respectively; or (vii) R₁ is CH₃-(CH₂-CH=CH)₆-(CH₂)₂-; R₂ is -NH-CH₂-CHOH-CH₂-O-; and R₃ is -CH₂-CH(N⁺(R₅)₃)- or -(CH₂)₂-CH(N⁺(R₅)₃)-, herein identified compound **Ib-13** and **Ib-14**, respectively. In all these compounds, R₅ can be either methyl or ethyl (**Table 2**).

Table 2: Specific compounds of the formulas Ia and Ib described herein *

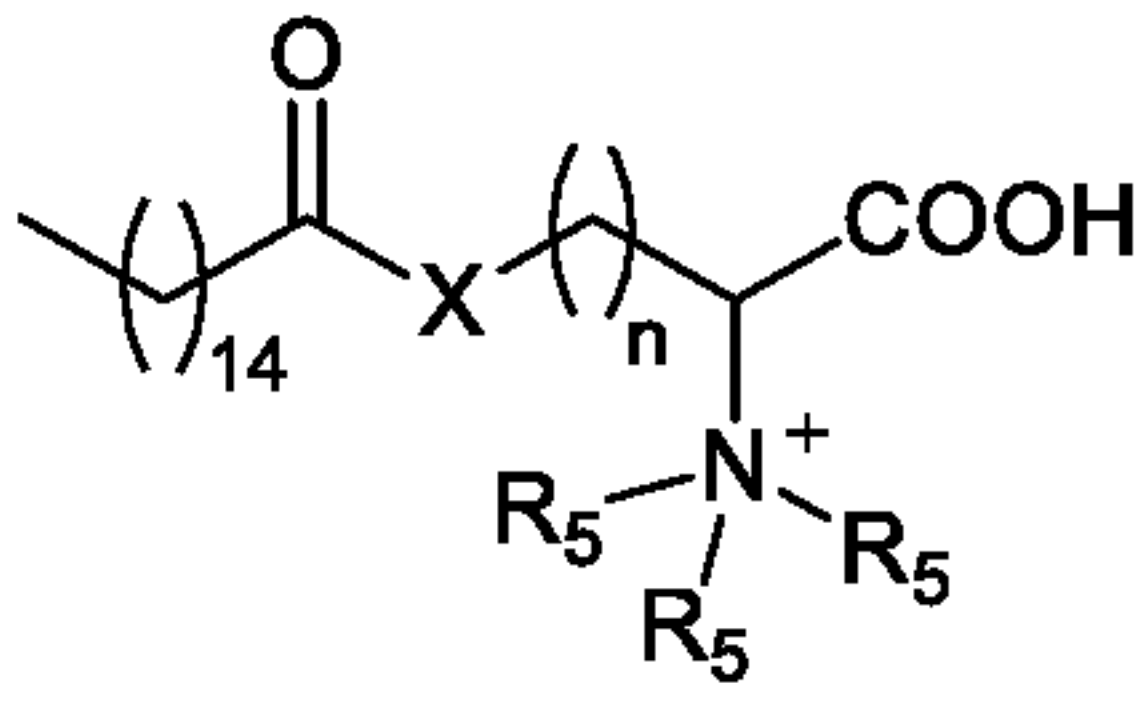
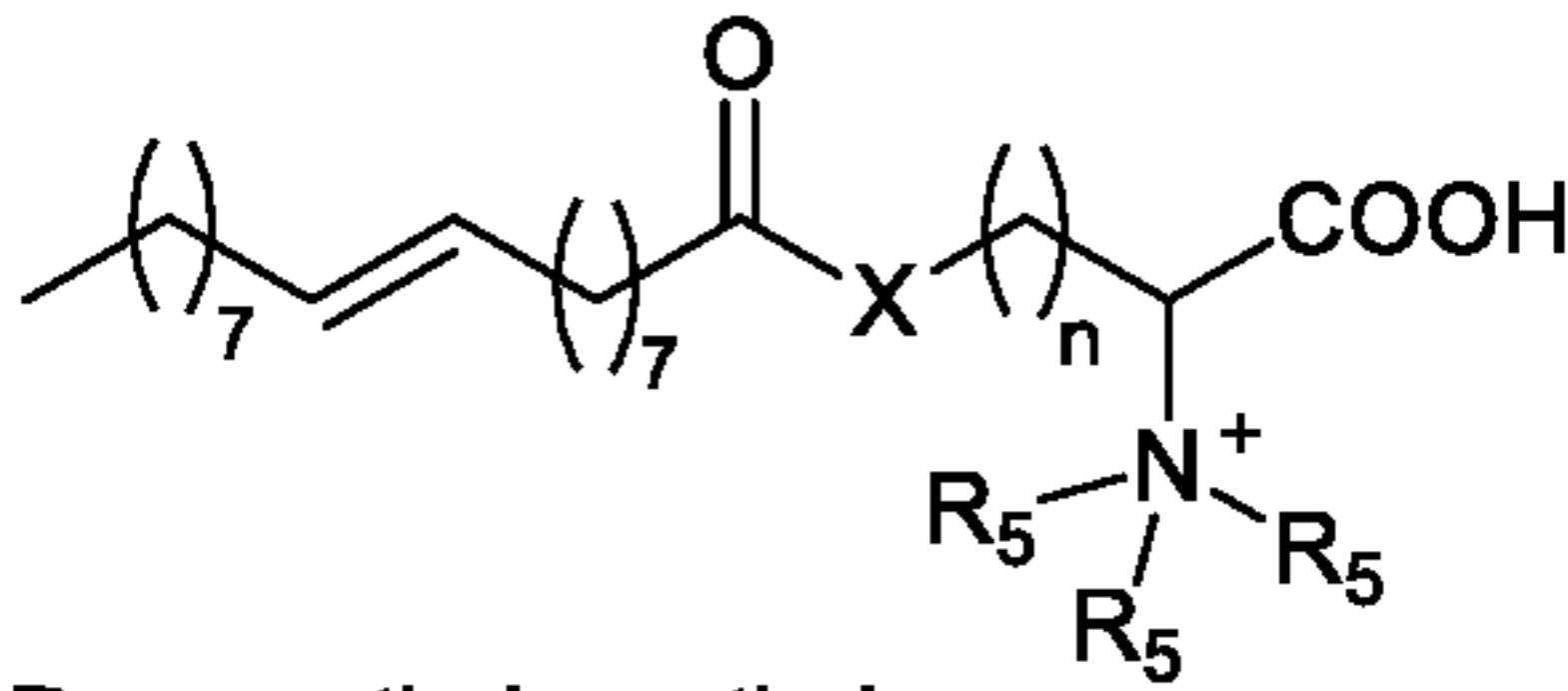
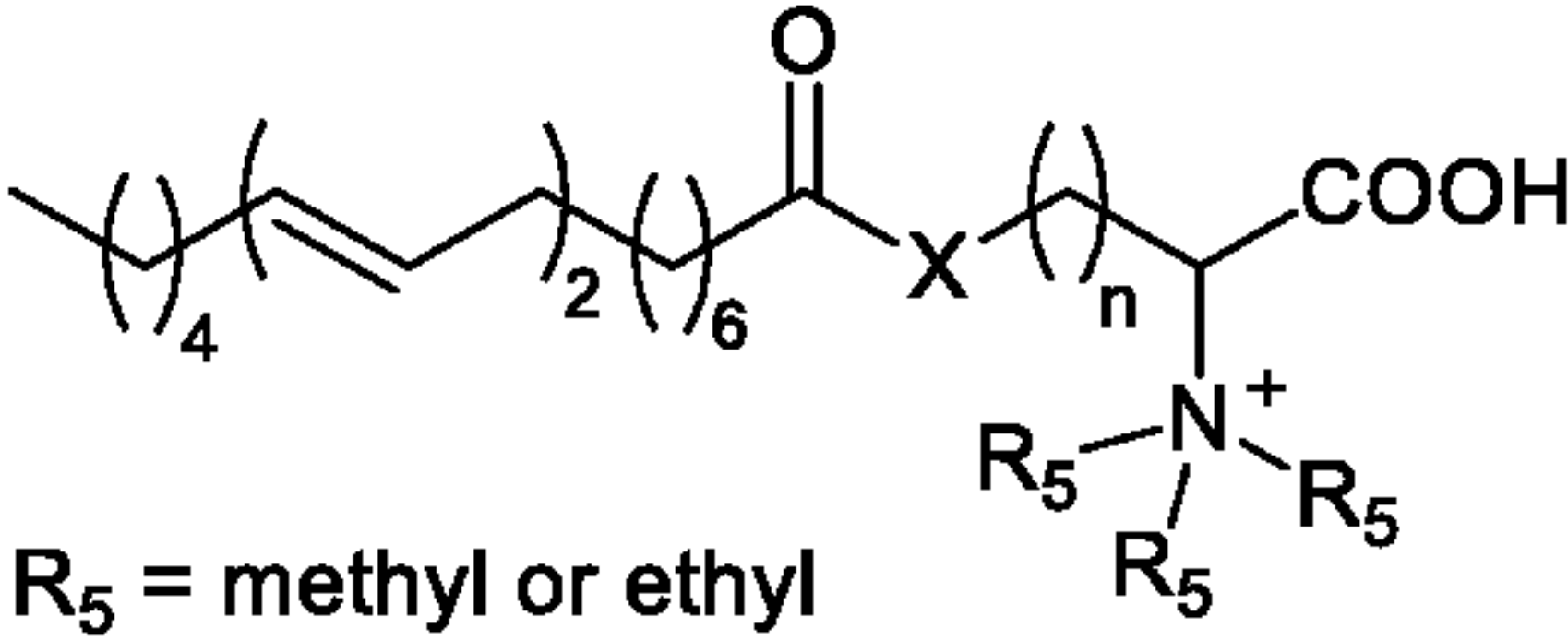
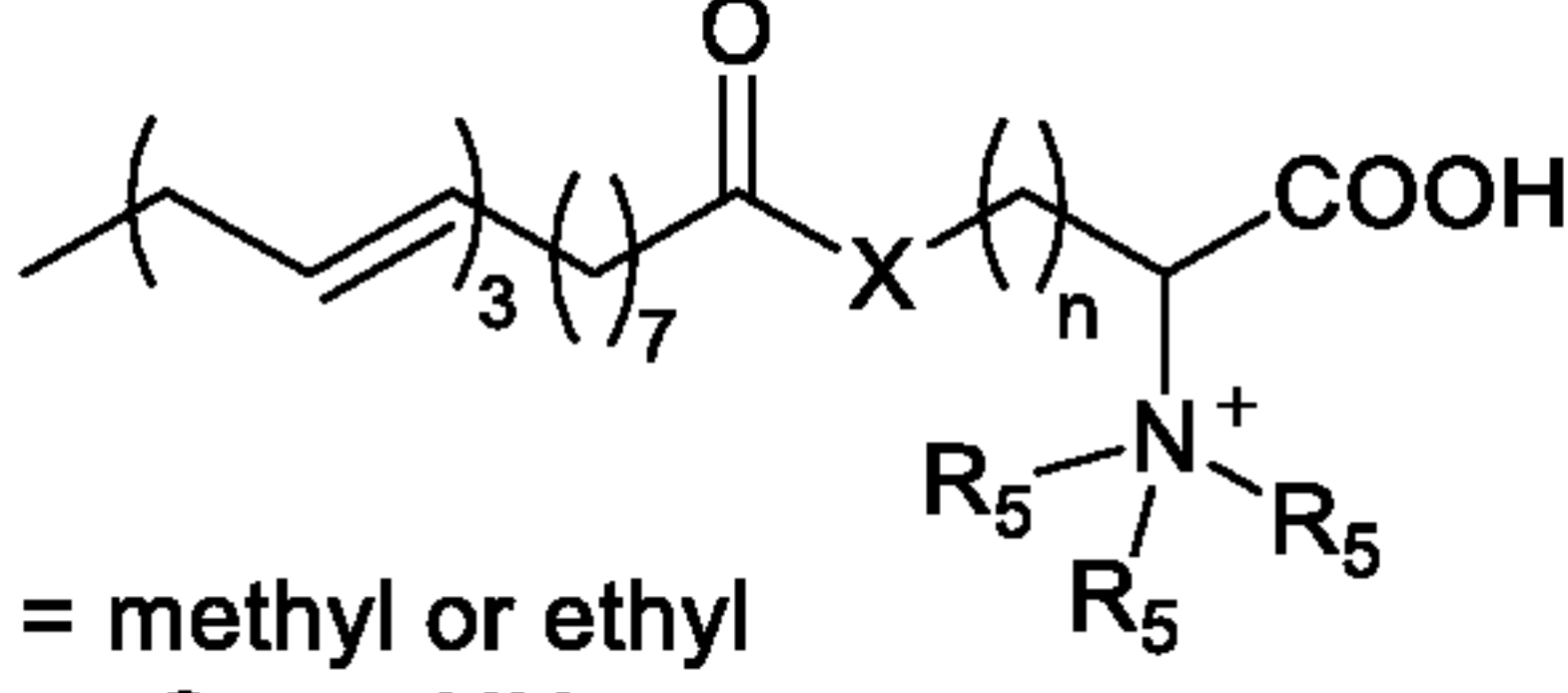
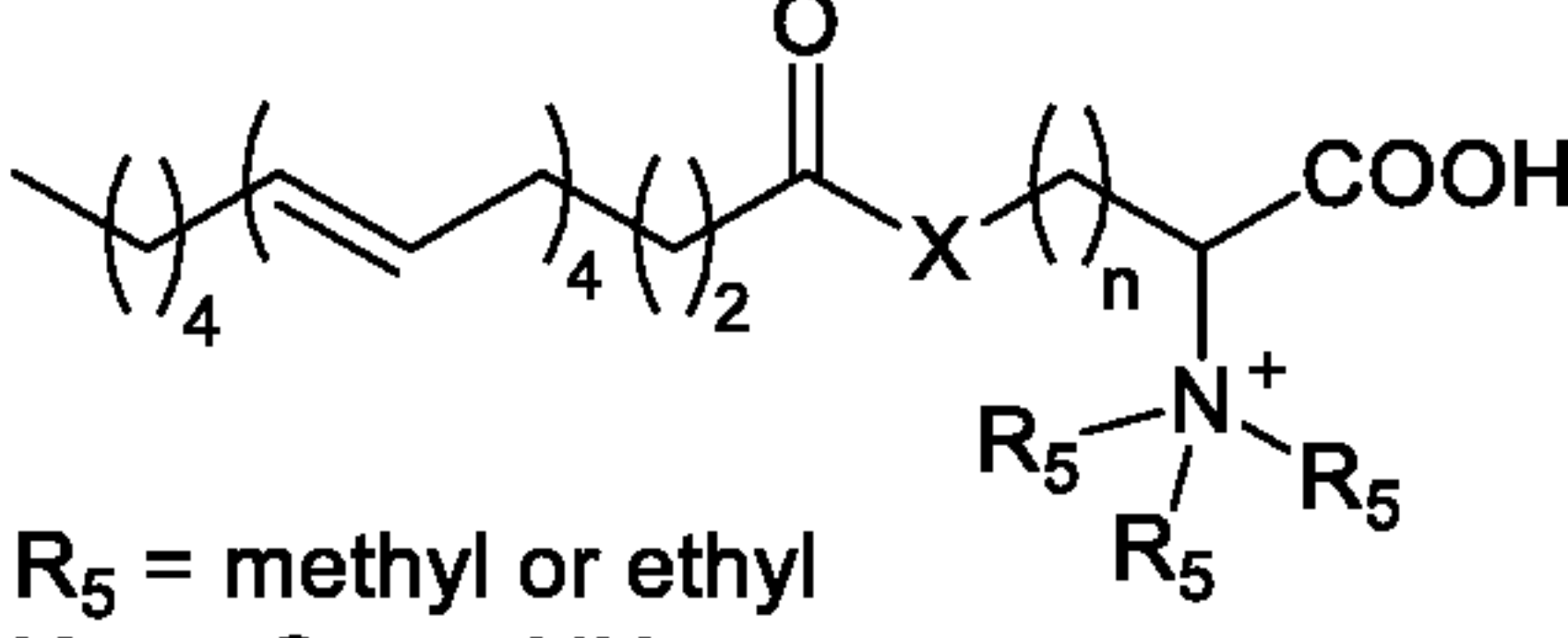
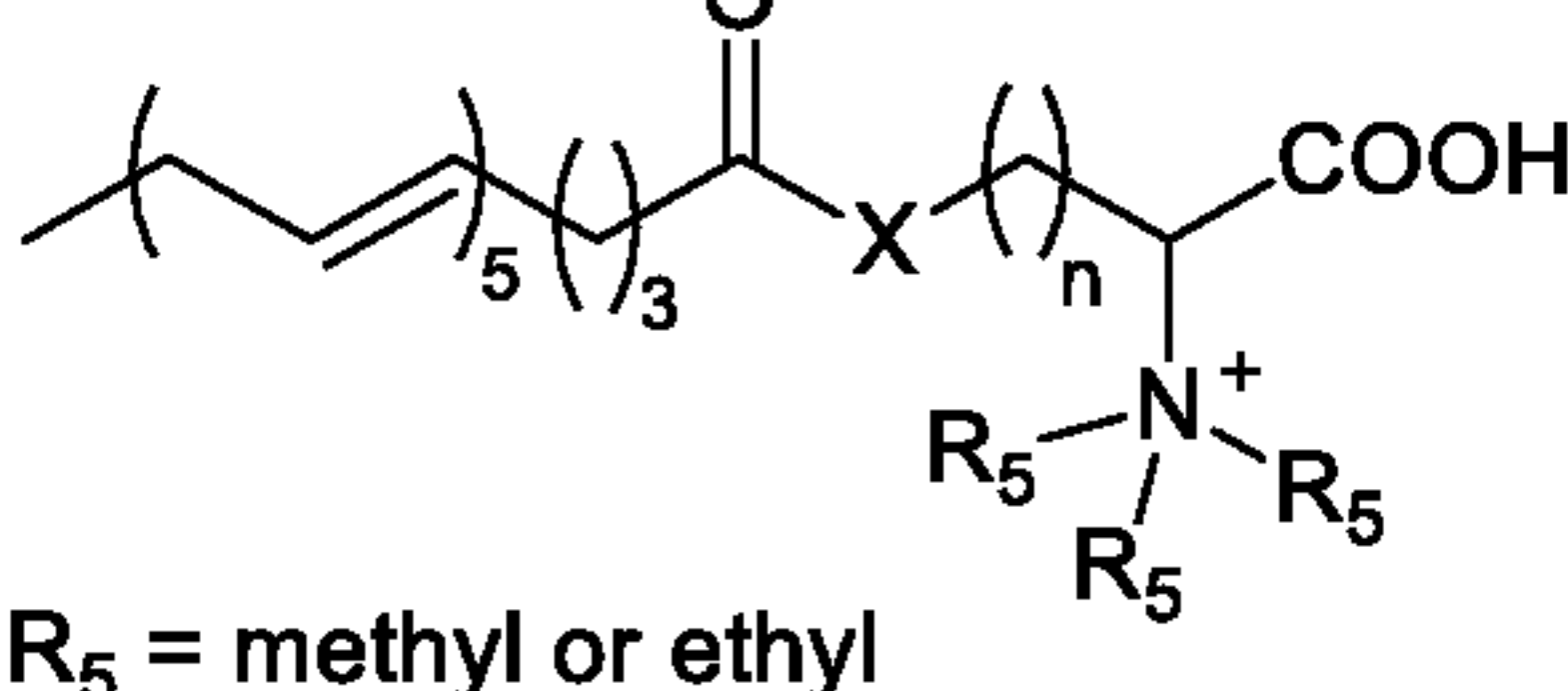
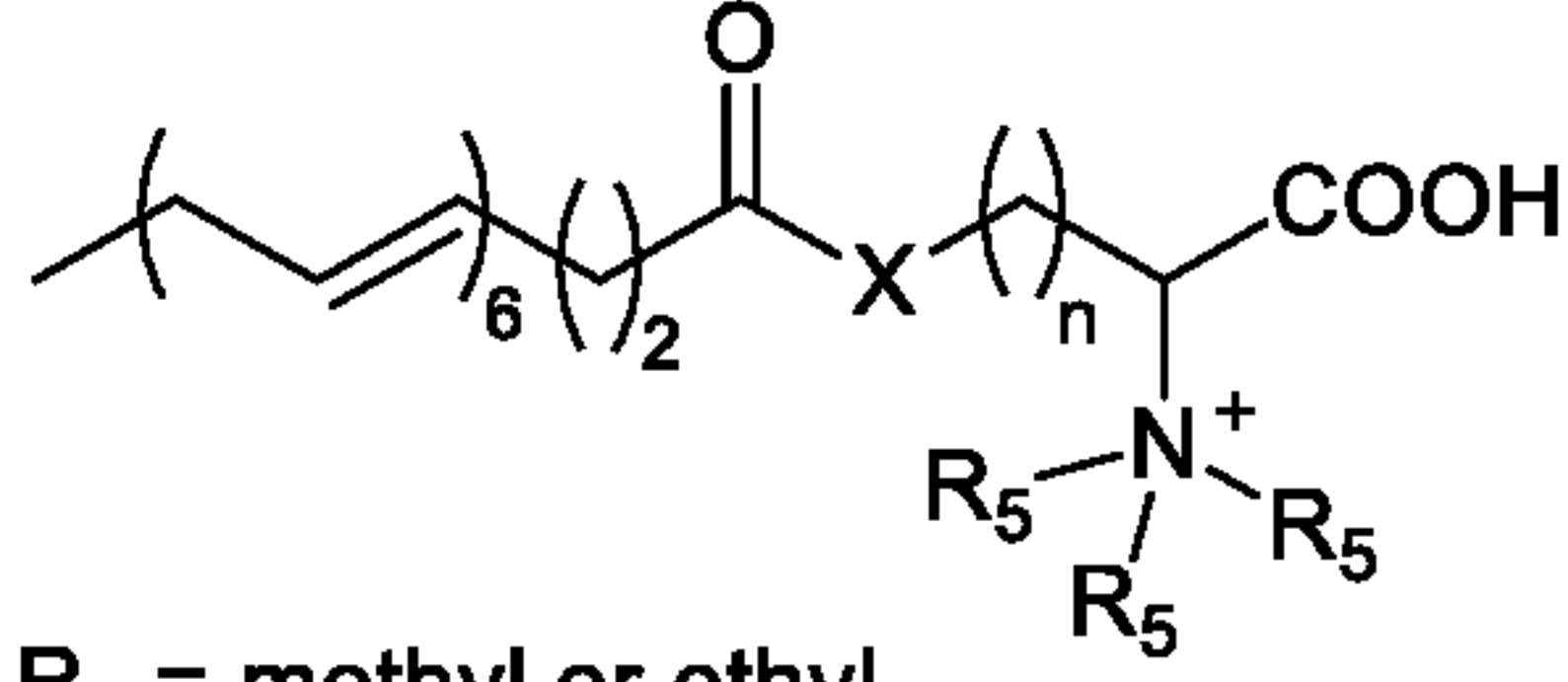
Ia-1/2 and Ib-1/2	Ia-3/4 and Ib-3/4
 <p>R₅ = methyl or ethyl X = -O- or -NH- n = 1 or 2</p>	 <p>R₅ = methyl or ethyl X = -O- or -NH- n = 1 or 2</p>
Ia-5/6 and Ib-5/6	Ia-7/8 and Ib-7/8
 <p>R₅ = methyl or ethyl X = -O- or -NH- n = 1 or 2</p>	 <p>R₅ = methyl or ethyl X = -O- or -NH- n = 1 or 2</p>
Ia-9/10 and Ib-9/10	Ia-11/12 and Ib-11/12
 <p>R₅ = methyl or ethyl X = -O- or -NH- n = 1 or 2</p>	 <p>R₅ = methyl or ethyl X = -O- or -NH- n = 1 or 2</p>
Ia-13/14 and Ib-13/14	
 <p>R₅ = methyl or ethyl X = -O- or -NH- n = 1 or 2</p>	

* Compounds wherein R₅ is methyl are also referred to herein as **Ia-1(methyl)** to **Ia-14(methyl)**, or **Ib-1(methyl)** to **Ib-14(methyl)**; and compounds wherein R₅ is ethyl are also referred to herein as **Ia-1(ethyl)** to **Ia-14(ethyl)**, or **Ib-1(ethyl)** to **Ib-14(ethyl)**.

[0057] In yet other specific such embodiments, the active agent comprised within the pharmaceutical composition of the present invention is a compound of the formula Ic, wherein (i) R₁ is CH₃-(CH₂)₁₄-; R₂ is -O-; and R₃ is -CH₂-CH(N⁺(R₅)₃)- or -(CH₂)₂-CH(N⁺(R₅)₃)-, herein identified compound **Ic-1** and **Ic-2**, respectively; (ii) R₁ is CH₃-(CH₂)₇-CH=CH-(CH₂)₇-; R₂ is -O-; and R₃ is -CH₂-CH(N⁺(R₅)₃)- or -(CH₂)₂-CH(N⁺(R₅)₃)-, herein identified compound **Ic-3** and **Ic-4**, respectively; (iii) R₁ is CH₃-(CH₂)₄-(CH=CH-CH₂)₂-(CH₂)₆-; R₂ is -O-; and R₃ is -CH₂-CH(N⁺(R₅)₃)- or -(CH₂)₂-CH(N⁺(R₅)₃)-, herein identified compound **Ic-5** and **Ic-6**, respectively; (iv) R₁ is CH₃-(CH₂-CH=CH)₃-(CH₂)₇-; R₂ is -O-; and R₃ is -CH₂-CH(N⁺(R₅)₃)- or -(CH₂)₂-CH(N⁺(R₅)₃)-, herein identified compound **Ic-7** and **Ic-8**, respectively; (v) R₁ is CH₃-(CH₂)₄-(CH=CH-CH₂)₄-(CH₂)₂-; R₂ is -O-; and R₃ is -CH₂-CH(N⁺(R₅)₃)- or -(CH₂)₂-CH(N⁺(R₅)₃)-, herein identified compound **Ic-9** and **Ic-10**, respectively; (vi) R₁ is CH₃-(CH₂-CH=CH)₅-(CH₂)₃-; R₂ is -O-; and R₃ is -CH₂-CH(N⁺(R₅)₃)- or -(CH₂)₂-CH(N⁺(R₅)₃)-, herein identified compound **Ic-11** and **Ic-12**, respectively; or (vii) R₁ is CH₃-(CH₂-CH=CH)₆-(CH₂)₂-; R₂ is -O-; and R₃ is -CH₂-CH(N⁺(R₅)₃)- or -(CH₂)₂-CH(N⁺(R₅)₃)-, herein identified compound **Ic-13** and **Ic-14**, respectively. In all these compounds, R₅ can be either methyl or ethyl (**Table 3**).

[0058] In still other specific such embodiments, the active agent comprised within the pharmaceutical composition of the present invention is a compound of the formula Id, wherein (i) R₁ is CH₃-(CH₂)₁₄-; R₂ is -NH-; and R₃ is -CH₂-CH(N⁺(R₅)₃)- or -(CH₂)₂-CH(N⁺(R₅)₃)-, herein identified compound **Id-1** and **Id-2**, respectively; (ii) R₁ is CH₃-(CH₂)₇-CH=CH-(CH₂)₇-; R₂ is -NH-; and R₃ is -CH₂-CH(N⁺(R₅)₃)- or -(CH₂)₂-CH(N⁺(R₅)₃)-, herein identified compound **Id-3** and **Id-4**, respectively; (iii) R₁ is CH₃-(CH₂)₄-(CH=CH-CH₂)₂-(CH₂)₆-; R₂ is -NH-; and R₃ is -CH₂-CH(N⁺(R₅)₃)- or -(CH₂)₂-CH(N⁺(R₅)₃)-, herein identified compound **Id-5** and **Id-6**, respectively; (iv) R₁ is CH₃-(CH₂-CH=CH)₃-(CH₂)₇-; R₂ is -NH-; and R₃ is -CH₂-CH(N⁺(R₅)₃)- or -(CH₂)₂-CH(N⁺(R₅)₃)-, herein identified compound **Id-7** and **Id-8**, respectively; (v) R₁ is CH₃-(CH₂)₄-(CH=CH-CH₂)₄-(CH₂)₂-; R₂ is -NH-; and R₃ is -CH₂-CH(N⁺(R₅)₃)- or -(CH₂)₂-CH(N⁺(R₅)₃)-, herein identified compound **Id-9** and **Id-10**, respectively; (vi) R₁ is CH₃-(CH₂-CH=CH)₅-(CH₂)₃-; R₂ is -NH-; and R₃ is -CH₂-CH(N⁺(R₅)₃)- or -(CH₂)₂-CH(N⁺(R₅)₃)-, herein identified compound **Id-11** and **Id-12**, respectively; or (vii) R₁ is CH₃-(CH₂-CH=CH)₆-(CH₂)₂-; R₂ is -NH-; and R₃ is -CH₂-CH(N⁺(R₅)₃)- or -(CH₂)₂-CH(N⁺(R₅)₃)-, herein identified compound **Id-13** and **Id-14**, respectively. In all these compounds, R₅ can be either methyl or ethyl (**Table 3**).

Table 3: Specific compounds of the formulas Ic and Id described herein *

Ic-1/2 and Id-1/2	Ic-3/4 and Id-3/4
 <p data-bbox="569 685 852 789"> R_5 = methyl or ethyl X = -O- or -NH- n = 1 or 2 </p>	 <p data-bbox="1140 661 1423 765"> R_5 = methyl or ethyl X = -O- or -NH- n = 1 or 2 </p>
Ic-5/6 and Id-5/6	Ic-7/8 and Id-7/8
 <p data-bbox="485 1077 768 1181"> R_5 = methyl or ethyl X = -O- or -NH- n = 1 or 2 </p>	 <p data-bbox="1119 1071 1402 1175"> R_5 = methyl or ethyl X = -O- or -NH- n = 1 or 2 </p>
Ic-9/10 and Id-9/10	Ic-11/12 and Id-11/12
 <p data-bbox="485 1472 768 1576"> R_5 = methyl or ethyl X = -O- or -NH- n = 1 or 2 </p>	 <p data-bbox="1140 1472 1423 1576"> R_5 = methyl or ethyl X = -O- or -NH- n = 1 or 2 </p>
Ic-13/14 and Id-13/14	
 <p data-bbox="499 1869 783 1973"> R_5 = methyl or ethyl X = -O- or -NH- n = 1 or 2 </p>	

* Compounds wherein R_5 is methyl are also referred to herein as **Ic-1(methyl)** to **Ic-14(methyl)**, or **Id-1(methyl)** to **Id-14(methyl)**; and compounds wherein R_5 is ethyl are also referred to herein as **Ic-1(ethyl)** to **Ic-14(ethyl)**, or **Id-1(ethyl)** to **Id-14(ethyl)**.

[0059] The compounds of the formula I may be synthesized according to any technology or procedure known in the art, e.g., as described in the Examples section and depicted in **Schemes 1-4** hereinafter.

[0060] The pharmaceutical compositions of the present invention can be provided in a variety of formulations, e.g., in a pharmaceutically acceptable form and/or in a salt or solvate form, as well as in a variety of dosages.

[0061] In one embodiment, the pharmaceutical composition of the present invention comprises a salt of a compound of the formula I with a non-toxic pharmaceutically acceptable anion. Pharmaceutically acceptable anions include, without being limited to, the hydrochloride salt, the hydrobromide salt, the hydroiodide salt, the acetate, mesylate, esylate, maleate, fumarate, tartrate, bitartrate, sulfate, *p*-toluenesulfonate, benzenesulfonate, methanesulfonate, ethanesulfonate (edisylate), ethanesulfonate (esylate), tosylate, benzoate, acetate, phosphate, carbonate, bicarbonate, succinate, and citrate. Multiple pharmaceutically acceptable anions can be used in a single preparation if desired.

[0062] Pharmaceutically acceptable salts of the compound of the formula I may be formed by conventional means, e.g., by reacting the free base form of the active agent with one or more equivalents of the appropriate acid in a solvent or medium in which the salt is insoluble, or in a solvent such as water which is removed *in vacuo* or by freeze drying, or by exchanging the anions of an existing salt for another anion on a suitable ion exchange resin.

[0063] The pharmaceutical compositions provided by the present invention may be prepared by conventional techniques, e.g., as described in Remington: The Science and Practice of Pharmacy, 19th Ed., 1995. The compositions can be prepared, e.g., by uniformly and intimately bringing the active agent, i.e., the compound of the formula I, into association with a liquid carrier, a finely divided solid carrier, or both, and then, if necessary, shaping the product into the desired formulation. The compositions may be in liquid, solid or semisolid form and may further include pharmaceutically acceptable fillers, carriers, diluents or adjuvants, and other inert ingredients and excipients. In one embodiment, the pharmaceutical composition of the present invention is formulated as nanoparticles.

[0064] The compositions can be formulated for any suitable route of administration, including oral, rectal, nasal, intravenous, intraarterial, intramuscular, intraperitoneal, intrathecal, intrapleural, intratracheal, subcutaneous, transdermal, intradermal, vaginal, and topical administration, as well as for inhalation. The exact dosage and regimen of administration of the composition will be determined as deemed appropriate by the practitioner, and dependent upon the therapeutic effect to be achieved and may vary with the particular formula, the route of administration, and the age and condition of the individual subject to whom the composition is to be administered.

[0065] For parenteral administration, the pharmaceutical composition of the invention may be in the form of a sterile injectable aqueous or oleagenous suspension, which may be formulated according to the known art using suitable dispersing, wetting or suspending agents. The sterile injectable preparation may also be a sterile injectable solution or suspension in a non-toxic parenterally acceptable diluent or solvent. Acceptable vehicles and solvents that may be employed include, without limiting, water, Ringer's solution, polyethylene glycol (PEG), 2-hydroxypropyl- β -cyclodextrin (HPCD), Tween-80, and isotonic sodium chloride solution. The compositions may be presented in unit-dose or multi-dose containers, e.g., sealed vials and ampoules, and may be stored in a freeze-dried (lyophilized) condition requiring only the addition of sterile liquid carrier, e.g. water, prior to use.

[0066] For transdermal administration, e.g., gels, patches or sprays can be contemplated.

[0067] Pharmaceutical compositions according to the present invention, when formulated for inhalation, may be administered utilizing any suitable device known in the art, such as metered dose inhalers, liquid nebulizers, dry powder inhalers, sprayers, thermal vaporizers, electrohydrodynamic aerosolizers, and the like.

[0068] Pharmaceutical compositions according to the present invention, when formulated for administration route other than parenteral administration, may be in a form suitable for oral use, e.g., as tablets, troches, lozenges, aqueous, or oily suspensions, dispersible powders or granules, emulsions, hard or soft capsules, or syrups or elixirs.

[0069] Compositions intended for oral use may be prepared according to any method known to the art for the manufacture of pharmaceutical compositions and may further comprise one or more agents selected from sweetening agents, flavoring agents, coloring agents and preserving agents in order to provide pharmaceutically elegant and palatable preparations. Tablets contain the active agent(s) in admixture with non-toxic pharmaceutically acceptable excipients, which are suitable for the manufacture of tablets. These excipients may be, e.g., inert diluents such as calcium carbonate, sodium carbonate, lactose, calcium phosphate, or sodium phosphate; granulating and disintegrating agents, e.g., corn starch or alginic acid; binding agents, e.g., starch, gelatin or acacia; and lubricating agents, e.g., magnesium stearate, stearic acid, or talc. The tablets may be either uncoated or coated utilizing known techniques to delay disintegration and absorption in the gastrointestinal tract and thereby provide a sustained action over a longer period. For

example, a time delay material such as glyceryl monostearate or glyceryl distearate may be employed. They may also be coated using the techniques described in the US Patent Nos. 4,256,108, 4,166,452 and 4,265,874 to form osmotic therapeutic tablets for control release. The pharmaceutical composition of the invention may also be in the form of oil-in-water emulsion.

[0070] The pharmaceutical compositions of the invention may be formulated for controlled release of the active agent. Such compositions may be formulated as controlled-release matrix, e.g., as controlled-release matrix tablets in which the release of a soluble active agent is controlled by having the active diffuse through a gel formed after the swelling of a hydrophilic polymer brought into contact with dissolving liquid (*in vitro*) or gastro-intestinal fluid (*in vivo*). Many polymers have been described as capable of forming such gel, e.g., derivatives of cellulose, in particular the cellulose ethers such as hydroxypropyl cellulose, hydroxymethyl cellulose, methylcellulose or methyl hydroxypropyl cellulose, and among the different commercial grades of these ethers are those showing fairly high viscosity. In other configurations, the compositions comprise the active agent formulated for controlled release in microencapsulated dosage form, in which small droplets of the active agent are surrounded by a coating or a membrane to form particles in the range of a few micrometers to a few millimeters.

[0071] Another contemplated formulation is depot systems, based on biodegradable polymers, wherein as the polymer degrades, the active agent is slowly released. The most common class of biodegradable polymers is the hydrolytically labile polyesters prepared from lactic acid, glycolic acid, or combinations of these two molecules. Polymers prepared from these individual monomers include poly (D,L-lactide) (PLA), poly (glycolide) (PGA), and the copolymer poly (D,L-lactide-co-glycolide) (PLG).

[0072] In another aspect, the present invention relates to a compound of the formula I as defined in any one of the embodiments above, or a pharmaceutically acceptable salt or solvate thereof, for use in the inhibition/treatment of atherosclerotic cardiovascular disease. Particular such compounds are those specifically described herein, i.e., the compounds herein identified **Ia-1** to **Ia-14**, **Ib-1** to **Ib-14**, **Ic-1** to **Ic-14**, and **Id-1** to **Id-14** (in each case, R₅ may be either methyl or ethyl).

[0073] In yet another aspect, the present invention relates to use of a compound of the formula I as defined in any one of the embodiments above, or a pharmaceutically acceptable salt or solvate thereof, for the preparation of a pharmaceutical medicament for

treatment of atherosclerotic cardiovascular disease. Particular such compounds are those specifically described herein, i.e., the compounds herein identified **Ia-1** to **Ia-14**, **Ib-1** to **Ib-14**, **Ic-1** to **Ic-14**, and **Id-1** to **Id-14** (in each case, R₅ may be either methyl or ethyl).

[0074] In still another aspect, the present invention relates to a method for treatment of atherosclerotic cardiovascular disease in a subject in need thereof, comprising administering to said subject a therapeutically effective amount of a compound of the formula I as defined in any one of the embodiments above, or a pharmaceutically acceptable salt or solvate thereof. Particular such compounds are those specifically described herein, i.e., the compounds herein identified **Ia-1** to **Ia-14**, **Ib-1** to **Ib-14**, **Ic-1** to **Ic-14**, and **Id-1** to **Id-14** (in each case, R₅ may be either methyl or ethyl).

[0075] The term "treatment" as used herein refers to the administering of a therapeutic amount of an active agent, i.e., a compound of the formula I as defined herein, which is effective to ameliorate undesired symptoms associated with the medical condition treated, i.e., atherosclerotic cardiovascular disease; prevent the manifestation of such symptoms before they occur; slow down the progression of said medical condition; slow down the deterioration of symptoms; enhance the onset of remission period; slow down the irreversible damage caused in the progressive chronic stage of said medical condition; delay the onset of said progressive stage; lessen the severity or cure said medical condition; improve survival rate or more rapid recovery; and/or prevent said medical condition from occurring.

[0076] The term "effective amount" as used herein means an amount of an active agent that will elicit the biological or medical response of a tissue, system, animal or human that is being sought. The amount must be effective to achieve the desired therapeutic effect as described above, depending, *inter alia*, on the type and severity of the medical condition to be treated and the treatment regime. The effective amount is typically determined in appropriately designed clinical trials (dose range studies) and the person versed in the art will know how to properly conduct such trials to determine the effective amount. As generally known, an effective amount depends on a variety of factors including the distribution profile of the active agent within the body, a variety of pharmacological parameters such as half-life in the body, on undesired side effects, if any, on factors such as age and gender, etc.

[0077] The term "subject" as used herein refers to any mammal, e.g., a human, non-human primate, horse, ferret, dog, cat, cow, and goat. In a preferred embodiment, the term "subject" denotes a human, i.e., an individual.

[0078] In a further aspect, the present invention provides a compound of the formula I as defined in any one of the embodiments above, but excluding the compounds wherein R_2 is $-O-CH_2-CHR_4-CH_2-O-$, i.e., a compound of the formula Ib wherein R_2 is $-NH-CH_2-CHR_4-CH_2-O-$; of the formula Ic wherein R_2 is $-O-$; or of the formula Id wherein R_2 is $-NH-$.

[0079] In certain embodiments, the compound of the present invention is a compound of the formula I, wherein R_1 is $(C_{15}-C_{21})$ alkyl, or $(C_{15}-C_{21})$ alkenyl having one or more, e.g., two, three, four, five or six, double bonds. Particular such embodiments are those wherein R_1 is a linear (C_{15}) alkyl, (C_{17}) alkenyl, (C_{19}) alkenyl, or (C_{21}) alkenyl. In more particular such embodiments, R_1 is $CH_3-(CH_2)_{14}-$, $CH_3-(CH_2)_7-CH=CH-(CH_2)_7-$, $CH_3-(CH_2)_4-(CH=CH-CH_2)_2-(CH_2)_6-$, $CH_3-(CH_2-CH=CH)_3-(CH_2)_7-$, $CH_3-(CH_2)_4-(CH=CH-CH_2)_4-(CH_2)_2-$, $CH_3-(CH_2-CH=CH)_5-(CH_2)_3-$, or $CH_3-(CH_2-CH=CH)_6-(CH_2)_2-$, and together with the carbonyl group attached thereto forms a palmitic acid residue, oleic acid residue, linoleic acid residue, linolenic acid residue, arachidonic acid residue, EPA residue, or DHA residue, respectively.

[0080] In certain embodiments, the compound of the present invention is a compound of the formula I, wherein R_2 is $-NH-CH_2-CHR_4-CH_2-O-$, $-O-$, or $-NH-$, wherein R_4 is $-OH$.

[0081] In other embodiments, the compound of the present invention is a compound of the formula I, wherein R_2 is $-NH-CH_2-CHR_4-CH_2-O-$, wherein R_4 is $-O-C(O)-R_6$, or $-NH-C(O)-R_6$. In particular such embodiments, R_6 is $(C_{15}-C_{21})$ alkyl, or $(C_{15}-C_{21})$ alkenyl having one or more double bonds, e.g., a linear (C_{15}) alkyl, (C_{17}) alkenyl, (C_{19}) alkenyl, or (C_{21}) alkenyl. In more particular such embodiments, R_6 is $CH_3-(CH_2)_{14}-$, $CH_3-(CH_2)_7-CH=CH-(CH_2)_7-$, $CH_3-(CH_2)_4-(CH=CH-CH_2)_2-(CH_2)_6-$, $CH_3-(CH_2-CH=CH)_3-(CH_2)_7-$, $CH_3-(CH_2)_4-(CH=CH-CH_2)_4-(CH_2)_2-$, $CH_3-(CH_2-CH=CH)_5-(CH_2)_3-$, or $CH_3-(CH_2-CH=CH)_6-(CH_2)_2-$, and together with the carbonyl group attached thereto forms a palmitic acid residue, oleic acid residue, linoleic acid residue, linolenic acid residue, arachidonic acid residue, EPA residue, or DHA residue, respectively.

[0082] In certain embodiments, the compound of the present invention is a compound of the formula I, wherein R_3 is a linear (C_1-C_8) alkylene substituted, preferably at the carbon atom attached to the carboxyl group, with a group of the formula $-N^+(R_5)_3$, i.e., $-(CH_2)_{1-7}-CH(N^+(R_5)_3)-$, that is optionally further substituted with one or more $-OH$ groups.

[0083] In certain embodiments, the compound of the present invention is a compound of the formula I, wherein R_5 each independently is (C₁-C₄)alkyl, e.g., methyl, ethyl, *n*-propyl, or isopropyl.

[0084] In certain embodiments, the compound of the present invention is a compound of the formula I, wherein (i) R_1 is (C₁₅-C₂₁)alkyl, or (C₁₅-C₂₁)alkenyl having one or more double bonds, preferably a linear (C₁₅)alkyl, (C₁₇)alkenyl, (C₁₉)alkenyl, or (C₂₁)alkenyl; (ii) R_2 is -NH-CH₂-CHR₄-CH₂-O-, -O-, or -NH-, wherein R_4 is -OH; (iii) R_3 is -(CH₂)₁₋₇-CH(N⁺(R₅)₃)-, optionally further substituted with one or more -OH groups; and (iv) R_5 each independently is (C₁-C₄)alkyl such as methyl, ethyl, *n*-propyl, or isopropyl.

[0085] In particular such embodiments, the compound of the present invention is a compound of the formula I, wherein R_1 is CH₃-(CH₂)₁₄-, CH₃-(CH₂)₇-CH=CH-(CH₂)₇-, CH₃-(CH₂)₄-(CH=CH-CH₂)₂-(CH₂)₆-, CH₃-(CH₂-CH=CH)₃-(CH₂)₇-, CH₃-(CH₂)₄-(CH=CH-CH₂)₄-(CH₂)₂-, CH₃-(CH₂-CH=CH)₅-(CH₂)₃-, or CH₃-(CH₂-CH=CH)₆-(CH₂)₂-. More particular such embodiments are those wherein (i) R_2 is -NH-CH₂-CHOH-CH₂-O-, R_3 is -CH₂-CH(N⁺(R₅)₃)-, or -(CH₂)₂-CH(N⁺(R₅)₃)-, forming together with the -O- and carboxyl group linked thereto either a serine or homoserine residue, respectively, in which the amino group is replaced by an ammonium cation; and R_5 each is methyl, ethyl, *n*-propyl, or isopropyl; (ii) R_2 is -O-; R_3 is -CH₂-CH(N⁺(R₅)₃)-, or -(CH₂)₂-CH(N⁺(R₅)₃)-, forming together with the -O- and carboxyl group linked thereto either a serine or homoserine residue, respectively, in which the amino group is replaced by an ammonium cation; and R_5 each is methyl, ethyl, *n*-propyl, or isopropyl; or (iii) R_2 is -NH-; R_3 is -CH₂-CH(N⁺(R₅)₃)-, or -(CH₂)₂-CH(N⁺(R₅)₃)-, forming together with the -NH- and carboxyl group linked thereto, a 2,3-diaminopropanoic acid or 2,3-diaminobutyric acid residue, respectively, in which the amino group linked to the carbon atom at position 2 is replaced by an ammonium cation; and R_5 each is methyl, ethyl, *n*-propyl, or isopropyl.

[0086] In specific such embodiments, the compound of the present invention is a compound of the formula Ib, Ic or Id, selected from the compounds herein identified **Ib-1** to **Ib-14**, **Ic-1** to **Ic-14**, and **Id-1** to **Id-14** (in each case, R_5 may be either methyl or ethyl).

[0087] In yet a further aspect, the present invention provides a pharmaceutical composition comprising a compound of the formula I as defined in any one of the embodiments above, but excluding the compounds wherein R_2 is -O-CH₂-CHR₄-CH₂-O-, or a pharmaceutically acceptable salt or solvate thereof, and a pharmaceutically acceptable carrier. Particular such compounds are those specifically described herein, i.e., the

compounds herein identified **Ib-1** to **Ib-14**, **Ic-1** to **Ic-14**, and **Id-1** to **Id-14** (in each case, R₅ may be either methyl or ethyl).

[0088] The invention will now be illustrated by the following non-limiting Examples.

EXAMPLES

Materials and Methods

Materials

[0089] Recombinant PON1 (rePON1), generated in *Escherichia coli* by direct evolution, was purchased from the Weizmann Institute of Science, Rehovot, Israel. Murine macrophage J774A.1 cells were purchased from the American Tissue Culture Collection (ATCC, Rockville, MD). Penicillin, streptomycin, glutamine, nystatin, fetal calf serum (FCS), trypsin and XTT Cell Proliferation Assay Kit were purchased from Biological Industries (Bet-Haemek, Israel). Other buffers, solvents and reagents were purchased from Sigma-Aldrich. Human serum was purchased from Industries biologic (Bet-Haemek, Israel).

[0090] *Nannochloropsis* sp. microalgae as raw material in the form of freeze-dried powder was provided by Seambiotic, Israel. Lyso-DGTS was isolated from *Nannochloropsis* sp. Microalgae.

The effect of lyso-DGTS on rePON1 activity

[0091] *Incubation of lyso-DGTS with rePON1.* To 200 µl of rePON1 solution (5 µg/ml) in Tris-HCl buffer pH=8.4 was added 1µl of lyso-DGTS dissolved in dimethyl sulfoxide (DMSO) to a final concentration of 1, 5, 10, 50, and 100 µg/ml. 1 µl DMSO was added to the control rePON1 solution. The mixtures were incubated at 37°C for 2, 4, 24 or 48 h.

[0092] *Lactonase activity.* 10 µl from each solution were taken to a UV 96-well microplate containing 90 µl Tris-HCL buffer pH=8.4 with 1 mM CaCl₂ (activity buffer) in each well. Then 100 µl dihydrocoumarin, 2 mM in the activity buffer was added (prepared from a stock of 100 mM dihydrocoumarin in DMSO). Dihydrocoumarine hydrolysis rate was measured at 270 nm, once in 25 seconds for 15 minutes, using SpectraMax M2 Reader. Non-enzymatic hydrolysis of dihydrocoumarin was subtracted from the total rate of hydrolysis. One unit of lactonase activity was equal to the hydrolysis of 1µmol of dihydrocoumarin /min.

[0093] *Esterase activity.* 10 µl from each solution were taken to a UV 96-well microplate wells containing 90 µl Tris-HCL buffer pH=8.4 with 1 mM CaCl₂ (activity buffer). Then

100 μ l phenyl acetate, 2 mM in the activity buffer was added (prepared from a stock of 100mM phenyl acetate in DMSO). Phenyl acetate hydrolysis rate was measured at 270 nm, once in 25 seconds, for 15 minutes using SpectraMax M2 Reader. One unit of esterase activity was equal to the hydrolysis of 1 μ mol of phenyl acetate/min. Lactonase and esterase unit activity were calculated by the following equation:

$$\text{Unit} = \text{slope (mOD/min)} \times 5(\text{per ml}) \times 666.7(\text{dilution}) / 700.$$

Human serum PON1 lactonase activity

[0094] 200 μ l of human serum diluted by 20 with phosphate-buffered saline (PBS) (PH=7.6) was incubated with lyso-DGTS at various concentrations (0, 1, 5, 10 and 50 μ g/ml) for 4 h at 37°C. Then, 10 μ l was taken to measure lactonase activity using the dihydrocoumarine assay.

Tryptophan fluorescence-quenching measurements

[0095] To 200 μ l rePON1 (50 μ g/ml=1.16 μ M) solution in black 96-well plate wells was added lyso-DGTS at various concentration (0, 1, 5, 10, 25, 50, 75, and 100 μ g/ml). The solutions were incubated for 2 h at 25°C or 37°C. Fluorescence measurements were performed with an Infinite M200 PRO fluorescence spectrophotometer (Tecan) with emission spectra recorded from 320 to 450 nm at an excitation wavelength of 290 nm.

Molecular docking

[0096] The crystal structure of PON1 was retrieved from the Protein Data Bank (PDB). The enzyme was prepared for docking by the AutoDock Tools (ADT) program, an accessory program allowing the user to interact with AutoDock 4.2 from a graphic user interface. Water molecules were removed from the protein PDB file. Polar hydrogen atoms were added and Kollman united atom charges assigned. The solvation parameters were added by the Addsol program (part of the ADT program) and the grid points were set to 90, 90, 90; the spacing value equivalent to 0.375; and the grid center to X-10.4, Y-11.794, Z +30.00. Ligand-docking was carried out with the AutoDock 4.2 Genetic Algorithm (GA).

HDL and LDL isolation

[0097] HDL and LDL were isolated from human plasma samples by discontinuous density gradient ultracentrifugation and dialyzed against saline containing sodium ethylenediaminetetraacetic acid (EDTA; 1 mmol/L) to protect the lipoproteins against

oxidation. Before generating the experiments, LDL and HDL were dialyzed twice, for 1 h each time, and once more overnight against PBS at 4°C to remove EDTA.

RePON1 influx to J774A.1 macrophages

[0098] rePON1 (2 mg/ml) was reacted with fluorescein isothiocyanate (FITC) (200 µg/ml) for 1 h at 37°C in the dark in borate buffer (PH=8.6). Glycine 10 mM was added and the solution was dialyzed using PBS buffer to remove FITC excess. RePON1-FITC conjugate (50 µg/ml) was incubated with lyso-DGTS at different concentration (10, 20, 50 and 100 µg/ml) into RPMI for 2 h. The solution was added to J774A.1 macrophages and incubated for 16 h. Cells were washed three times with sterile PBS buffer (0.1% sodium azid, 0.2% bovine serum albumin (BSA)), harvested in PBS (buffer) and analyzed by fluorescence-activated cell sorting (FACS) (Facsclibur 4ca). Results are presented as mean fluorescence intensity (MFI).

OxLDL-induced foam cell formation

[0099] J774A.1 macrophage cells were grown in RPMI 1640 media containing 10% FBS in cell culture flask till ~90% confluence (37°C incubator containing 5% CO₂). The cells were incubated at 37°C overnight under sterile conditions, approximately 1×10⁵ J774.1 cells/well in a 96-well plate. Macrophage cells were incubated for an additional 24h with lyso-DGTS (50 and 100 µg/ml), rePON1 (50 µg/ml), or rePON1 preincubated with different concentrations of lyso-DGTS (10, 20, 50 and 100 µg/ml). The cells were washed and ox-LDL (25 µg/ml in a RPMI medium) was added for another 24 h to yield foam cells. The cells were washed 3 times with PBS, following fixation with 4% formaldehyde for 10 min, the cells were stained with Oil Red O (0.35 mg/100ml in 60% isopropanol; Sigma-Aldrich) for 15 min at 37°C to evaluate the characteristic lipid accumulation in macrophage-derived foam cells. Foam cell formation was observed under microscope.

[00100] The density of lipid content was evaluated by alcohol extraction after staining. The absorbance at 514 nm was measured using microplate reader (Infinite M200 PRO fluorescence spectrophotometer (Tecan)).

HDL-cholesterol efflux

[00101] Cholesterol efflux Fluorometric Assay Kit (Cell-Based), Biovision was used to measure the effect of lyso-DGTS on HDL-cholesterol efflux.

[00102] J774.1 macrophage cells were grown in RPMI 1640 media containing 10% FBS in cell culture flask till ~90% confluence (37°C incubator containing 5% CO₂). The cells

were splitted under sterile conditions using basic cell culture techniques and plate to approximately 1×10^5 cells/well in a 96-well plate (white plate with clear bottom) using 100 μ l media/well. After 2 h, the cells attached to the plates, washed with RPMI 1640 media (no serum added) and labeled with 50 μ l labeling reagent and 50 μ l equilibration buffer, supplied by the kit, for 16 h. 100 μ l equilibration buffer alone were added to the background control for measuring background fluorescence. The cells were washed with media and treated for another 4-6 h with 100 μ l of RPMI 1640 media containing HDL (25 μ g protein) preincubated with lyso-DGTS at various concentrations (0, 10, 20, 50, and 100 μ g/ml) for 4 h. To the negative control was added RPMI 1640 media alone.

[00103] The fluorescence of the supernatant was measured (excitation/emission =482/515 nm). The cells were solubilized adding 100 μ l of Cell Lysis Buffer and shaking on a plate shaker for 30 min at room temperature, and its fluorescence was also measured.

[00104] Cholesterol efflux of the treatments was calculated by dividing the fluorescence intensity of the media by total fluorescence intensity of the cell lysate of the same treatment and media.

In-vivo experiment using Balb/c mice

[00105] Eight weeks old Balb/c mice where fed with normal rodent diet (the "non" group $n=11$) for 12 weeks or with high-fat diet (HFD) for 8 weeks. After 8 weeks, the HFD group was divided into two groups both treated via osmotic mini-pumps implanted subcutaneously: (1) vehicle group (the pumps contained 100 μ l of DDW+2% Tween 80; $n=9$); (2) Lyso-DGTS group (the pumps contained 100 μ l lyso-DGTS 1.4 mg/ml in DDW+2% Tween 80; $n=11$). The mice then continued with the same diet for another 4 weeks. The pumps injected 3.5 μ l solution each day for 28 days until the end of the experiment. Blood was drawn and centrifuged at 2000 rpm for five minutes, and the serum was stored at -70°C until the analyses. Clinical parameters were measured. Serum diluted by 20 with PBS and PON1 lactonase activity was measured using dihydrocoumarine assay.

Example 1. Effect of lyso-DGTS on rePON1 lactonase and esterase activities

[00106] The effect of lyso-DGTS on lactonase and arylerase activities of rePON1 was examined. rePON1 (5 μ g/ml in Tris buffer pH=8.4) was incubated with different concentrations of lyso-DGTS for 2, 4, 24, and 48 h at 37°C , and its lactonase and arylerase activities were measured using dihydrocoumarin and phenyl acetate assays, respectively.

[00107] Incubation of rePON1 with lyso-DGTS increased enzyme lactonase activity in a dose dependent manner. The enzyme activity altered significantly from 3.00 units without lyso-DGTS to 4.05, 5.73, 8.10, 11.61, and 12.7 units at 1, 5, 10, 50, and 100 $\mu\text{g/ml}$ lyso-DGTS, respectively, after 2 h of incubation (**Fig. 1A**).

[00108] Lactonase activity of rePON1 in buffer solution decreased with time and was abolished after 48 h, whereas the presence of lyso-DGTS stabilized and preserved protein lactonase activity for at least 48 h. Lyso-DGTS at 1, 5, 10, 50, and 100 $\mu\text{g/ml}$ preserved rePON1 lactonase activity after incubation for 48 h by 9%, 33%, 49%, 69%, and 66%, respectively (**Fig. 1A**).

[00109] A similar effect was observed with/without lyso-DGTS incubated with rePON1 when arylesterase activity was monitored. However, in contrast to lactonase activity, aryl esterase activity of the enzyme remained stable after 4 h (**Fig. 1B**) and also after 24 h of incubation (data not shown).

Example 2. The effect of lyso-DGTS on human serum PON1 lactonase activity

[00110] The effect of lyso-DGTS on lactonase activity of human serum PON1 was examined. Human serum was diluted by 20 with PBS buffer and incubated with and without lyso-DGTS at concentrations of 1, 5, 10, and 50 $\mu\text{g/ml}$ for 4 h at 37°C. Lactonase activity of the enzyme was measured using dihydrocoumarin assay. As shown in Example 1, lyso-DGTS increased human serum lactonase activity in a dose dependent manner up to 10 $\mu\text{g/ml}$, from 1.8 units without lyso-DGTS to 2.16, 2.82, 3.01, and 2.80 units at 1, 5, 10 and 50 $\mu\text{g/ml}$ lyso-DGTS, respectively, . The change at 1 $\mu\text{g/ml}$ of lyso-DGTS was not statistically significant (**Fig 2**).

Example 3. rePON1-lyso-DGTS interaction using Trp. fluorescence quenching method

[00111] The effect of lyso-DGTS on rePON1 can result from a specific interaction between the lipid and the enzyme which was studied using Trp fluorescence quenching method. **Fig. 3** shows the emission spectra of rePON1 in the presence of various concentrations of lyso-DGTS at 25°C (**Fig. 3A**) and 37°C (**Fig. 3B**) in the 300-450 nm range with an excitation wavelength of 290 nm. Lyso-DGTS quenched the fluorescence of rePON1 in a dose dependent manner at both temperatures.

[00112] Quenching pathways can be described by the Stern-Volmer equation (eq. 1):

$$\text{Eq. 1} \quad \frac{F_0}{F} = 1 + K_{sv}[Q]$$

where F_0 and F are the fluorescence intensities in the absence and presence of quencher (lyso-DGTS), respectively, K_{sv} is the Stern-Volmer quenching constant, and $[Q]$ is the quencher concentration (μM).

[00113] The Stern-Volmer curve (F_0/F vs. $[Q]$) was linear at the tested concentrations of lyso-DGTS at both temperatures (with $R^2 > 0.99$ and $p < 0.0001$). The K_{sv} value was $(1.18 \pm 0.13) \times 10^4 \text{ M}^{-1}$ and $(0.93 \pm 0.03) \times 10^4 \text{ M}^{-1}$ for 25°C (Fig. 4B) and 37°C (Fig. 4A), respectively. This K_{sv} value indicates that the quenching is initiated via formation of a complex between the quencher and rePON1 (Atrahimovich *et al.*, 2012).

[00114] The binding constant and binding sites were calculated using (eq. 2):

$$\text{Eq. 2} \quad \log\left(\frac{F_0 - F}{F}\right) = \log K_a + n \log[Q]$$

where K_a is the binding constant, reflecting the degree of interaction between rePON1 and lyso-DGTS, and n is the number of binding sites specifying the number of lyso-DGTS molecules bound to a rePON1. The highest K_a value for the association of lyso-DGTS with rePON1 was obtained at 25°C ($1.052 \times 10^4 \text{ M}^{-1}$; Fig. 4D), and a lower K_a value was obtained at 37°C ($2.377 \times 10^3 \text{ M}^{-1}$; Fig. 4C). The values obtained for n were not affected by the temperature and were equal to ~ 1 (Table 4).

The thermodynamic parameters: enthalpy (ΔH), entropy (ΔS), and free energy (ΔG) were calculated to characterize the type of rePON1-lyso-DGTS interaction. Table 4 shows negative values for ΔG and for ΔH and ΔS .

Table 4: Binding constants (K_a), number of binding sites (n) and thermodynamic parameters for the lyso-DGTS-rePON1 interaction

T (K)	K_a (M^{-1})	ΔH (kJ/mol)	ΔG (kJ/mol)	ΔS (J/mol K)	N
310	2.377×10^3	-94.992	-19.97	-242.16	0.84 ± 0.05
298	1.052×10^4		-22.876		0.98 ± 0.05

Example 4. Molecular modeling calculation of rePON1-lysoDGTS interactions

[00115] Docking analysis of lyso-DGTS in the potential binding groove site of rePON1 was carried out to predict the location of the lyso-DGTS binding site within the complete rePON1 crystal structure and to compare the modeling prediction with the Trp.-quenching-

fluorescence result. The calculated binding energy was ~ -2 kcal/mol, indicating a spontaneous interaction between lyso-DGTS and rePON1. According to the docking analysis, the main dominating forces in the binding site were found to be van der Waals and hydrogen bonds. These results are in accordance with the Trp. fluorescence results.

[00116] Fig. 5A shows that the fatty acid substructure of lyso-DGTS was oriented to the hydrophobic part of the groove (blue), and the glyceryl-methylated homoserine substructure was oriented to the hydrophilic part with hydrogen bonds interactions.

[00117] Hydrogen bonds can be observed between the carboxylic oxygen of lyso-DGTS with ser193 (distance 4.72Å) and lys192 (distance 6.093Å), the carbonyl group of the fatty acid of lyso-DGTS with the amine group of tyr294 (distance 1.762Å) and the hydroxyl group of lyso-DGTS with Phe 292 (distance of 2Å) (**Fig. 5B**).

Example 5. Effect of lyso-DGTS on rePON1 influx to macrophage cells

[00118] As previously shown, PON1 interacts with macrophages specifically and internalized into the cytoplasm of the cells (Efrat *et al.*, 2008), and may thus protect the macrophages from oxidation and prevent foam cell formation. The effect of lyso-DGTS on rePON1 influx into macrophage cells is shown herein.

[00119] RePON1 was labeled with FITC and incubated with lyso-DGTS at different concentrations (10, 20, 50, and 100 $\mu\text{g/ml}$) for 2 h. Each solution was added to J774A.1 macrophages and incubated at 37°C for 16 h, and then analyzed by fluorescence-activated cell sorting (FACS). **Fig. 6A** shows that lyso-DGTS significantly increased rePON1 internalization into macrophages in a dose dependent manner. The MFI increased from 61.62 for rePON1-FITS alone to 131.02, 368.61, 386.46, and 517.45 for rePON1 incubated with lyso-DGTS at 10, 20, 50, and 100 $\mu\text{g/ml}$, respectively (**Fig. 6B**).

Example 6. The effect of lyso-DGTS-rePON1 interaction on ox-LDL-induced foam cell formation in J774A.1 macrophages

[00120] Macrophages uptake of ox-LDL, forming foam cell, is the hallmark of atherogenesis. The ability of lyso-DGTS or rePON1 incubated with lyso-DGTS to attenuate foam cell formation was examined. J774A.1 macrophages were incubated with rePON1 (50 $\mu\text{g/ml}$), rePON1 pre-incubated with lyso-DGTS (50 and 100 $\mu\text{g/ml}$) or lyso-DGTS (50 $\mu\text{g/ml}$) alone, and were then washed and incubated with ox-LDL (25 $\mu\text{g/ml}$) for 24h.

[00121] Incubation of the cells with ox-LDL resulted in lipid deposition in macrophages and foam cell formation (**Fig. 7A**). The quantitative analysis of oil red staining intensity showed that pre-incubation of the macrophages with lyso-DGTS alone significantly reduced the oil red staining intensity by 32%. While pre-incubation of the cells with rePON1 and rePON1 incubated with lyso-DGTS at 50 and 100 $\mu\text{g/ml}$ significantly reduced the oil red intensity by 49%, 45% and 60% respectively (**Fig. 7B**). The results confirm the ability of lyso-DGTS to inhibit ox-LDL-induced foam cell formation. Also, rePON1 inhibited ox-LDL-induced foam cell formation while incubation of the enzyme with 100 $\mu\text{g/ml}$ lyso-DGTS enhanced its ability to inhibit foam cell formation by ~10% (not significant).

Example 7. The effect of lyso-DGTS on HDL-mediated cholesterol efflux from macrophage cells

[00122] HDL removes cholesterol from cells, including macrophages. HDL particles were incubated with lyso-DGTS at different concentrations. The HDL ability to efflux cholesterol from J774A.1 macrophages was measured using flouromtric assay (cell-based cholesterol efflux flouromtric assay kit, supplied by Biovision) and expressed as % of cholesterol efflux. Lyso-DGTS significantly increased the ability of HDL to take out cholesterol from macrophages in a dose dependent manner. The cholesterol removal enhanced from 16.5% (without lyso-DGTS) to 22.5%, 31.5%, 36.5%, and 46.5% after incubation with lyso-DGTS at 10, 20, 50, and 100 $\mu\text{g/ml}$, respectively (**Fig. 8**).

Example 8. The effect of lyso-DGTS on APOA1-mediated cholesterol efflux from macrophage cells

[00123] Apolipoprotein A1 (APOA1) is the major structural and functional HDL protein which accounts for approximately 70% of total HDL protein. It has been repeatedly demonstrated that APOA1 is a particularly efficient acceptor of cholesterol released from cells. The effect of lyso-DGTS on APOA1 mediated cholesterol efflux from macrophage cells was examined.

[00124] APOA1 was incubated with lyso-DGTS at different concentrations (0, 10, 20, 50, and 100 $\mu\text{g/ml}$), and its ability to remove cholesterol from J774A.1 macrophages was measured by fluorometric assay (cell-based Cholesterol Efflux Fluorometric Assay Kit) and expressed as % of cholesterol efflux. **Fig. 9** shows that lyso-DGTS significantly

enhanced the APOA1 cholesterol efflux from macrophage cells in a dose dependent manner, starting at APOA1+50 μ g/ml lyso-DGTS (~25%; $p < 0.05$) up to max APOA1 efflux at 100 μ g/ml lyso-DGTS (~35%; $p < 0.0001$).

Example 9. Investigation of HDL-lyso-DGTS and APOA1-lyso-DGTS interactions using Trp-fluorescence-quenching method

[00125] In order to test whether the protective effect of lyso-DGTS on HDL occurs via specific interaction between lyso-DGTS and the lipoprotein, the HDL-lyso-DGTS interaction was investigated by the Trp-fluorescence-quenching method. Fig. 10 shows the emission spectra of HDL in the presence of various concentrations of lyso-DGTS at 37°C (Fig. 10A) and 25°C (Fig. 10B) in the 300-450 nm range with an excitation wavelength of 290 nm. Lyso-DGTS quenched HDL fluorescence in a dose-dependent manner at both temperatures.

[00126] Quenching pathways can be described by the Stern-Volmer equation (eq. 1 above). The Stern-Volmer curve was linear at the tested concentration of lyso-DGTS at both temperatures (with $R > 0.99$ and $p < 0.0001$). The Ksv values were $(5.59 \pm 0.42) \times 10^3 \text{ M}^{-1}$ at 37°C (Fig. 11A) and $(4.83 \pm 0.59) \times 10^3 \text{ M}^{-1}$ at 25°C (Fig. 11A), indicating that the quenching is initiated via formation of a complex between the quencher and HDL.

[00127] The binding constant and binding sites were calculated as shown for rePON1, using eq. 2 above. The highest Ka value for the association of lyso-DGTS with HDL at 37°C was $2.165 \times 10^4 \text{ M}^{-1}$ (Fig. 11C), decreasing to $3.78 \times 10^3 \text{ M}^{-1}$ at 25°C (Fig. 11D). The values obtained for n were not affected by temperature and were equal to 1 (Table 5). The thermodynamic parameters: enthalpy (ΔH), entropy (ΔS), and free energy (ΔG) were calculated to characterize the HDL-lyso-DGTS interaction type. Table 5 shows negative values for ΔG , and positive values for ΔH and ΔS , indicating a spontaneous interaction supported by hydrophobic forces.

Table 5: Binding constants (K_a), number of binding sites (n) and thermodynamic parameters for the lyso-DGTS-HDL interaction

T (K)	K_a (M^{-1})	ΔH (kJ/mol)	ΔG (kJ/mol)	ΔS (J/mol K)	N
310	2.165×10^4	26.6	-6.127	105.59	1.19 ± 0.05
298	3.78×10^3		-4.86		0.96 ± 0.05

[00128] The Trp-fluorescence-quenching method was further used to examine the interaction between lyso-DGTS and APOA1, the major protein component of HDL. Ka

and thermodynamic parameters were also calculated (**Table 6**). The highest K_a value for the association of lyso-DGTS with APOA1 at 37°C was $2.28 \times 10^4 \text{ M}^{-1}$, decreasing to $2.37 \times 10^3 \text{ M}^{-1}$ at 25°C. The values obtained for n were not affected by temperature and were equal to 1 (**Table 6**).

The thermodynamic parameters: enthalpy (ΔH), entropy (ΔS), and free energy (ΔG) were calculated to characterize the APOA1-lyso-DGTS interaction type. **Table 6** shows negative values for ΔG , and positive values for ΔH and ΔS , indicating a spontaneous interaction supported by hydrophobic forces. The parameters obtained for the lyso-DGTS-APOA1 interaction were similar to those obtained for lyso-DGTS-HDL interaction, indicating that lyso-DGTS mainly interacts with APOA1 in the HDL particle.

Table 6: Binding constants (K_a), number of binding sites (n) and thermodynamic parameters for the lyso-DGTS-APOA1 interaction

T (K)	K_a (M^{-1})	ΔH (kJ/mol)	ΔG (kJ/mol)	ΔS (J/mol K)	N
310	2.28×10^4	34.49	-6.125	131.126	1.23 ± 0.05
298	2.37×10^3		-4.58		1.01 ± 0.05

Example 10. The effect of lyso-DGTS on HDL surface polarity

[00129] HDL particles are plurimolecular, quasi-spherical or discoid, pseudomicellar complexes predominantly composed of polar lipids solubilized by apolipoproteins. In order to determine a possible interaction between lyso-DGTS and the HDL lipid core, the Laurdan General Polarization (Gp) assay was used. Gp values of Laurdan incorporated with HDL incubated with graded doses of lyso-DGTS were measured, and as shown, lyso-DGTS significantly decreased the HDL Gp values at a dose dependent manner at 20, 50, and 100 $\mu\text{g/ml}$, indicating an increase of the HDL lipid core polarity when incubated with lyso-DGTS (**Fig. 12**). These results show that lyso-DGTS interacts with the HDL proteomics and lipidomics. This interaction may cause a change in its physical state and lipid core polarity and thus affect its functionality.

Example 11. The effect of lyso-DGTS on HDL ability to induce endothelial nitric oxide (NO) release

[00130] NO is a soluble gas continuously synthesized from the amino acid L-arginine in endothelial cells by the constitutive calcium-calmodulin-dependent enzyme nitric oxide synthase (NOS). This substance has a wide range of biological properties that maintain

vascular homeostasis, including modulation of vascular dilator tone, regulation of local cell growth, and protection of the vessel from injurious consequences of platelets and cells circulating in blood, playing in this way a crucial role in the normal endothelial function. The effect of lyso-DGTS on the ability of HDL to induce endothelial NO release was examined and the results were compared to Sphingosine 1-Phosphate (S1P), an important lipid component identified in HDLs that may account for NO-mediated vasodilatory effects of HDLs.

[00131] Human umbilical vein endothelial cells (HUVECs) were incubated for 2 hours with HDL preincubated with different concentration of lyso-DGTS or S1P for 3 hours, and NO production determined using 2,3-diaminonaphthalene (DAN) assay. Similar to S1P, lyso-DGTS significantly increased the HDL ability to induce endothelial NO release at a dose dependent manner (**Fig.13**).

Example 12. The effect of lyso-DGTS on serum PON1 lactonase activity on Balb/c mice fed with high fat diet (HFD)

[00132] The effect of lyso-DGTS on lactonase PON1 activity was examined using Balb/c mice fed with HFD. Three groups of Balb/c mice were used: 1) the "non" group $n=11$ mice which was fed with normal rodent diet for 12 weeks; 2) the "vehicle" group $n=9$ mice which was fed with HFD for 8 weeks and then continued with the same diet for another 4 weeks with the injection of DDW+2% Tween via osmotic mini-pumps implanted subcutaneously; and 3) the lyso-DGTS group $n=11$ mice which was fed similar to the vehicle group and injected with lyso-DGTS at 1.43 mg/ml in DDW +2% Tween 80 (**Fig. 14**). At the end of the protocol, blood was withdrawn and clinical parameters and lactonase PON1 activity were measured. The body weight and cholesterol levels in the blood of the mice fed with HFD were significantly higher than those in mice fed with normal diet. HFD increased blood glucose level from 6.3 ± 1.6 μM in the "non" group to 7.15 ± 0.74 in the "vehicle" group (not statistically significant), while injecting the mice with lyso-DGTS significantly decreased blood glucose levels to 5.99 ± 1.4 μM (**Table 7**). Lactonase PON1 activity of the mice serum was measured using dehydrocumarine assay. HFD significantly decreased mice serum lactonase PON1 activity (decrease of ~ 2 units) and injecting the mice with lyso-DGTS significantly increased their serum lactonase PON1 activity (increase of ~ 2.3 units).

Table 7: Clinical parameters of the in-vivo experiment

	Non	Vehicle	Lyso-DGTS
n	12	12	12
BW (end of protocol)	27.4±2.1	30.4±1.9 ^a	29.8±2.4 ^a
Delta BW*	4.1±2.0	6.5±2.2 ^{a1}	5.7±2.18
Glucose (µM)	6.3±1.6	7.15±0.74	5.99±1.4 ^b
Triglycerides (µM)	0.77±0.40	0.98±0.31	0.84±0.26
Cholesterol (µM)	3.66±0.39	4.25±0.62 ^a	4.03±0.40
HDL (µM)	3.57±0.52	4.39±1.05	4.37±0.42 ^{a1}

* The change in body weight from baseline (at the beginning of the experiment, time zero);

^a $p < 0.05$ related to non group;

^{a1} $p < 0.01$ related to non group;

^b $p < 0.05$ related to vehicle group.

Example 13. The effect of lyso-DGTS on the anti-inflammatory properties of HDL in high fat diet (HFD) fed Balb/c mice

[00133] In order to examine the effect of lyso-DGTS on HDL- anti-inflammatory effects *in-vivo*, 3.5 µl lyso-DGTS a day were administered for 28 days, via a subcutaneously implanted osmotic mini-pump, to HFD fed mice. As described in Example 12, the mice were divided into three groups: 1) mice fed with regular diet for 12 weeks (the "non" group; $n=11$); 2) mice fed with HFD for 12 weeks and injected with lyso-DGTS (1.43 mg/ml in DDW+2% Tween) from week 9 (the lyso-DGTS group; $n=11$); and 3) mice fed with HFD for 12 weeks and injected with DDW+2% Tween (the vehicle group; $n=9$). As found, HDL isolated from the lyso-DGTS group showed a significantly lower inflammatory value (inflammatory value < 1 ; $p < 0.05$) as compared to HDL isolated from the vehicle group and from the non group which showed pro-inflammatory properties (inflammatory values > 1 ; $p < 0.05$) (**Fig.15**), indicating that lyso-DGTS enhances HDL anti-inflammatory properties in HFD fed mice.

Example 14. Preparation of lyso-DGTS derivatives

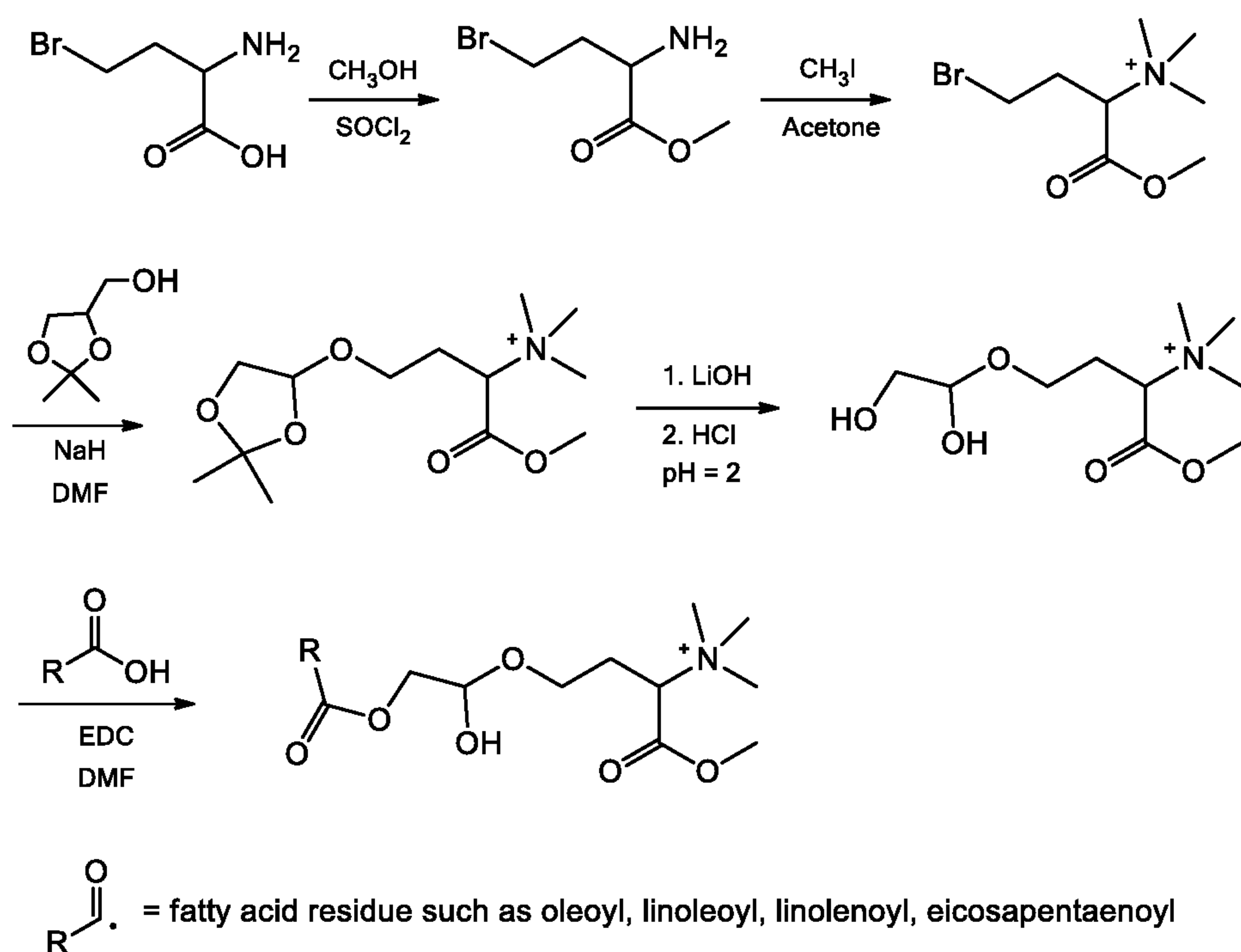
[00134] In this study, lyso-DGTS derivatives are synthesized and tested for their activity.

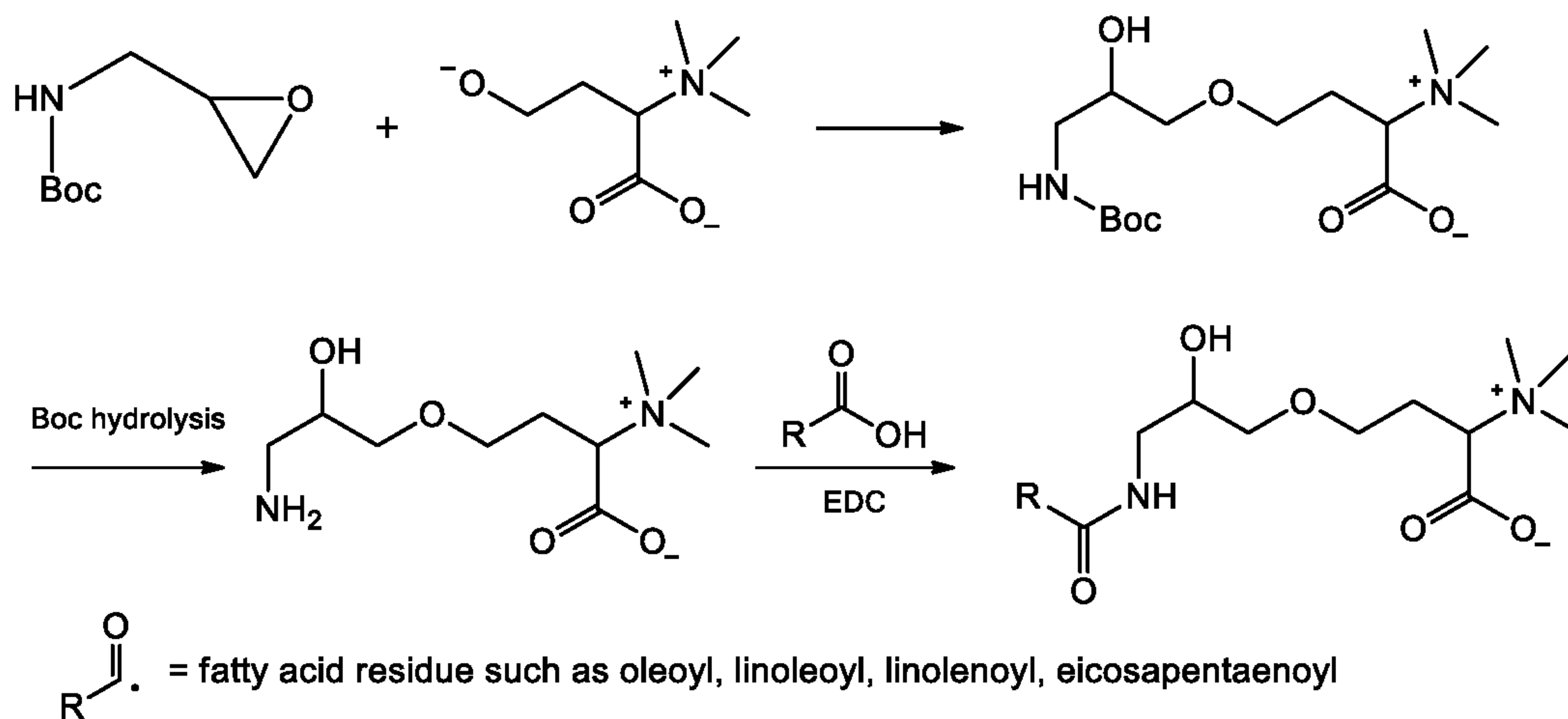
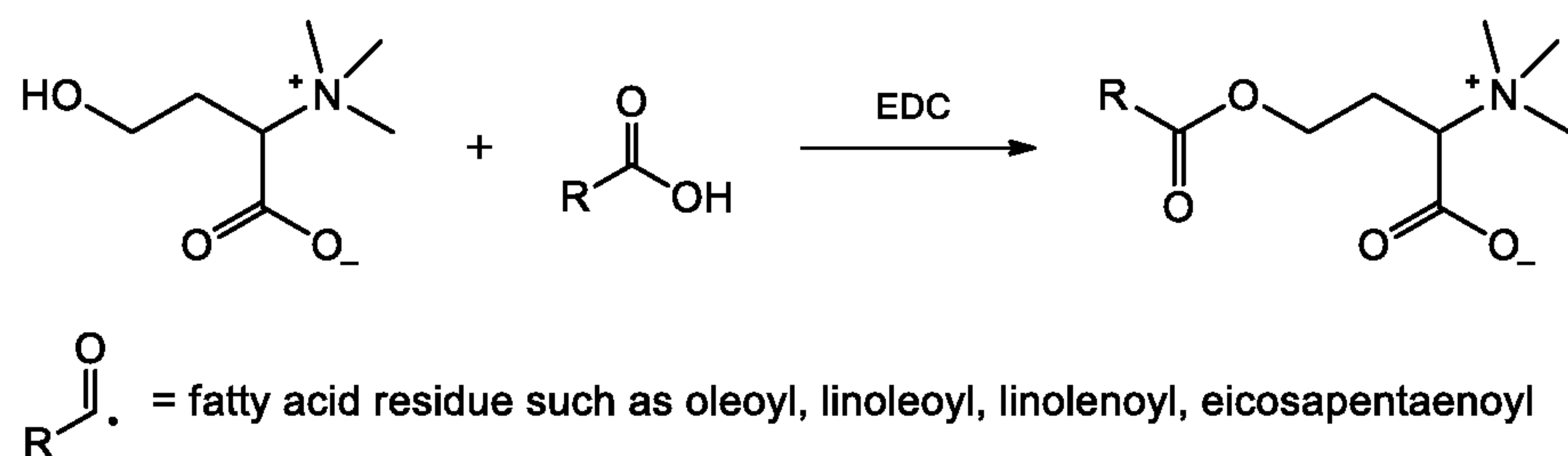
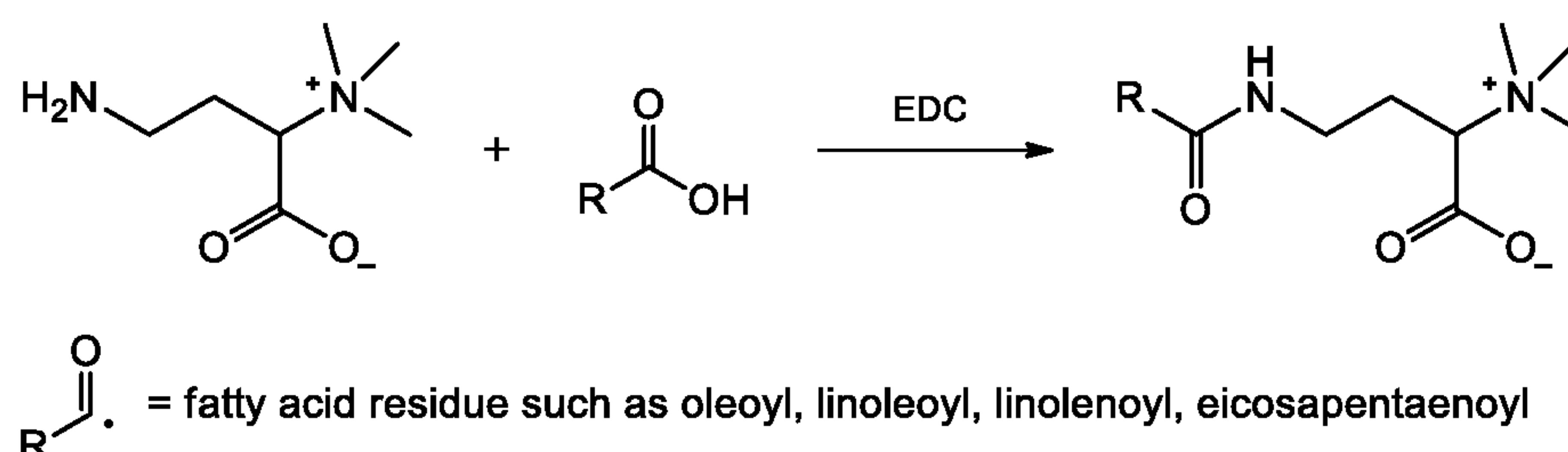
[00135] In certain derivatives, the EPA residue of lyso-DGTS is replaced with a residue of a different fatty acid. Since EPA is a polyunsaturated fatty acid that might be easily oxidized, the alternative fatty acid used are either saturated fatty acids, e.g., palmitic acid, or an unsaturated fatty acid having one, two or three double bonds only, e.g., oleic acid, linoleic acid, and linolenic acid, respectively. The synthesis of such lyso-DGTS derivatives is schematically depicted in **Scheme 1**.

[00136] In other derivatives, the fatty acid residue of lyso-DGTS is linked to the glyceryl via an amide bond rather than ester bond. Since amide bond is more stable than ester bond, such compounds are expected to be more stable than lyso-DGTS and might thus be administered orally. Yet, it should be noted that in such derivatives, the glyceryl nuclei is replaced with a ceramide-like nuclei having an amino group replacing a terminal hydroxyl group rather than the hydroxyl group at position 2, as in the case of ceramide. The synthesis of such lyso-DGTS derivatives is schematically depicted in **Scheme 2**.

[00137] In further derivatives, a fatty acid residue is linked directly, via either an ester or an amide bond to a terminal carbon atom of the side chain of an alpha amino acid having a quaternary ammonium. The synthesis of such lyso-DGTS derivatives is schematically depicted in **Schemes 3 and 4**.

Scheme 1. Synthesis of compounds of the formula Ia



Scheme 2. Synthesis of compounds of the formula Ib**Scheme 3.** Synthesis of compounds of the formula Ic**Scheme 4.** Synthesis of compounds of the formula Id

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CLAIMS

1. A pharmaceutical composition for treatment of atherosclerotic cardiovascular disease, comprising a pharmaceutically acceptable carrier and a compound of the formula I:



wherein

R₁ is (C₁₅-C₂₁)alkyl, (C₁₅-C₂₁)alkenyl, or (C₁₅-C₂₁)alkynyl;

R₂ is -O-CH₂-CHR₄-CH₂-O-, -NH-CH₂-CHR₄-CH₂-O-, -O-, or -NH-;

R₃ is (C₁-C₈)alkylene substituted with a group of the formula -N⁺(R₅)₃, and optionally further substituted with one or more -OH groups;

R₄ is -OH, -O-C(O)-R₆, or -NH-C(O)-R₆;

R₅ each independently is (C₁-C₈)alkyl; and

R₆ is (C₁₅-C₂₁)alkyl, (C₁₅-C₂₁)alkenyl, or (C₁₅-C₂₁)alkynyl,

or a pharmaceutically acceptable salt or solvate thereof.

2. The pharmaceutical composition of claim 1, wherein R₁ is (C₁₅-C₂₁)alkyl, or (C₁₅-C₂₁)alkenyl.

3. The pharmaceutical composition of claim 2, wherein R₁ is a linear (C₁₅)alkyl, (C₁₇)alkenyl, (C₁₉)alkenyl, or (C₂₁)alkenyl.

4. The pharmaceutical composition of claim 3, wherein R₁ is CH₃-(CH₂)₁₄-, CH₃-(CH₂)₇-CH=CH-(CH₂)₇-, CH₃-(CH₂)₄-(CH=CH-CH₂)₂-(CH₂)₆-, CH₃-(CH₂-CH=CH)₃-(CH₂)₇-, CH₃-(CH₂)₄-(CH=CH-CH₂)₄-(CH₂)₂-, CH₃-(CH₂-CH=CH)₅-(CH₂)₃-, or CH₃-(CH₂-CH=CH)₆-(CH₂)₂-.

5. The pharmaceutical composition of claim 1, wherein R₂ is -O-CH₂-CHR₄-CH₂-O-, -NH-CH₂-CHOH-CH₂-O-, -O-, or -NH-; and R₄ is -OH, or -O-C(O)-R₆.

6. The pharmaceutical composition of claim 1, wherein R₃ is -(CH₂)₁₋₇-CH(N⁺(R₅)₃)-, optionally further substituted with one or more -OH groups.

7. The pharmaceutical composition of claim 1, wherein R₅ each independently is (C₁-C₄)alkyl such as methyl, ethyl, *n*-propyl, or isopropyl.

8. The pharmaceutical composition of claim 1, wherein R₆ is (C₁₅-C₂₁)alkyl, or (C₁₅-C₂₁)alkenyl having one or more double bonds.
9. The pharmaceutical composition of claim 8, wherein R₆ is a linear (C₁₅)alkyl, (C₁₇)alkenyl, (C₁₉)alkenyl, or (C₂₁)alkenyl.
10. The pharmaceutical composition of claim 1, wherein:
 R₁ is (C₁₅-C₂₁)alkyl, or (C₁₅-C₂₁)alkenyl, preferably a linear (C₁₅)alkyl, (C₁₇)alkenyl, (C₁₉)alkenyl, or (C₂₁)alkenyl;
 R₂ is -O-CH₂-CHR₄-CH₂-O-, -NH-CH₂-CHOH-CH₂-O-, -O-, or -NH-;
 R₃ is -(CH₂)₁₋₇-CH(N⁺(R₅)₃)-, optionally further substituted with one or more -OH groups;
 R₄ is -OH, or -O-C(O)-R₆;
 R₅ each independently is (C₁-C₄)alkyl such as methyl, ethyl, *n*-propyl, or isopropyl;
 and
 R₆ is (C₁₅-C₂₁)alkyl, or (C₁₅-C₂₁)alkenyl, preferably a linear (C₁₅)alkyl, (C₁₇)alkenyl, (C₁₉)alkenyl, or (C₂₁)alkenyl.
11. The pharmaceutical composition of claim 10, wherein R₁ is CH₃-(CH₂)₁₄-, CH₃-(CH₂)₇-CH=CH-(CH₂)₇-, CH₃-(CH₂)₄-(CH=CH-CH₂)₂-(CH₂)₆-, CH₃-(CH₂-CH=CH)₃-(CH₂)₇-, CH₃-(CH₂)₄-(CH=CH-CH₂)₄-(CH₂)₂-, CH₃-(CH₂-CH=CH)₅-(CH₂)₃-, or CH₃-(CH₂-CH=CH)₆-(CH₂)₂-.
12. The pharmaceutical composition of claim 11, wherein
- (i) R₂ is -O-CH₂-CHOH-CH₂-O-; R₃ is -CH₂-CH(N⁺(R₅)₃)-, or -(CH₂)₂-CH(N⁺(R₅)₃)-; and R₅ each is methyl, ethyl, *n*-propyl, or isopropyl;
 - (ii) R₂ is -NH-CH₂-CHOH-CH₂-O-; R₃ is -CH₂-CH(N⁺(R₅)₃)-, -(CH₂)₂-CH(N⁺(R₅)₃)-; and R₅ each is methyl, ethyl, *n*-propyl, or isopropyl;
 - (iii) R₂ is -O-; R₃ is -CH₂-CH(N⁺(R₅)₃)-, or -(CH₂)₂-CH(N⁺(R₅)₃)-; and R₅ each is methyl, ethyl, *n*-propyl, or isopropyl; or
 - (iv) R₂ is -NH-; R₃ is -CH₂-CH(N⁺(R₅)₃)-, or -(CH₂)₂-CH(N⁺(R₅)₃)-; and R₅ each is methyl, ethyl, *n*-propyl, or isopropyl.
13. The pharmaceutical composition of any one of claims 1 to 12, formulated for oral, rectal, nasal, intravenous, intraarterial, intramuscular, intraperitoneal, intrathecal,

intrapleural, intratracheal, subcutaneous, transdermal, intradermal, vaginal, or topical administration, or for inhalation.

14. A compound of the formula I in claim 1, or a pharmaceutically acceptable salt or solvate thereof, for use in the inhibition/treatment of atherosclerotic cardiovascular disease.

15. Use of a compound of the formula I in claim 1, or a pharmaceutically acceptable salt or solvate thereof, for the preparation of a pharmaceutical medicament for treatment of atherosclerotic cardiovascular disease.

16. A method for treatment of atherosclerotic cardiovascular disease in a subject in need thereof, comprising administering to said subject a therapeutically effective amount of a compound of the formula I in claim 1, or a pharmaceutically acceptable salt or solvate thereof.

17. A compound of the formula I in claim 1, but excluding the compounds wherein R₂ is -O-CH₂-CHR₄-CH₂-O-.

18. The compound of claim 17, wherein R₁ is (C₁₅-C₂₁)alkyl, or (C₁₅-C₂₁)alkenyl.

19. The compound of claim 18, wherein R₁ is a linear (C₁₅)alkyl, (C₁₇)alkenyl, (C₁₉)alkenyl, or (C₂₁)alkenyl.

20. The compound of claim 19, wherein R₁ is CH₃-(CH₂)₁₄-, CH₃-(CH₂)₇-CH=CH-(CH₂)₇-, CH₃-(CH₂)₄-(CH=CH-CH₂)₂-(CH₂)₆-, CH₃-(CH₂-CH=CH)₃-(CH₂)₇-, CH₃-(CH₂)₄-(CH=CH-CH₂)₄-(CH₂)₂-, CH₃-(CH₂-CH=CH)₅-(CH₂)₃-, or CH₃-(CH₂-CH=CH)₆-(CH₂)₂-.

21. The compound of claim 17, wherein R₂ is -NH-CH₂-CHOH-CH₂-O-, -O-, or -NH-.

22. The compound of claim 17, wherein R₃ is -(CH₂)₁₋₇-CH(N⁺(R₅)₃)-, optionally further substituted with one or more -OH groups.

23. The compound of claim 17, wherein R₅ each independently is (C₁-C₄)alkyl such as methyl, ethyl, *n*-propyl, or isopropyl.

24. The compound of claim 17, wherein:

R_1 is $(C_{15}-C_{21})$ alkyl, or $(C_{15}-C_{21})$ alkenyl, preferably a linear (C_{15}) alkyl, (C_{17}) alkenyl, (C_{19}) alkenyl, or (C_{21}) alkenyl;

R_2 is $-NH-CH_2-CHOH-CH_2-O-$, $-O-$, or $-NH-$;

R_3 is $-(CH_2)_{1-7}-CH(N^+(R_5)_3)-$, optionally further substituted with one or more $-OH$ groups; and

R_5 each independently is (C_1-C_4) alkyl such as methyl, ethyl, *n*-propyl, or isopropyl.

25. The compound of claim 24, wherein R_1 is $CH_3-(CH_2)_{14}-$, $CH_3-(CH_2)_7-CH=CH-(CH_2)_7-$, $CH_3-(CH_2)_4-(CH=CH-CH_2)_2-(CH_2)_6-$, $CH_3-(CH_2-CH=CH)_3-(CH_2)_7-$, $CH_3-(CH_2)_4-(CH=CH-CH_2)_4-(CH_2)_2-$, $CH_3-(CH_2-CH=CH)_5-(CH_2)_3-$, or $CH_3-(CH_2-CH=CH)_6-(CH_2)_2-$.

26. The compound of claim 25, wherein

(i) R_2 is $-NH-CH_2-CHOH-CH_2-O-$; R_3 is $-CH_2-CH(N^+(R_5)_3)-$, $-(CH_2)_2-CH(N^+(R_5)_3)-$; and R_5 each is methyl, ethyl, *n*-propyl, or isopropyl;

(ii) R_2 is $-O-$; R_3 is $-CH_2-CH(N^+(R_5)_3)-$, or $-(CH_2)_2-CH(N^+(R_5)_3)-$; and R_5 each is methyl, ethyl, *n*-propyl, or isopropyl; or

(iii) R_2 is $-NH-$; R_3 is $-CH_2-CH(N^+(R_5)_3)-$, or $-(CH_2)_2-CH(N^+(R_5)_3)-$; and R_5 each is methyl, ethyl, *n*-propyl, or isopropyl.

27. A pharmaceutical composition comprising a compound according to any one of claims 17 to 26, or a pharmaceutically acceptable salt or solvate thereof, and a pharmaceutically acceptable carrier.

Fig. 1A

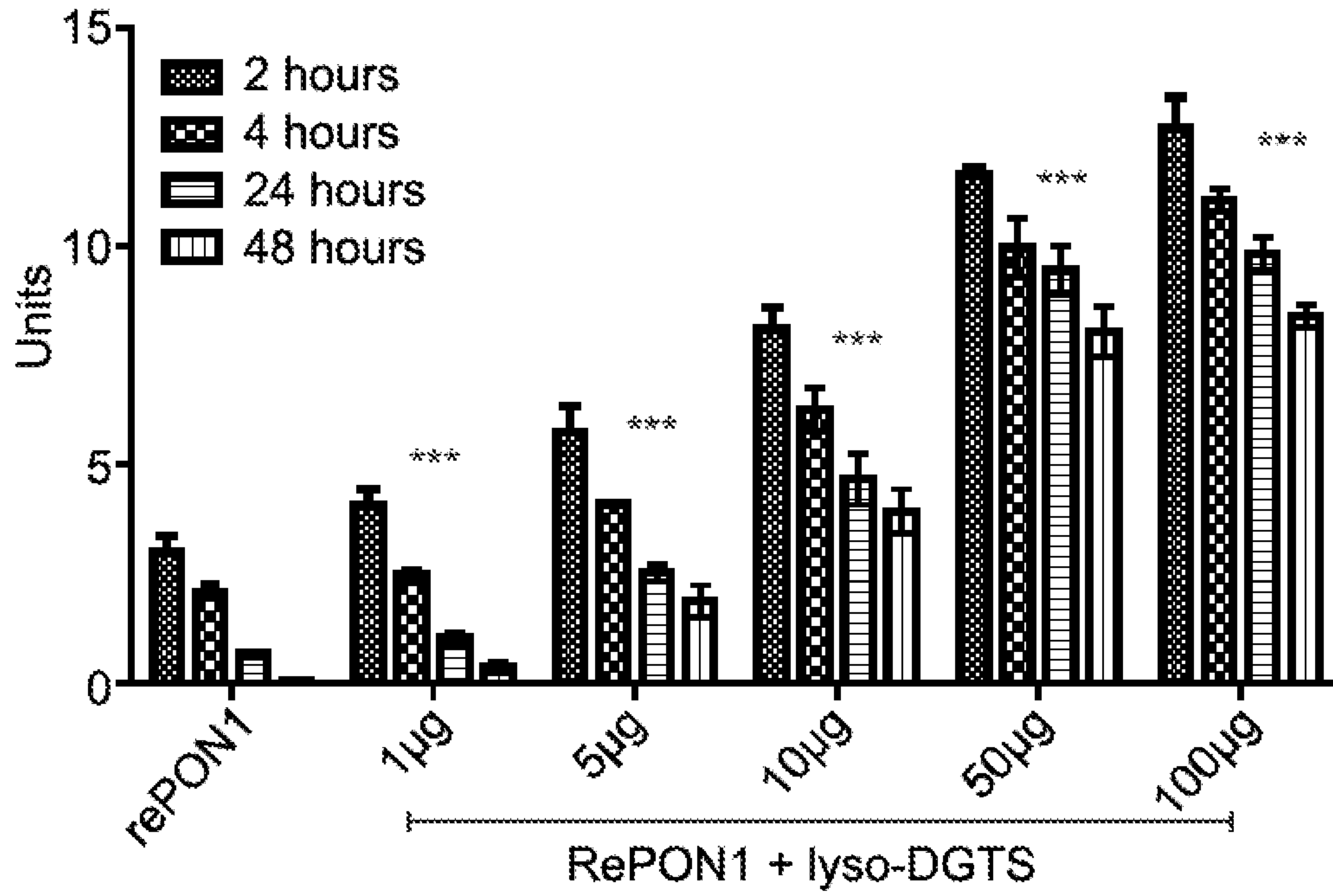
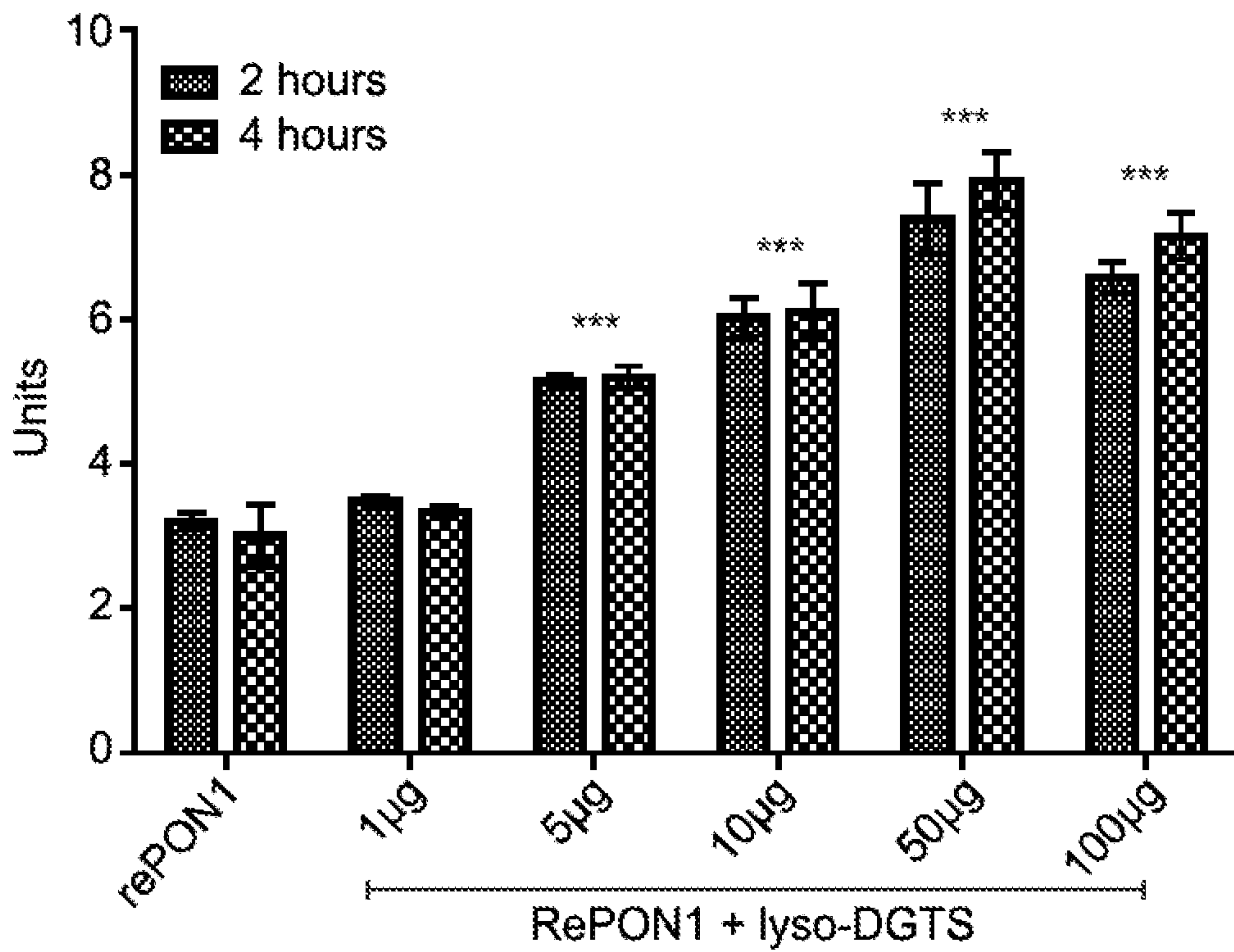


Fig. 1B



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Fig. 2

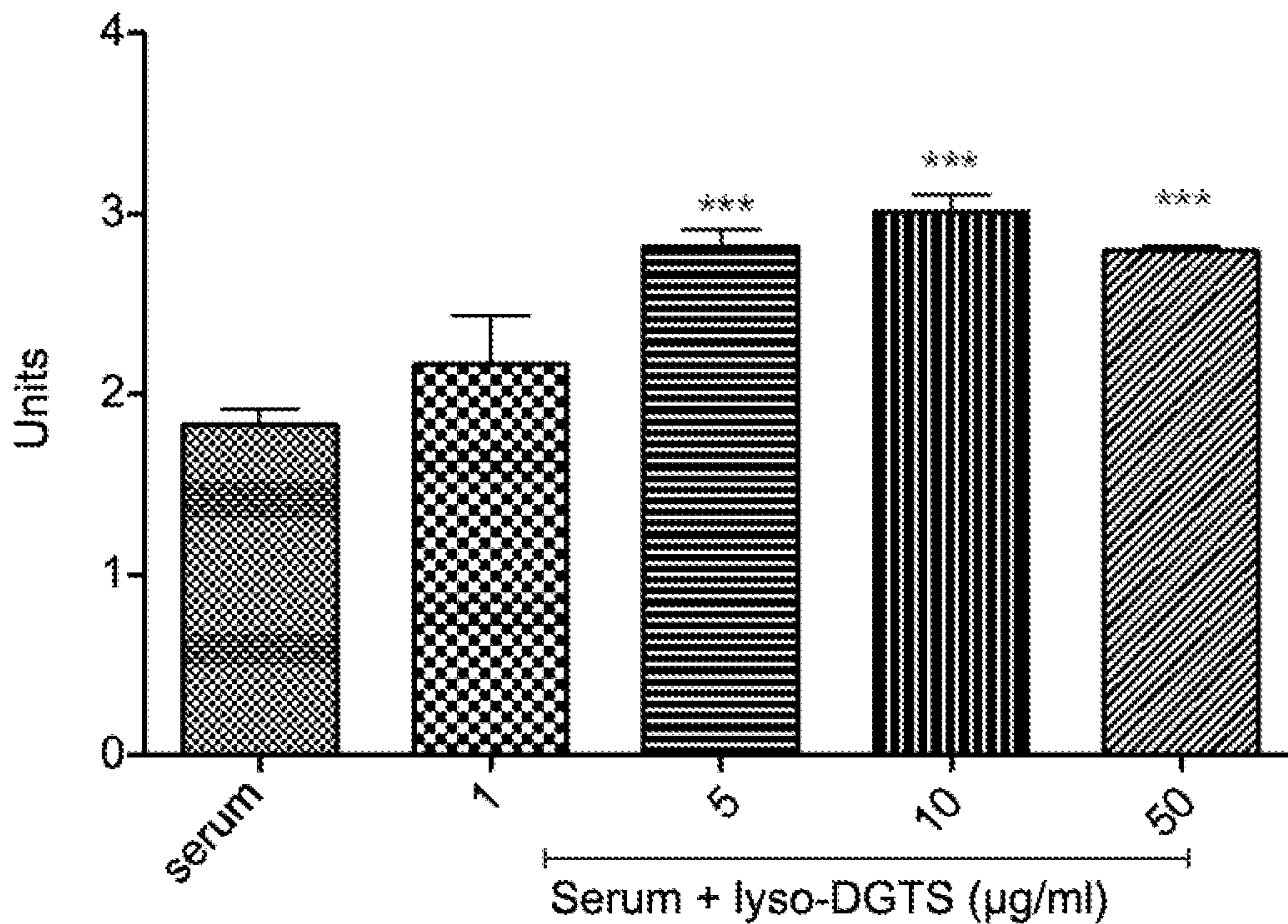


Fig. 3A

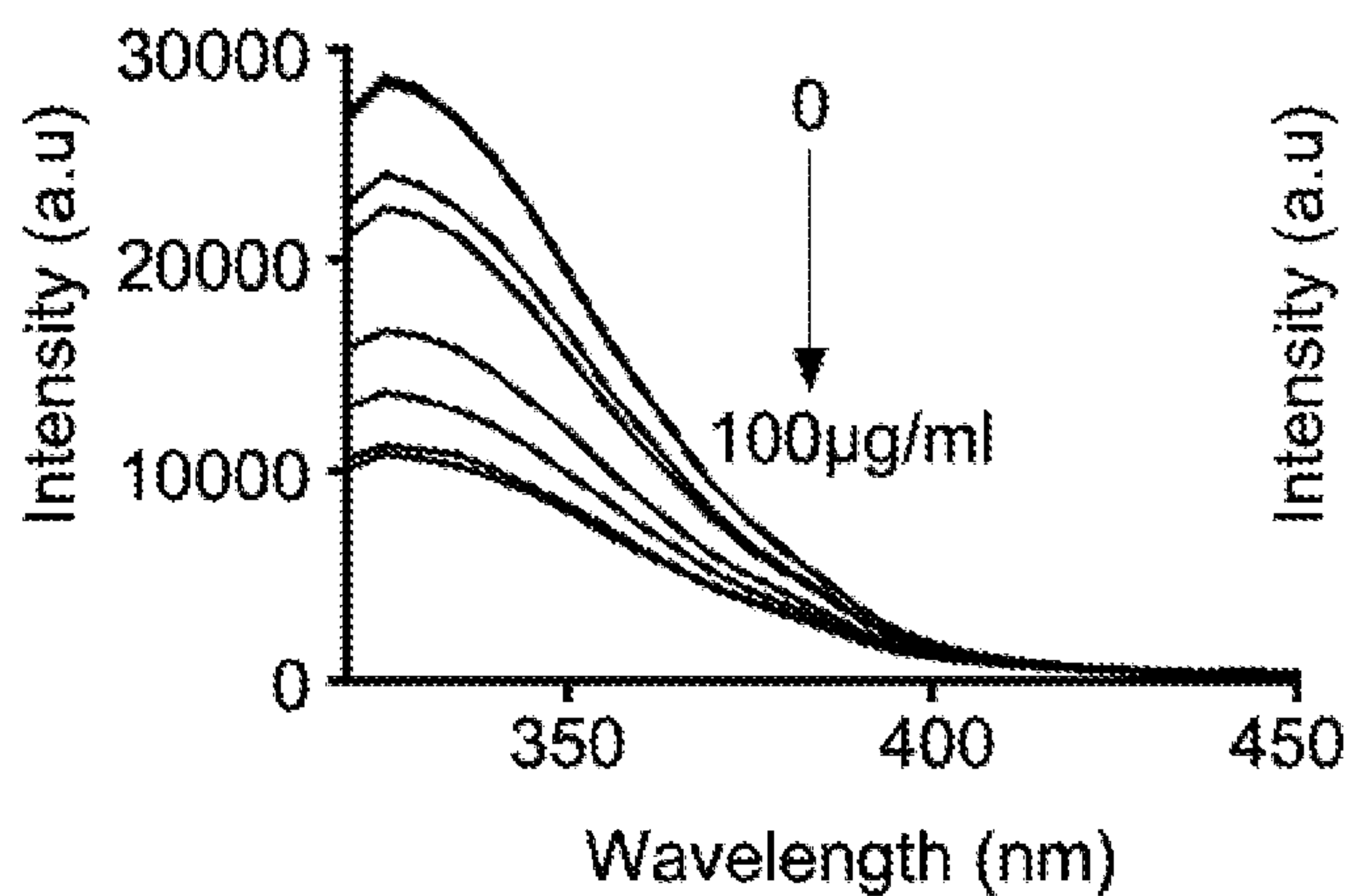


Fig. 3B

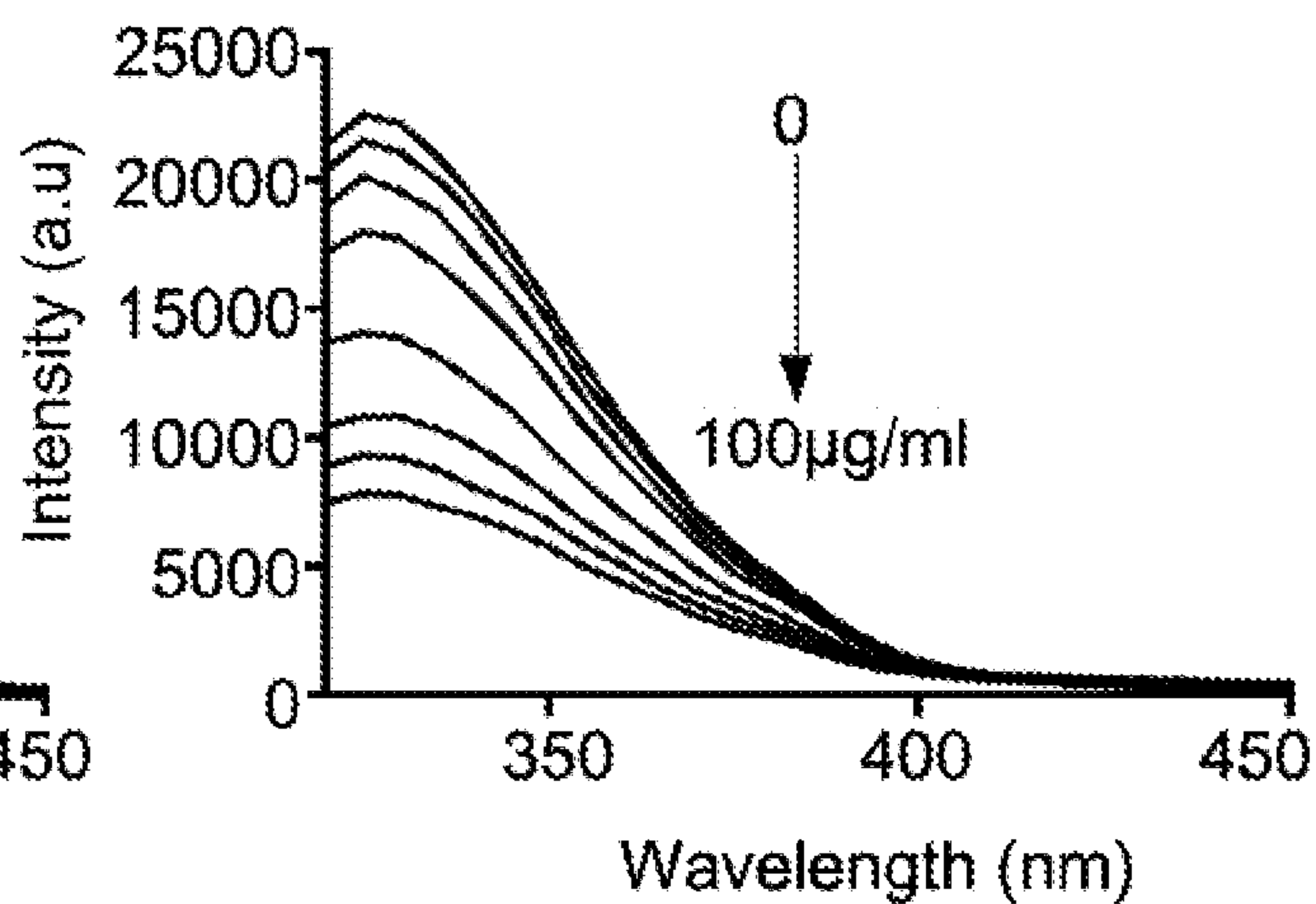


Fig. 4A

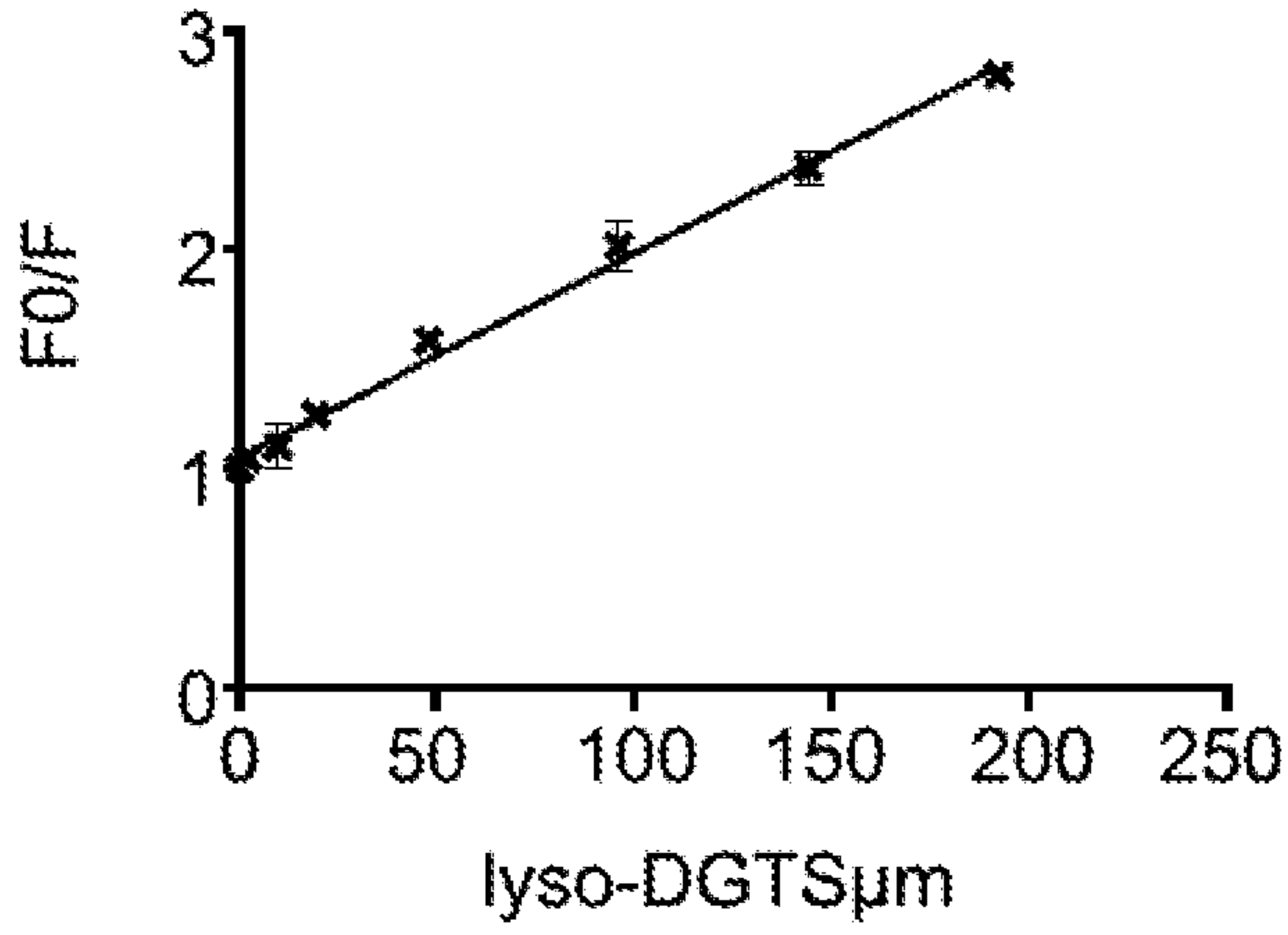


Fig. 4B

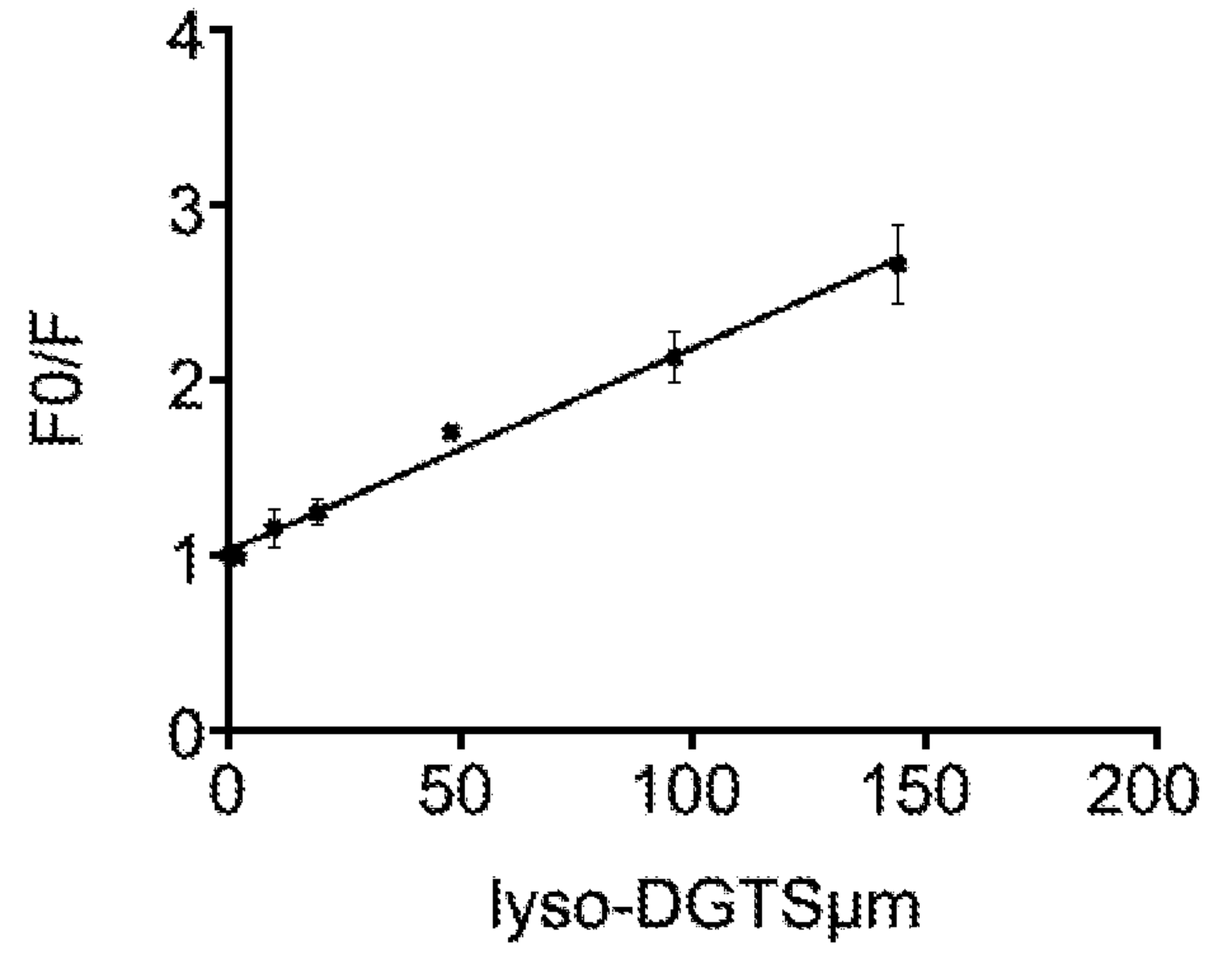


Fig. 4C

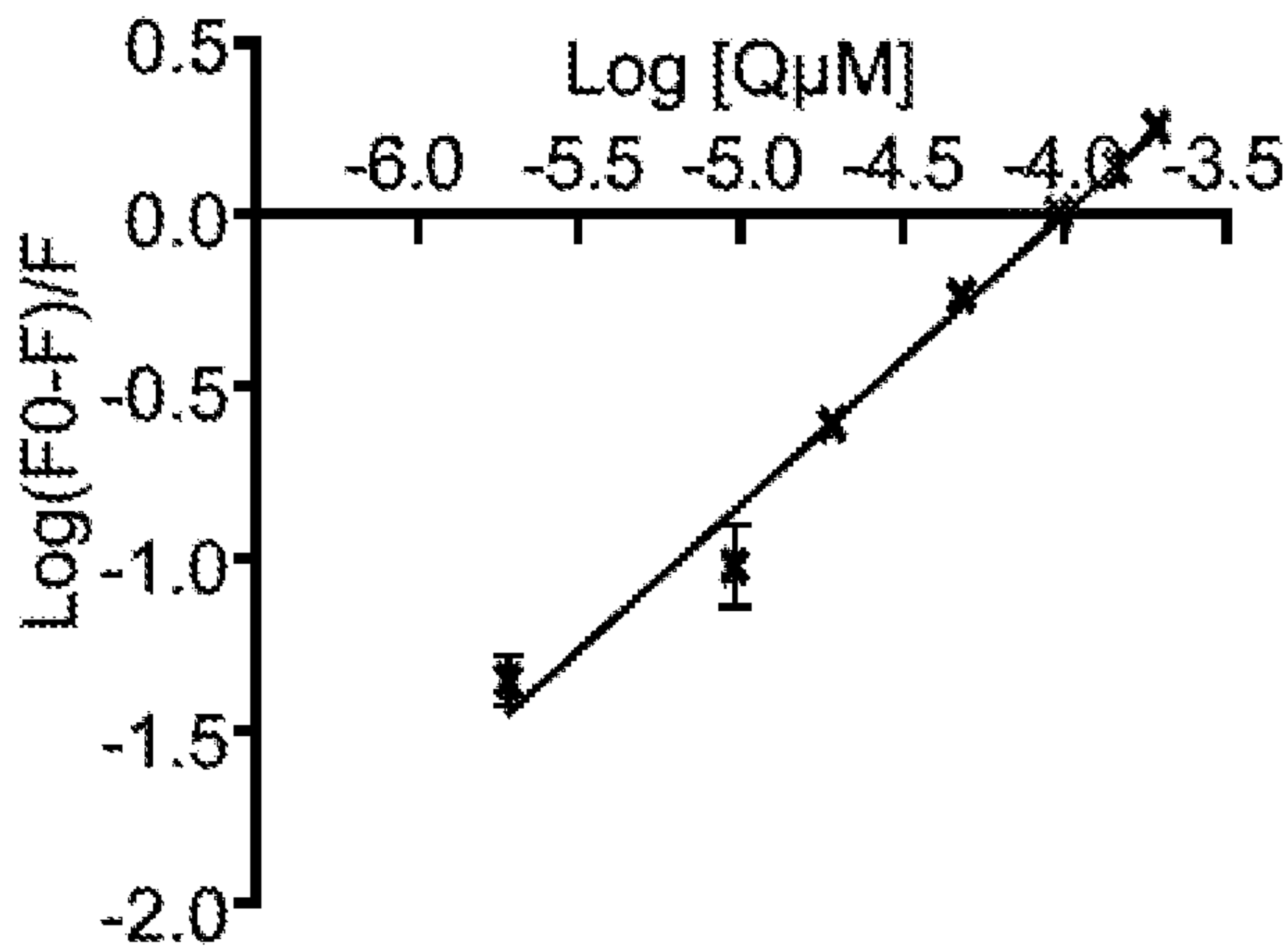


Fig. 4D

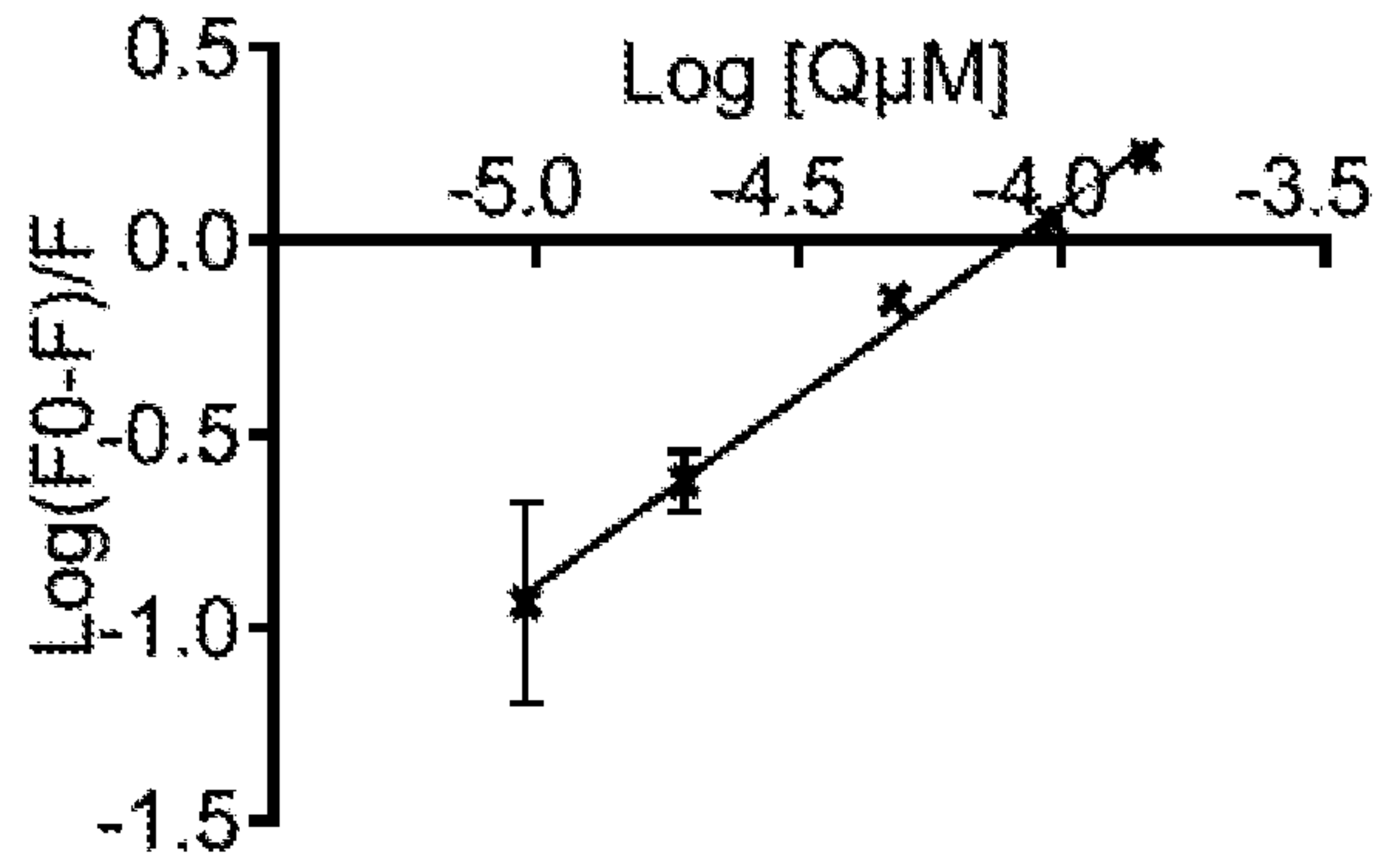


Fig. 5A

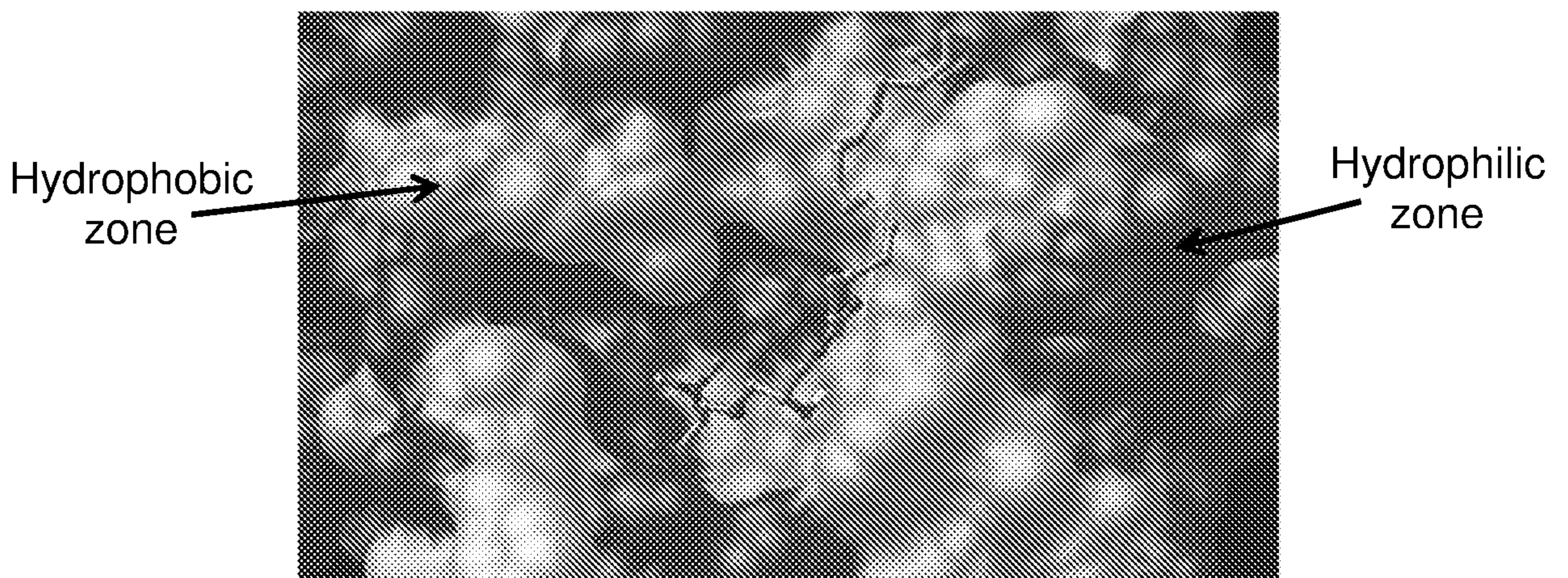
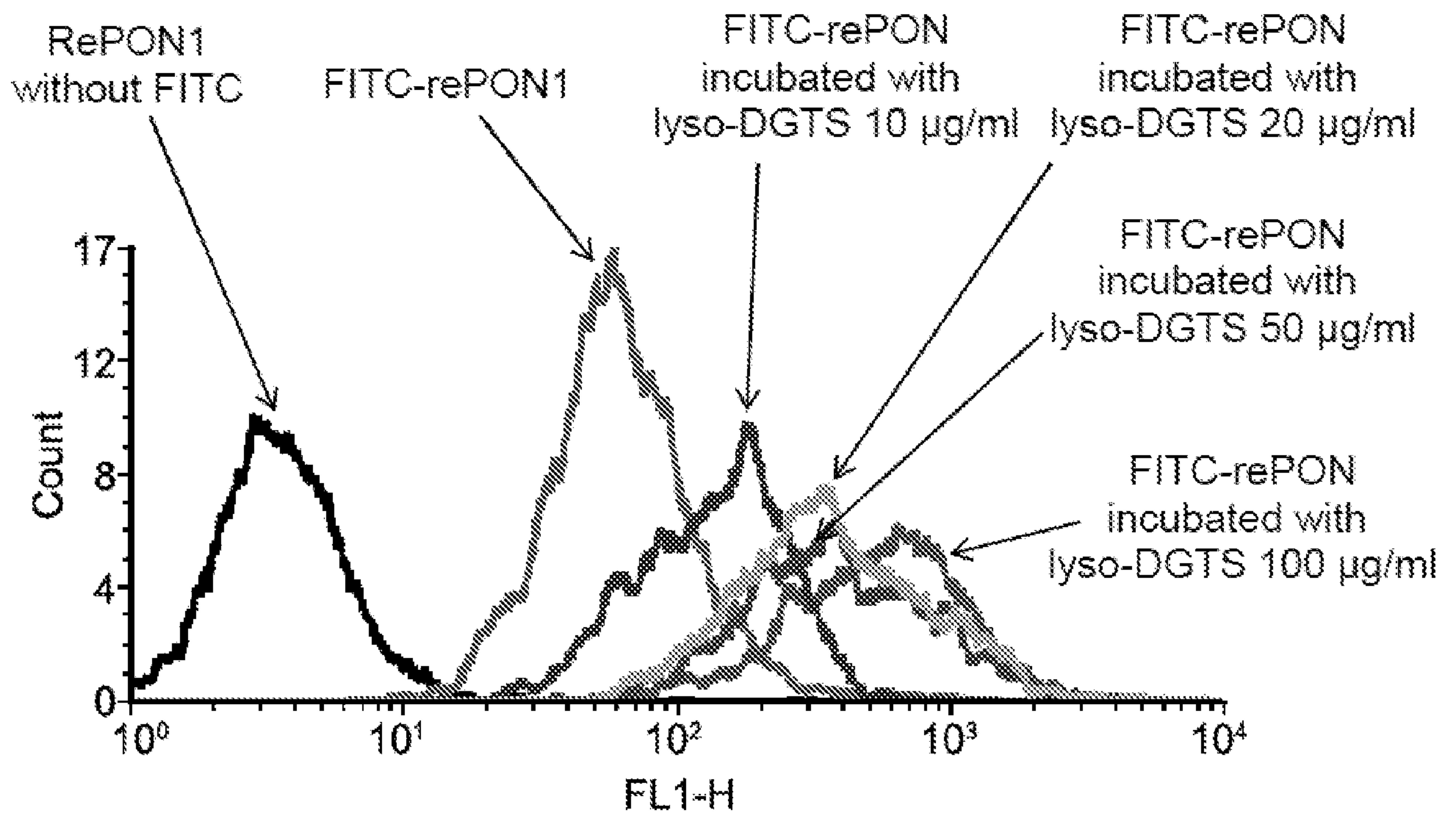


Fig. 5B



Fig. 6A



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Fig. 6B

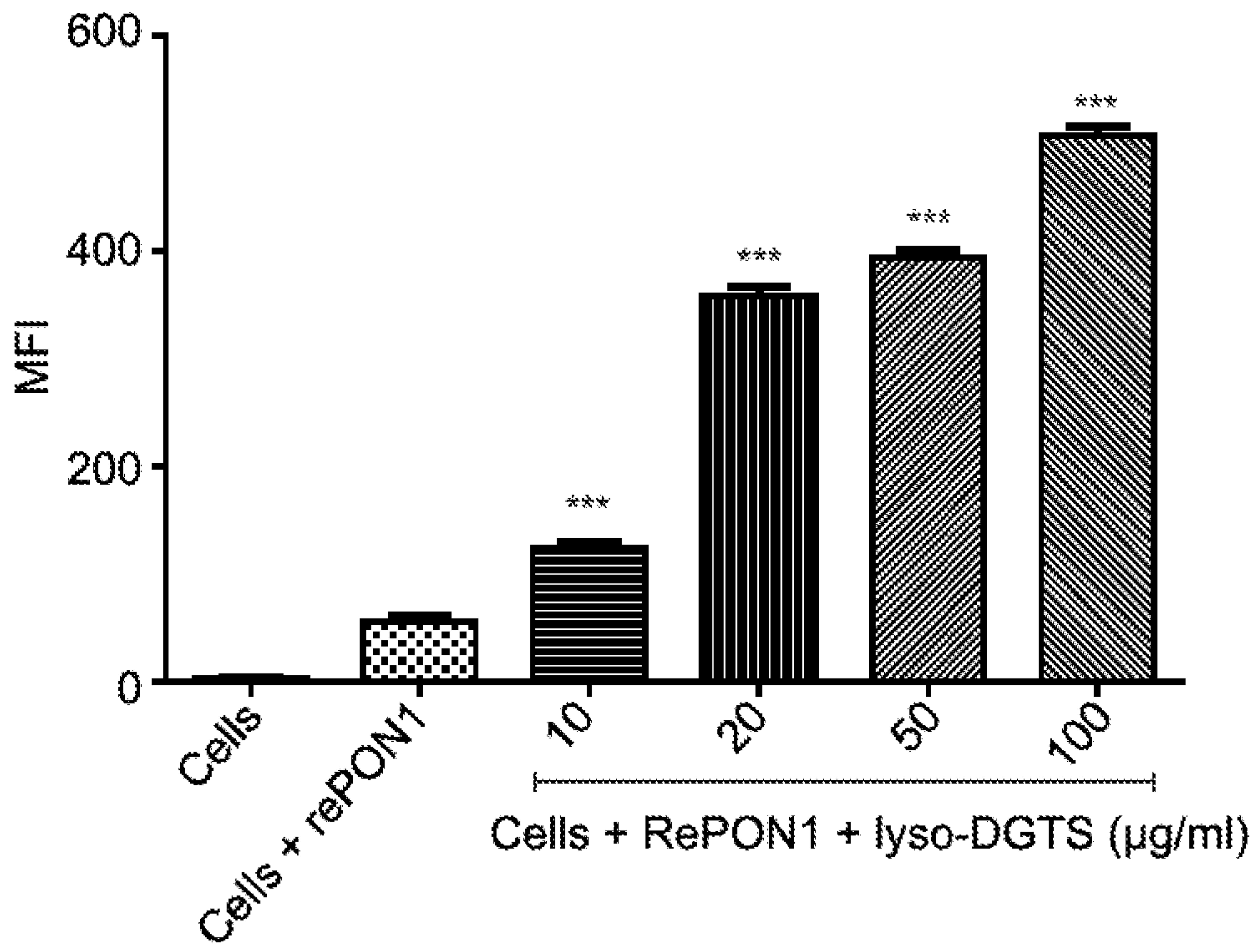
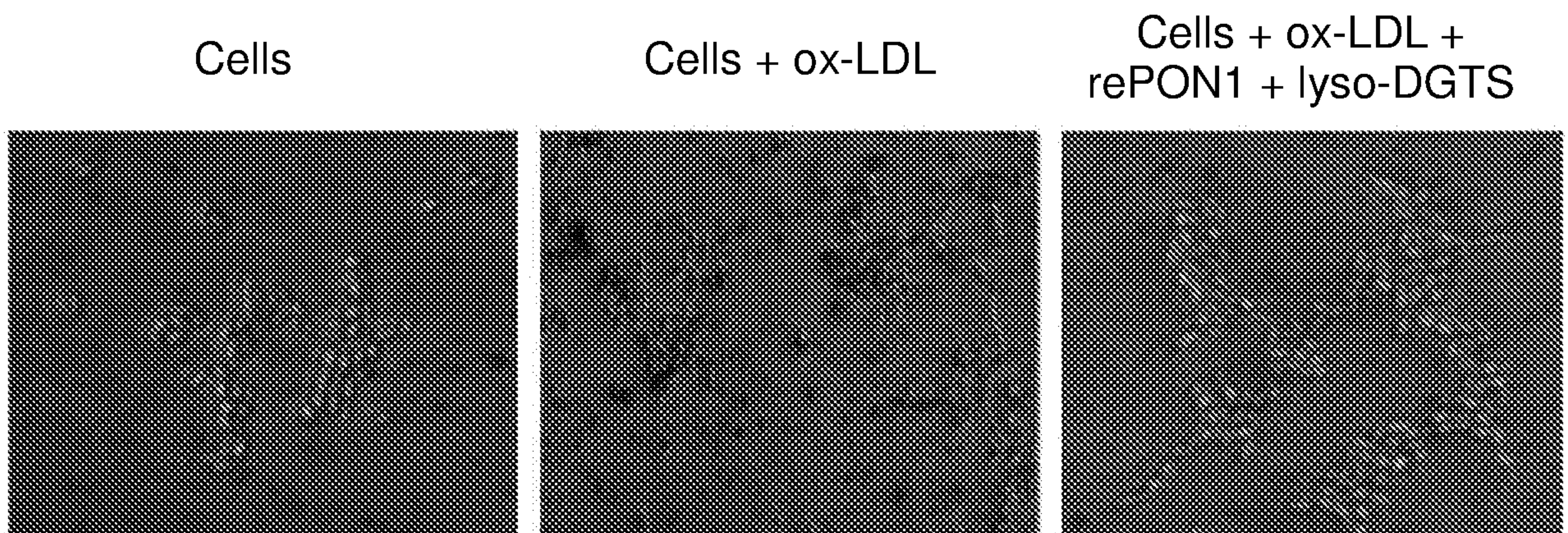


Fig. 7A



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Fig. 7B

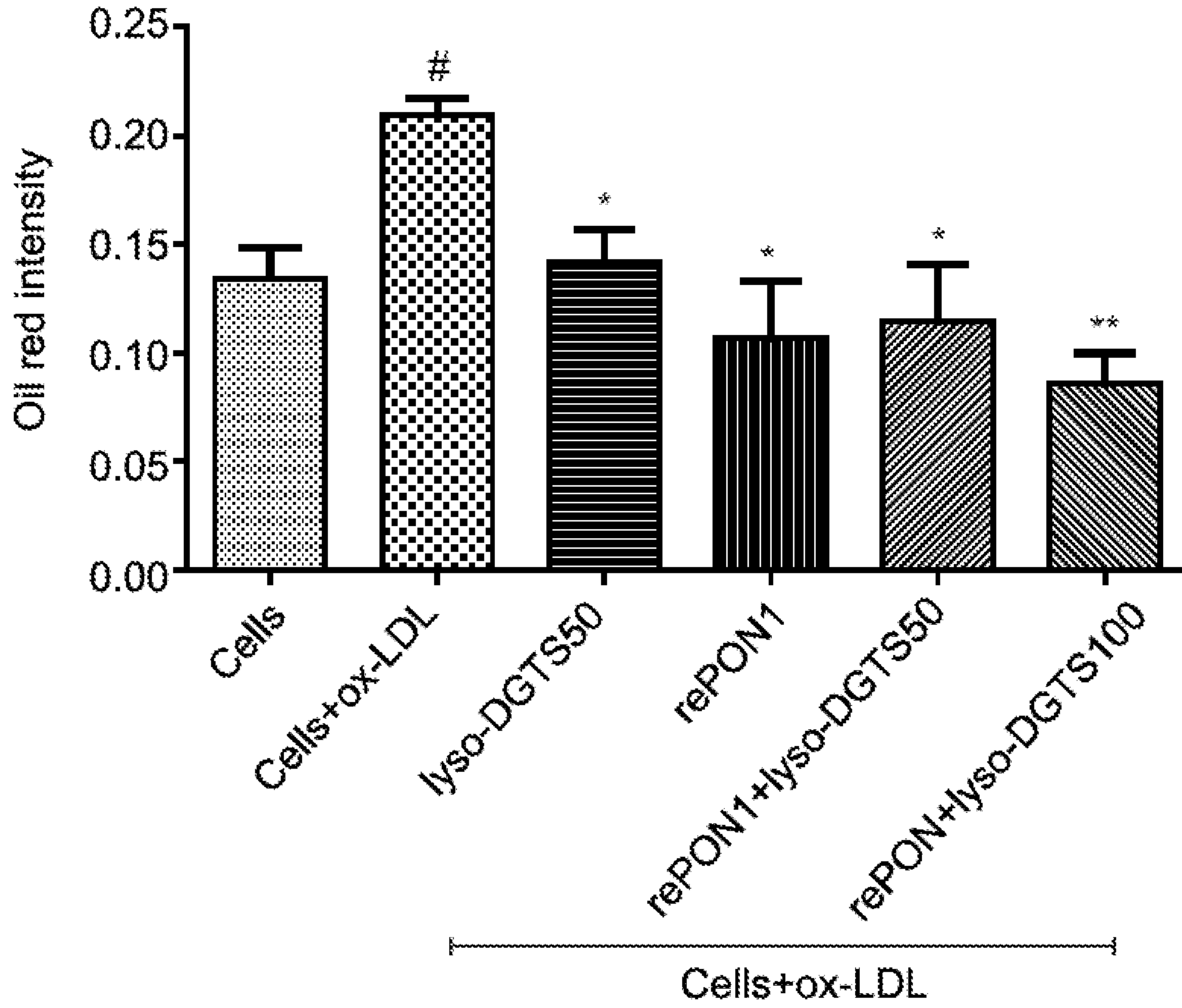
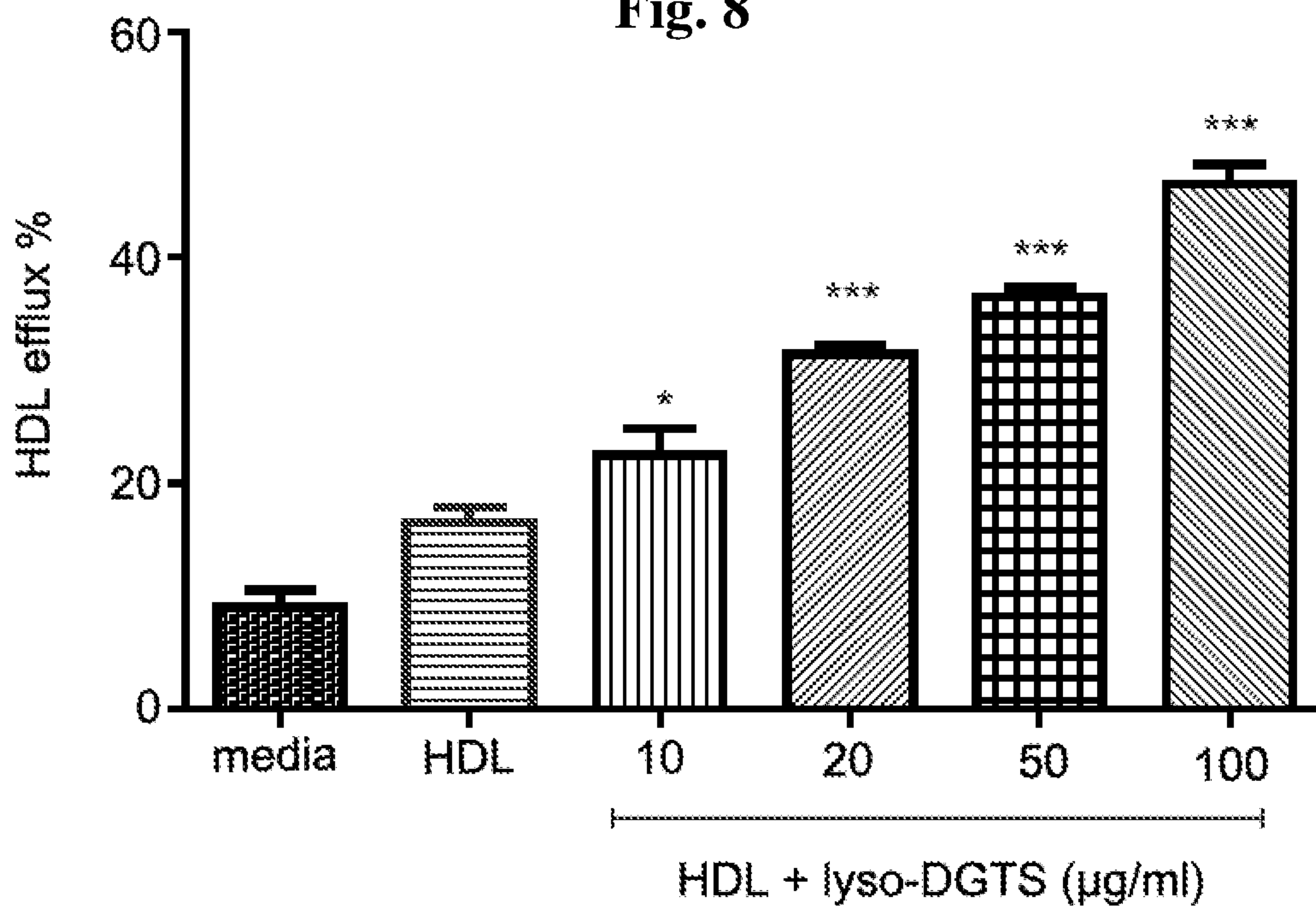


Fig. 8



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Fig. 9

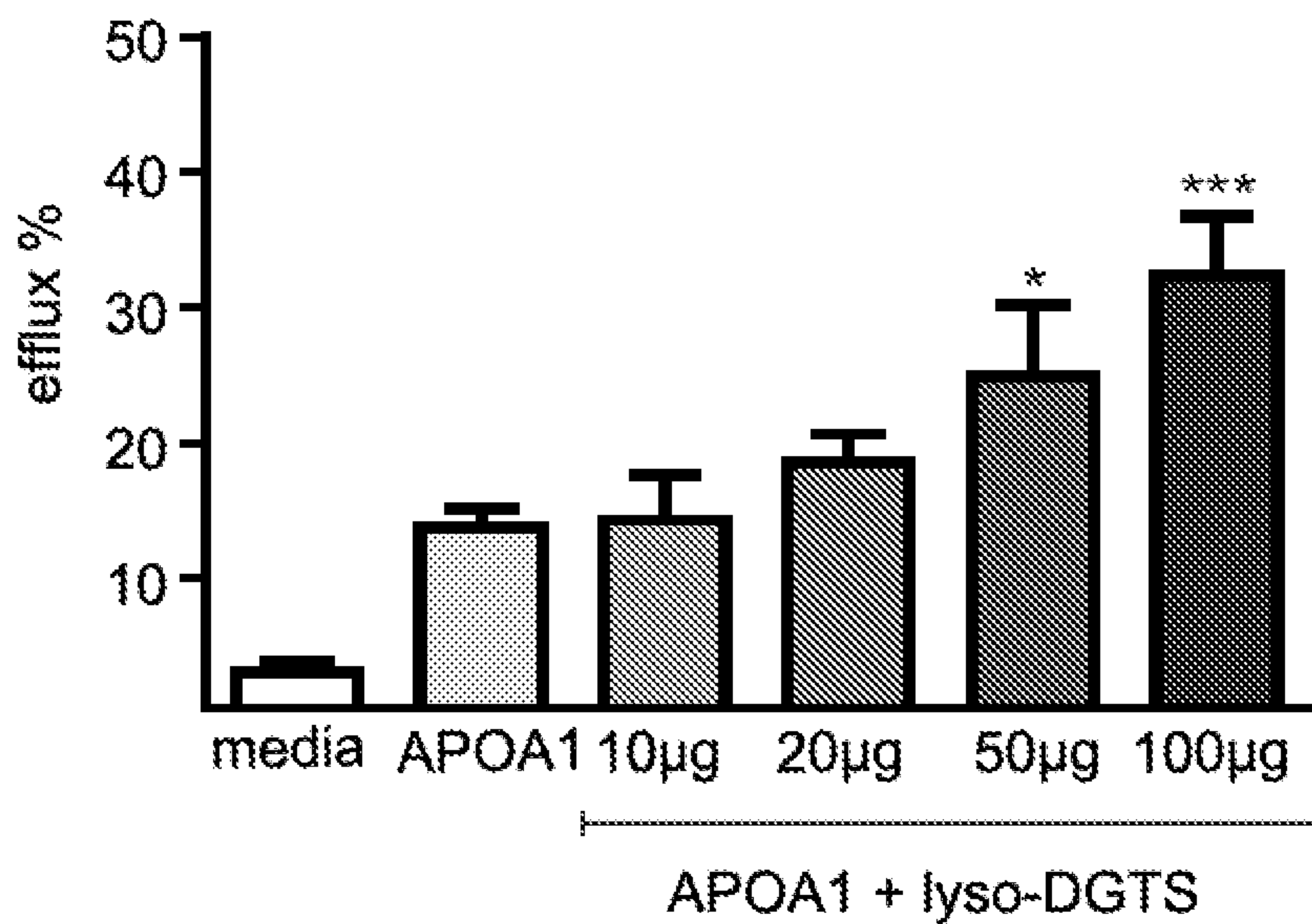


Fig. 10A

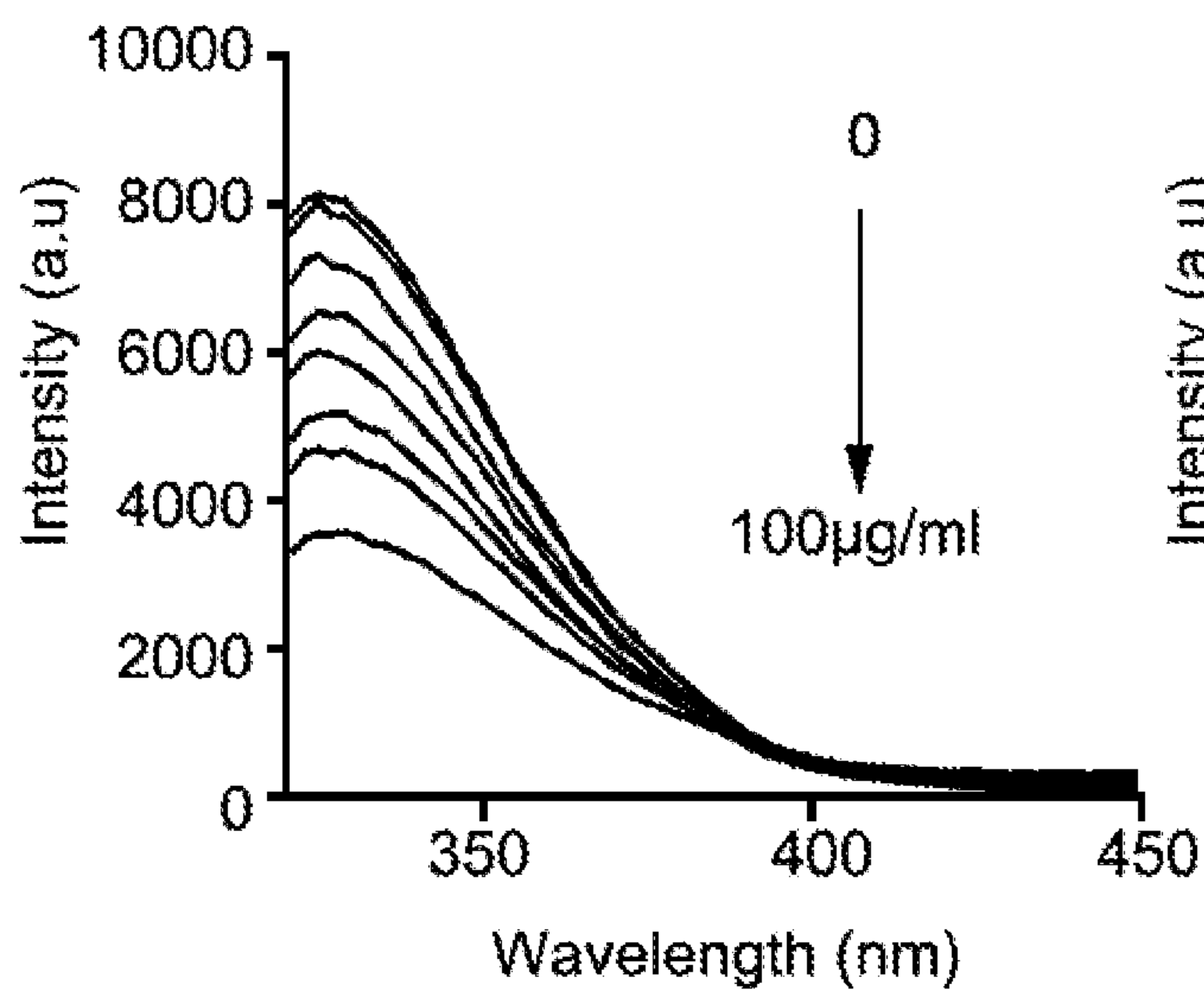


Fig. 10B

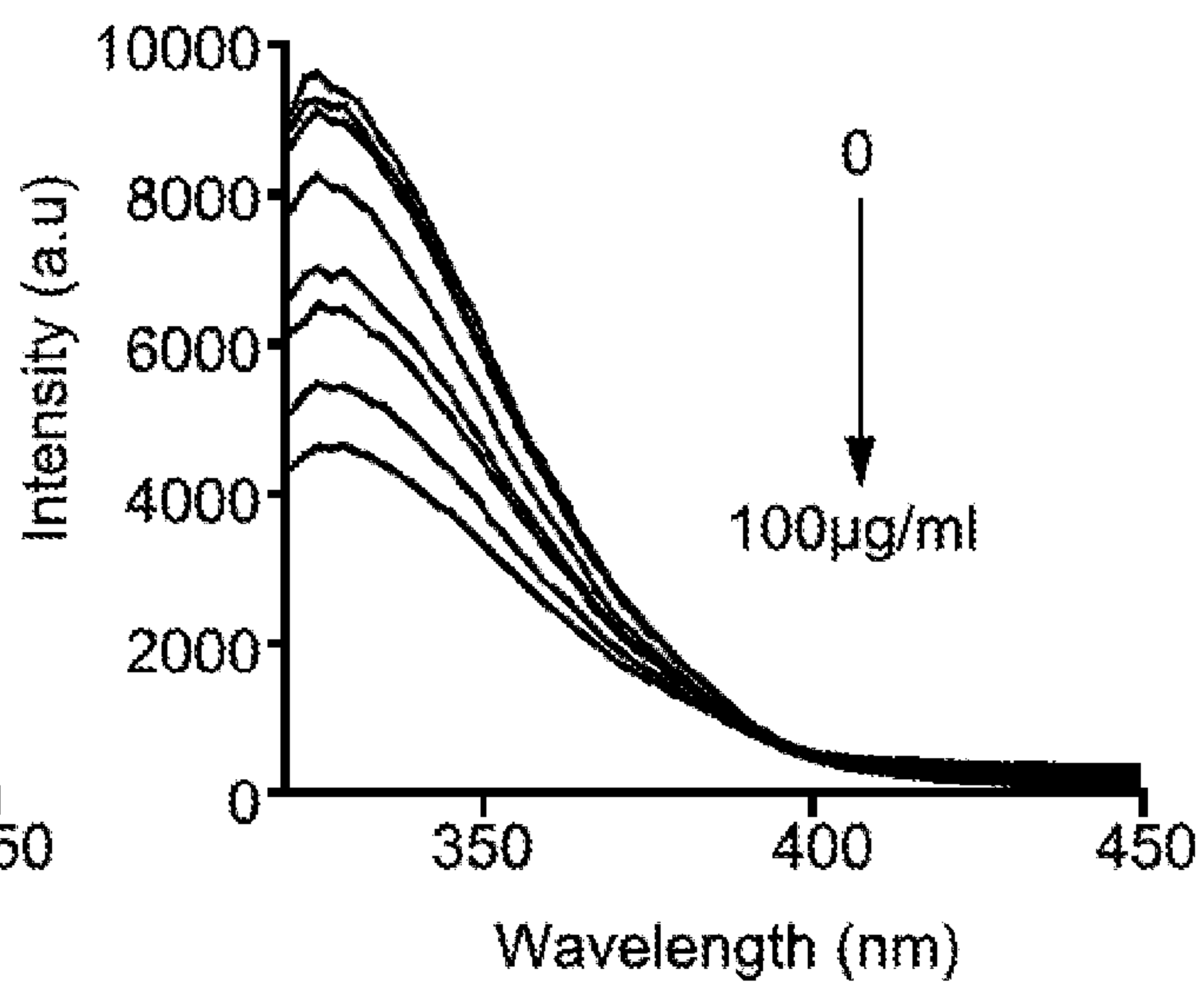


Fig. 11A

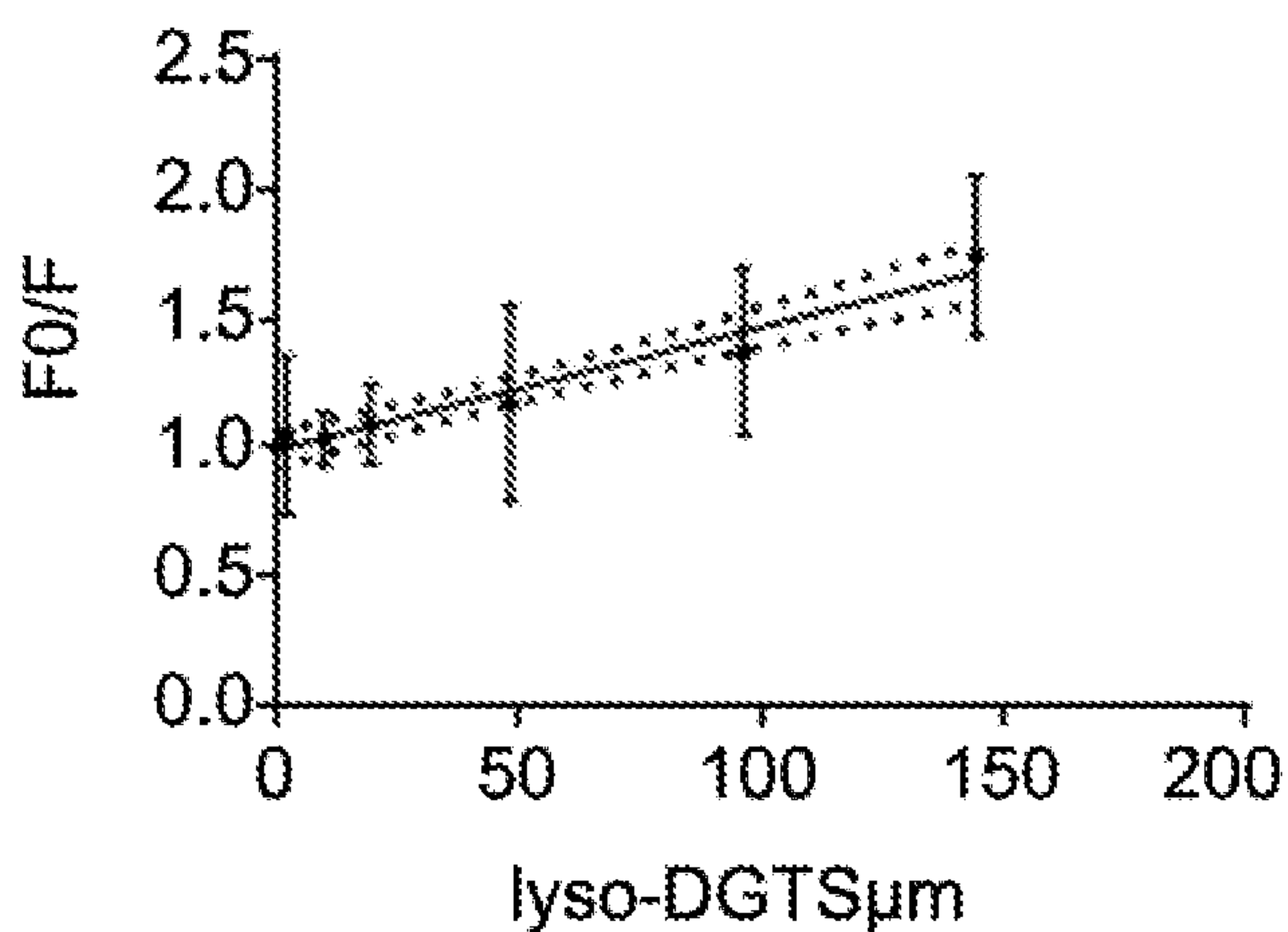


Fig. 11B

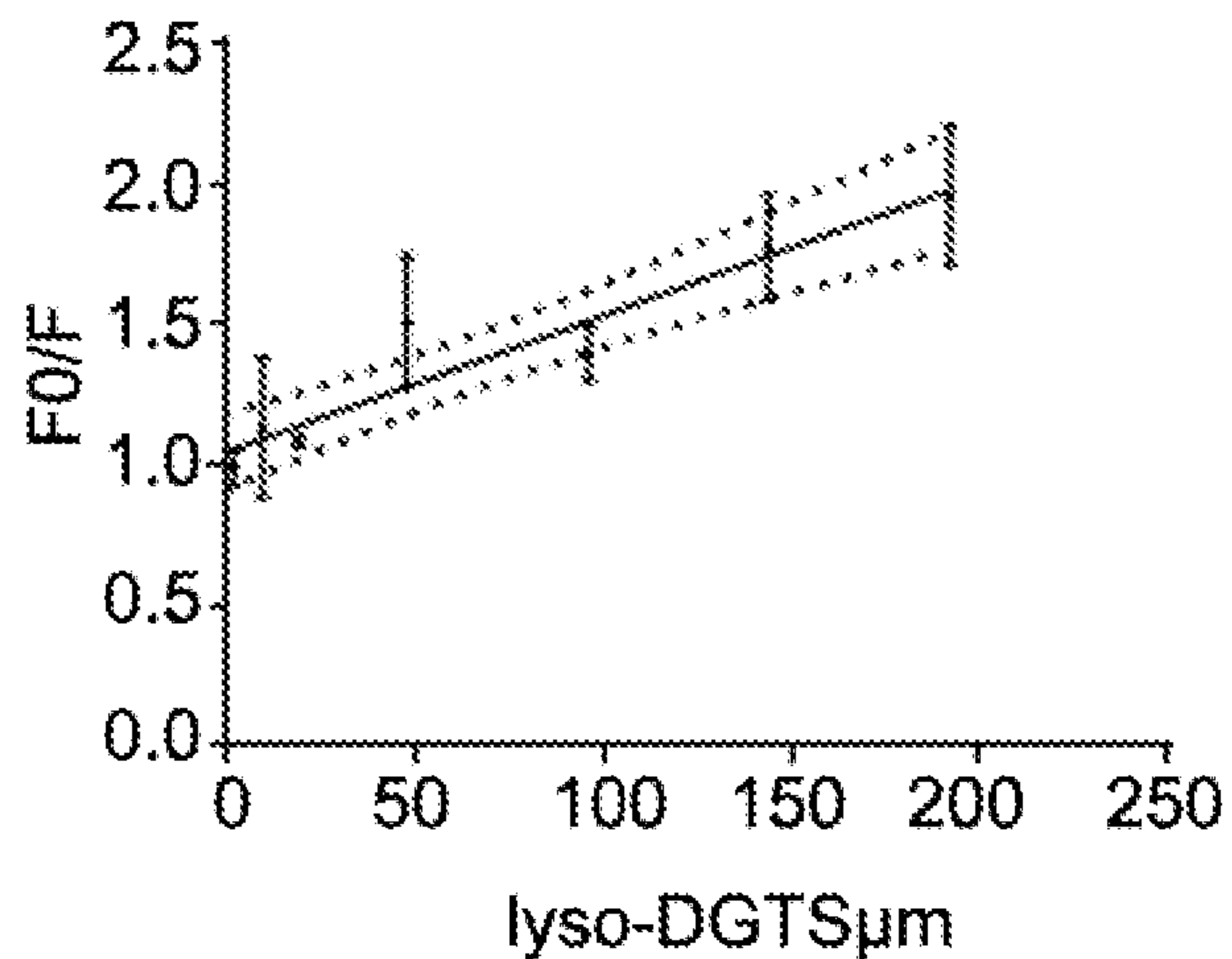


Fig. 11C

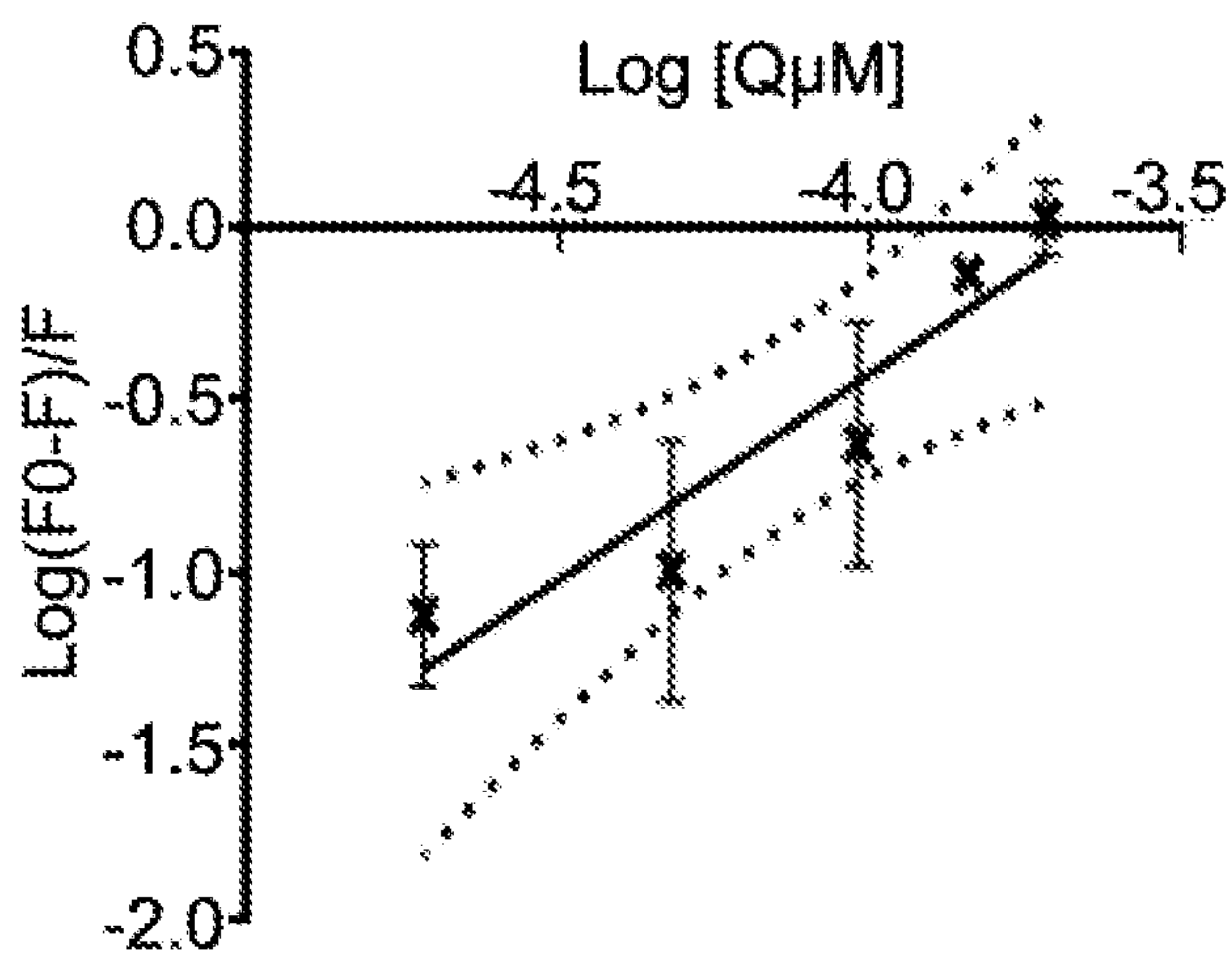


Fig. 11D

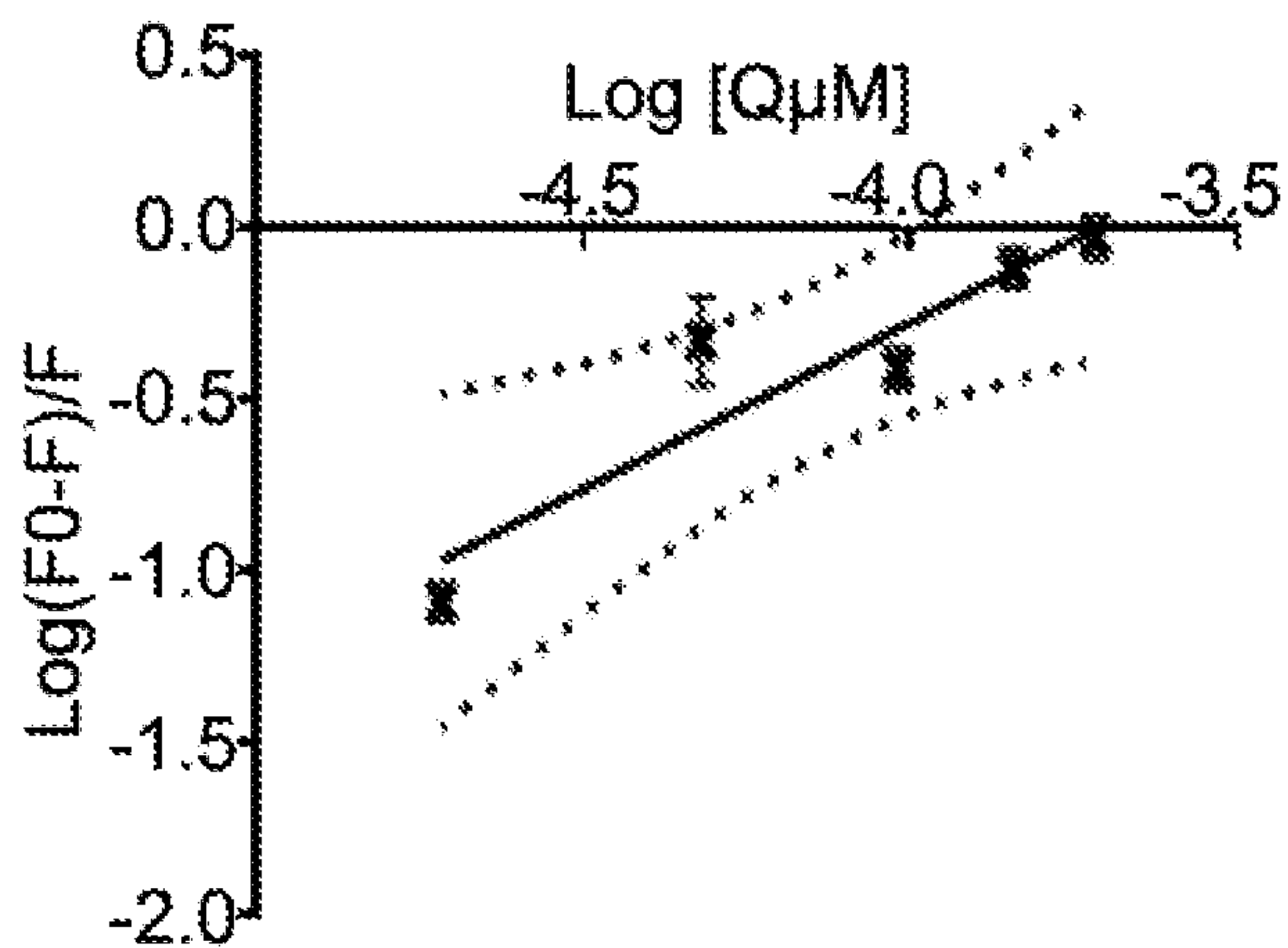


Fig. 12

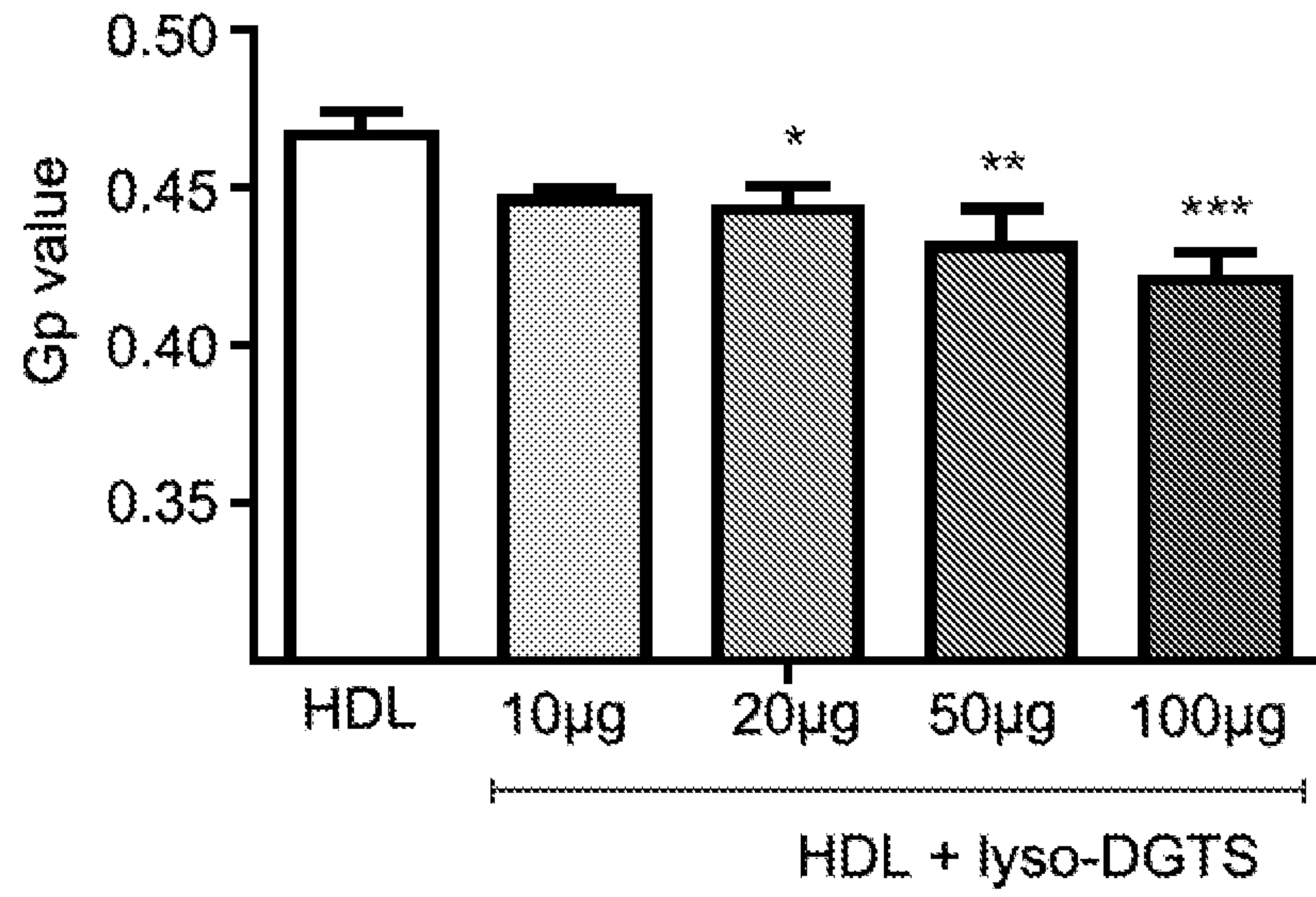
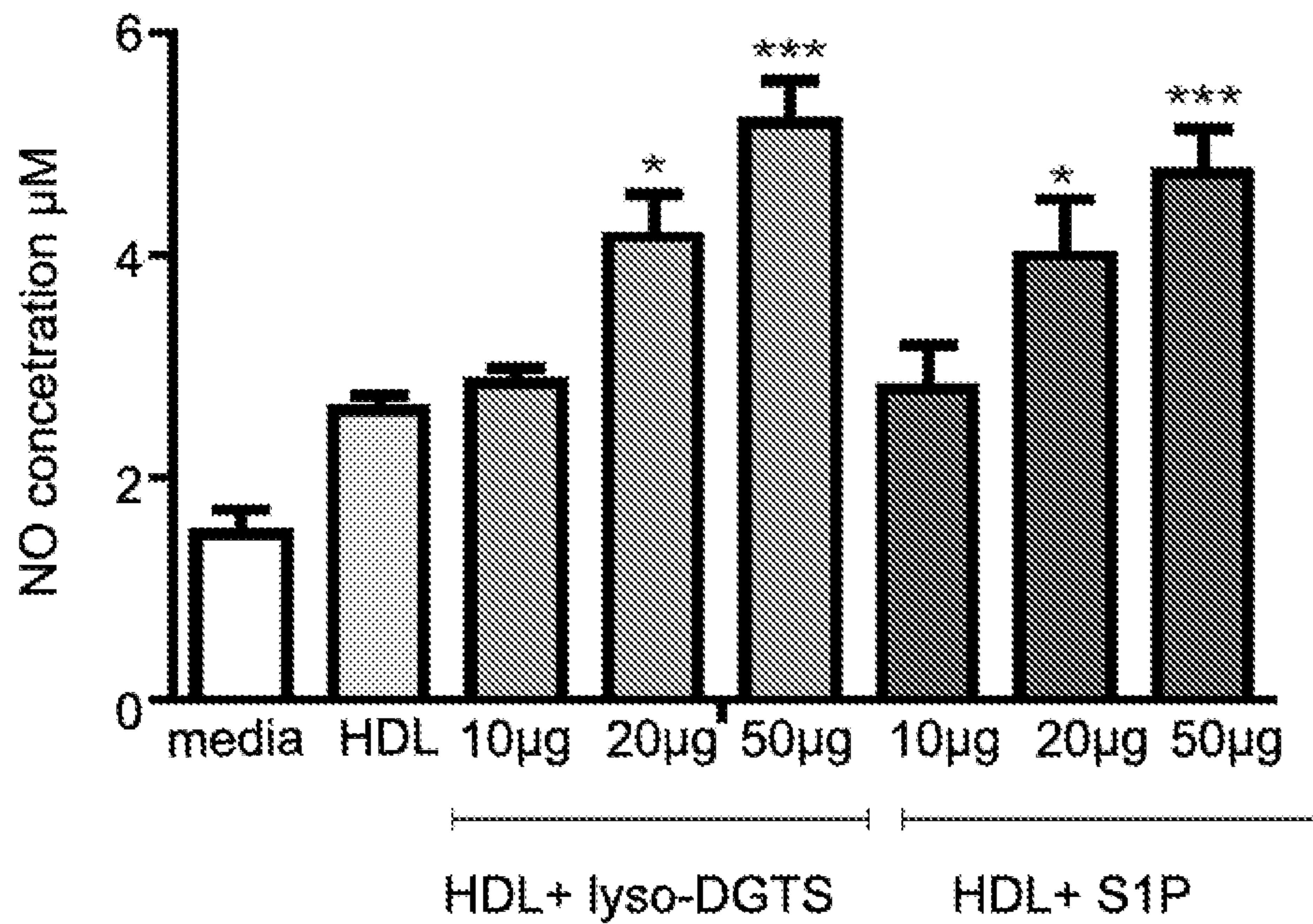


Fig. 13



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Fig. 14

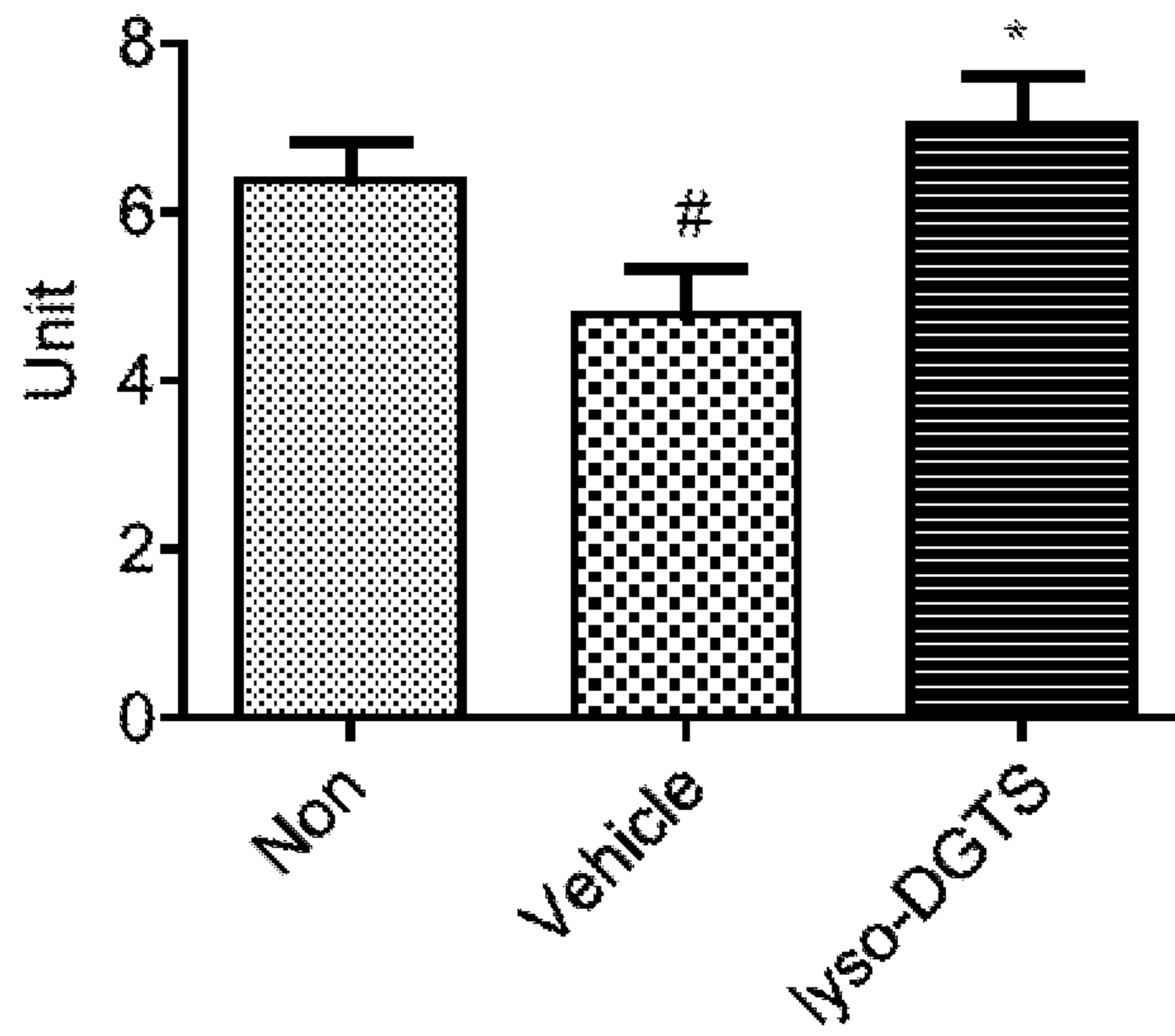


Fig. 15

