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Original Research Article

Repeated intratracheal instillation of TiO_2 nanoparticles affect on *MMP-12* expression in rat's lung

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Abstract

Titanium dioxide (TiO_2) nanoparticles have biological effects that may be caused fibrosis or emphysema through effects on matrix metalloproteinase expression. The aim of this study investigates the effect of TiO_2 nanoparticles on MMP-12 expression. Sixty-three rats were intratracheally instillation with (0.5, 1.5, 5, 15, 50, 150) mg/kg body weight of TiO_2 nanoparticles for 4 weeks. Animals were sacrificed at 4 days, a month and 3 months post-instillation, immunohistochemistry of MMP-12 antibody and lung mRNA of *MMP-12* gene expression. At 4 days post-instillation TiO_2 nanoparticles decreased macrophage MMP-12 expression with emphysema at high doses and fibrosis at low doses caused fibrosis while after a month and 3 months post-instillation macrophage MMP-12 increased and induce pulmonary response with emphysema at low doses. TiO_2 nanoparticles aggravated elastase-induced emphysema and caused histological inflammation and downregulate MMP-12 mRNA expression and protein expression in macrophage and matrix extracellular.

Keywords: MMP-12 expression, TiO_2 nanoparticles effects, MMP-12 immunostaining, emphysema

INTRODUCTION

Nanotechnology implementations, speared very quickly while very little has been done to measure and assess the hazard of nanoparticles (NPs) to an ecosystem and to the biological systems. The characteristic of nanoparticles and their small size can become easily a carriage for linking and transmit of poison chemical pollutants. There are numeral studies showing that NPs and nanotubes can be released into the environment and cause harmful effects to humans and/or living organisms. (Valavanidis and Vlachogianni, 2010).Titanium dioxide, as well as called titanium (IV) oxide or titania, is the naturally synthesized oxide of titanium, chemical formula TiO_2. When utilized as a Pigment, it is termed titanium white: Pigment White 6 (PW6), or CI 77891. Generally, it is sourced form rutile, ilmenite, and anatase. It has a huge range of applications, from sunscreen to paint to food coloring. When utilized as a food coloring, it has E number 171 (E171). World production in 2014 was about 7.5 milliontons and the amount is raising (http://nanopartikel.info/en/nanoinfo/materials/titanium-dioxide).

Extracellular matrix (ECM) is nearly connected with inflammation and followed by fibrosis. Extracellular matrix precipitation probably counts on synthesis and degeneration of collagen. Degeneration of collagen is controlled by matrix metalloproteinase and their inhibitors (TIMPs); matrix metalloproteinases (MMPs) are a group of zinc and calcium-subordinate endopeptidases that assume a key part in ECM remodeling in the lung (Gill and Parks, 2008). MMPs have the capacity to corrupt the different parts of connective tissue matrixes, particularly coordinated to ECM compounds. However, the MMPs activities are controlled at a few levels incorporating with particular inhibitors, the tissue inhibitors of metalloproteinases (TIMPs) (Morimoto et al., 2011). An instability between MMPs and TIMPs has been caused

metalloproteinase activation or inactivation, and relative levels of MMPs instead of TIMPs may take part on degeneration or synthesis of collagen in the interstitial space. Fibrosis may occur when the balance between these proteins was described due to the infiltration of inflammatory cell, inflammation and increased density of collagen fiber (Gill and Parks, 2008). Among MMPs, macrophage elastase or MMP-12 is released as a 54 kDa proenzyme and is transferred into a 45 and 22 kDa active forms. MMP-12 main function degradation elastin and a broad selection of other substrates, including type IV collagen, laminin, fibronectin, gelatin proteoglycan, heparin and chondroitin sulfates. MMP-12 originally detected in alveolar macrophages of cigarette smokers (Kaspiris et al., 2015).

In the latest few years, nanomaterials component was assumed in many fields, for example, instruments, optics, beautifiers and nourishment, additionally utilized as a part of the medication and diagnostics. This emotional increment of modern generation and utilization of nanomaterials has prompted explore their potential well-being impacts. For sure, the nanotoxicology is a field entrenched. Investigations of the impacts of nanoparticles (NPs) from various industry branches on cells and pathways are rising, and the majority of the natural impacts of NPs appear to be because of their associations with proteins.

MATERIALS AND METHODS

Preparation of Nano-TiO2 solution

Manufactured nano-TiO2 was purchased from Sigma with characteristic white powder with a mean diameter of 21 mm, and the solutions were prepared as describe in Jasim *et al*. (2017). Briefly, theTiO_2 powder was sterilization then it was scattered into a fluid with 0.9% (w/w) sodium chloride (NaCl) arrangement. For adequately scatter particles, arrangements containing TiO2 particles were sonicated for 5 min at 30% abundance by Ultrasonicator processor and vortexes before it's utilized as a part of each treatment.

Animals and treatments

Sixty-three male rats (8weeks age) with an average body weight of 123.87±22.47 g were used. The experiment design as described in Jasim *et al.* (2017) briefly, rats were divided into seven groups included: acontrol group which treated with 0.9% *w*/*w* NaCl solution, experimental groups which treated with (0.5, 1.5, 5, 15, 50, 150) mg/kg of nano-TiO2. Intratracheal instillation with nano-TiO_2 solutions was repeated twice a week for 4 weeks. Then rats were sacrificed at the day 4th, a month and 3 months after instillation, then lung was isolated.

Immunohistochemistry of MMP-12

The lung specimens were fixed in 10% buffered formalin for a maximum of 24 h, followed by paraffin embedding. From each block, 5-µm thick sections were cut and mounted on 3-amino-propyltriethoxy-silane coated slides then dewaxed in xylene and rehydrated in graded ethanols according to standard procedures. Endogenous peroxidaseactivity was blocked by pretreatment of slides with 3% hydrogen peroxidase for 10 min. Rabbit Polyclonal Antibody Matrix Metalloproteinase-12 (ab66157, ABCAM) for the MMP-12. The antigenic epitope was unmasked by antigen retrieval. The most commonly used antigen retrieval is a citrate buffer method. The slides were arranged in a staining container. Cast 300 ml of 10 mM citrate buffer, pH 6.0 into the staining container and incubate it at 95-100℃ for 10 min then the staining container was removed to room temperature and the slides were allowed to cool for 20 min. Slides were incubated with the primary antibodies diluted in Tris -buffered solution (50 mmol/L Tris-HCl, 150 mmol/L NaCl, pH 7.4). 100 µl diluted Sav-HRP conjugates (using the antibody dilution buffer) was applied to the sections on the slides and incubated in a humidified chamber for 30 min (kept protected from light). 100 µl DAB substrate solution (freshly made: 0.05% DAB - 0.015% H_2O_2 in PBS) was applied to the sections on the slides to reveal the color of antibody staining this take < 5 min to obtain desired color intensity. Slides were counterstained with Mayer's hematoxylin. TheMMP-12 immunohistochemistry was evaluated using a semiquantitative immunoreactive score (0 - 6) based on the percentage of positively stained cells (PS) (0-3) points and the intensity of staining (SI) (0-3) points, and shown in the table (1). The total score (TS) was calculated by adding the PS and SI scores, and the mean of the TS was used for the statistical analysis (Poulopoulos et al., 2013).

Total RNA extraction and cDNA synthesis

A thirty mg specimens of lung tissue took from each animal to use for RNA extraction by RN easy Mini Kit (QIAGEN Hilden, Germany) according to the manufacturer's instruction. TotalRNA concentration was measured using a Nano Drop spectrophotometer (Mecasys Co., Korea).Then single strand cDNA was synthesized using Accupower Rocketscript RT PreMix (Bioneer, Korea)

MMP-12 expression by RT-qPCR

Real-time quantitative PCR (qPCR) was performed to evaluate the expression of *MMP-12* mRNA. Gene expression was normalized to that of hypoxanthine

Table 1. Immunoreactive score for matrix metalloproteinase immunohistochemistry

score	Percentage of immunopositive cells (PS)	Staining intensity
0	0	Negative
1	<10%	Weak
2	10%-50%	Moderate
3	>50%	Stronge

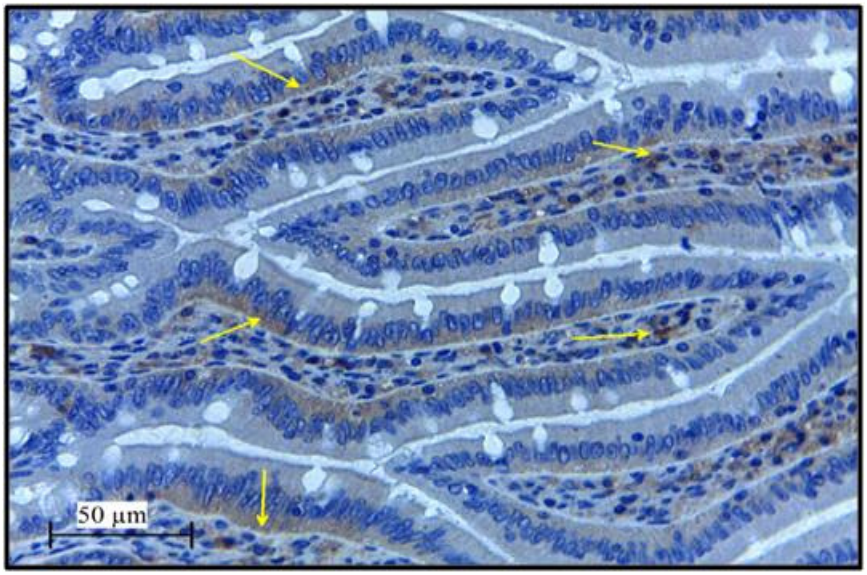

Figure 1. Positive control specimen to specify MMP-12 antibody staining reaction in intestinal section

phosphoribosyltransferase (*HPRT*) as a housekeeping gene. It was expressed stably under the experimental conditions used in this study. Real-time qPCR analysis was performed using AccuPower^{R} 2X Greenstar^{TM} qPCR master mix (Bioneer, Korea) The following primer sequences were used:*MMP-12,* forward primer: CCCCAACACATTTCGTCTCTCT, reverse primer: GGATTTGTCAAGGATGGGTTT, *HPRT,* forward primer: TTGGAAAGGGTGTTTATTCCTCAT, reverse primer: ATCCAGCAGGTCAGCAAAGAA (Roulet et.al., 2012). at 95 ℃ for 10 min, followed by 45 cycles at 95 ℃ for 1 min, 50.9 ℃ for 1 min and 72 ℃ for 1 min, melting from 50˚C to 95˚C for 1sec each temp. for 1 cycle. Relative quantification values were calculated as described previously (Ma et al., 2009).

Statistical analysis

Statistical analysis of all data was carried out using the ANOVA test with differences at $p<0.05$ considered to be statistically significant. This calculation was carried out according to the Statistical Package for Social Science (SPSS version 20) and the least significant difference (L.S.D) at a level less than (0.05) also used.

RESULTS

Immunohistochemistry

Semiquantitative expression was performed by immunostaining of anti-MMP-12. A positive control confirmed the specific of the staining reaction (Figure 1) in the areas of fragmented, distorted and thickened elastic fiber, in additionally MMP-12 expression in chronic inflammatory cells and most in the macrophage. The results show that anti-MMP-12 was minimal to the negative reaction after 4 days of instillation in treated groups compared with the control group (figure 2,3A). After a month of instillation noticed a significant increase in the immunostaining reaction which was moderate to a strong reaction in all treated groups (figure 2,3B). Also, the same observation was after 3 months of instillation (figure 2,3C).

Real-Time qPCR

Real-Time quantitative polymerase chain reaction (RT-qPCR) was used to utilize the effect of TiO2 NP on the MMP-12 mRNA expression. Specificity of RT-qPCR

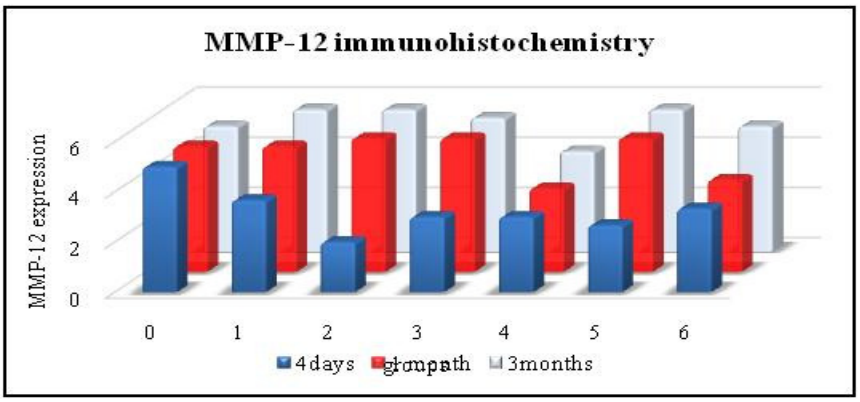

Figure 2. Immunohistochemistry analysis showing the change in MMP-12 expression between treated groups compared with control group during the entire interval of study. groups 0-6 (0.5 ,1.5, 5, 15, 50, 150) mg/kg B.W. respectively.

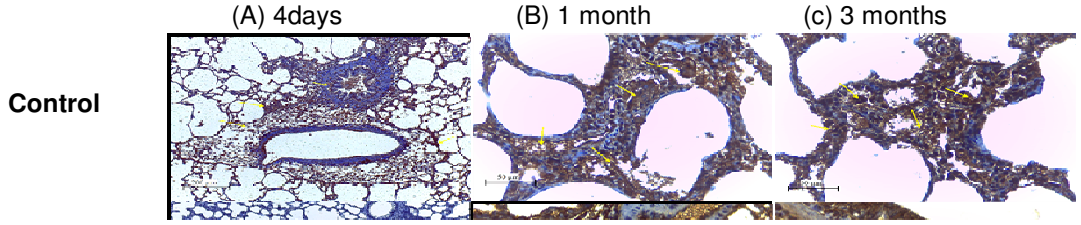

Figure 3. Moderate immunostaining of MMP-12 in lung tissue of control and treated groups. A: after 4 days, B: after a month, C: after 3 months. MMP-12 was selectively stained in the extracellular matrix and in the macrophage (arrows).

Figure 4. Analysis RT-qPCR results. (A) 2% Gel electrophoresis (at 60 volts for 45 min) of RT-qPCR products of *HPRT* and *MMP-12* in all groups: lane 1:100bp DNA molecular ladder, lanes 2-9: treated groups with TiO_2 NP showing the genes bands and lane 10: NC: negative control. (B) Quantification of *HPRT* and *MMP-12* mRNA level by real-time quantitative PCR (RT-qPCR), (C) Melting point for *MMp-12* gene. (D)) Effect of TiO_2 NP on the mRNA expression of *HPRT* and *MMP-12* in the lung after 4 days, a month and 3 months post- instillation.

Table 2. Effect of TiO_2 NP on the amplification of *MMP-12* mRNA by RT-qPCR analysis after 4days, a month and 3 months post-instillation.

		TiO_2NP (mg/kg BW)						
Genes		**0**	**0.5**	**1.5**	**5**	**15**	**50**	**150**
4days *MMP-12*	**Ct**	32.055	32.112	32.196	32.002	32.198	32.420	32.469
	Relative Copies	1.26E+3	1.42E+3	3.41E+3	1.05E+3	1.75E+3	3.00E+3	3.45E+3
	Ratio of MMP-12/HPRT	0.002±0.0003	0.002±0.0002	0.002±0.001	0.002±0.001	0.002±0.001	0.002±0.0005	0.002±0.001
1month *MMP-12*	**Ct**	29.072	28.229	29.602	28.963	28.792	29.379	28.459

Table 2. Continue

	Relative Copies	1.26E+3	1.417E+3	3.412E+3	1.052E+3	1.746E+3	3.003E+3	3.451E+3
3months *MMP-12*	**Ratio of MMP12/HPRT**	0.013±0.004	0.024±0.012	0.019±0.018	0.016±0.009	0.019±0.007	0.016±0.008	0.019±0.006
	Ct	25.242	25.389	25.068	24.759	25.169	24.191	24.691
	Relative Copies	2.09E+5	2.37E+6	1.39E+5	7.82E+4	3.05E+5	4.12E+4	1.31E+5
	Ratio of MMP-12/HPRT	0.189±0.078	0.542±0.408	0.529±0.232	0.451±0.171	0.507±0.319	0.433±0.262	0.388±0.218

Values present mean ± Sd, (n=3)
[a] The mean difference is significant ($p < 0.05$)

product was archived by gel electrophoresis, which resulted in asingle band with size 90 bp. In addition, a lightcycler melting curve was performed to detect the melting temperature for each gene (figure 4A-C).The result showed the decrease in *MMP-12* expression but with no significant ($p>0.05$) compared with the control group at 4days post-instillation. While it was up-regulated with no significant difference ($p>0.05$) after a month and 3 months post-instillation. Figure (4D), Table (2)

DISCUSSION

Immunohistochemistry of MMP-12 antibody showed weak to negative stain after 4 days from instillationthen gradually increased after a month and 3 months post-instillation. MMP12 is a matrix metalloproteinase with elastolytic ability, that is secreted by activated macrophages and has been involved in emphysema pathogenesis in mouse models of chronic obstructive pulmonary disease (COPD) and asthma via different independent mechanisms including (i) proteolytic inactivation of antiproteases such as α1-antitrypsin, (ii) degradation of the extracellular matrix, and (iii) proteolytic activation of pro-inflammatory cytokines including TNFα (Zheng et al., 2000; Churg and Wright 2005). Interestingly, MMP12 is also a signature gene of alternatively activated macrophages (AAM) and the plurality of genes that were diversely upregulated in the lungs from mice (Wagner et al., 2016). Alveolar macrophages are known the provenance of both MMP-9 and MMP-12 (Demedts et al., 2005). Increased in cytokines secretion which detected by ELISA led to increasing MMP-12 in macrophage and in the extracellular matrix. Cytokines are known regulators of MMP expression (Greenlee et al., 2007).

Different particles, such Paris Metro or atmospheric particulate matter (PM 10), could stimulate MMP-12 expression in macrophages (Kobayashi et al., 2009). Cobos-Correa *et al*. (2009) study provided the first confirmation of an increase in MMP-12 expression by manufactured NPs, both at the mRNA and protein levels. The increase in MMP-12 expression after a single exposure CB NPs could have remarkable pathophysiological consequences because this protease plays a crucial role in emphysema and COPD (Hunnunghak et al., 2009). Oxidative stress, revealed by the increased HO-1 expression, could explain MMP-12 creation after CB NPs administration (Lavigne and Eppihimer, 2005) while TiO_2 NP on MMP-12 expression is independent of oxidative stress or IL-1β induction (Roulet et al., 2012).

While *MMP-12* expression which demonstrated by RT-qPCR was downregulated at 4 days post-instillation then gradually increased in a month and 3 months post-instillation comparing with the control group due to the effect of TiO_2 NP.

TiO2 NPs stimulated inflammation or protease expression but, rather, potentiated MMP-12 mRNA induction by elastase, potentiated toluene di-isocyanate induced allergic inflammation in mice without inducing inflammation (Hussain et al., 2011). However, the relation of the potentiation of elastase-induced MMP-12 mRNA expression by TiO2 is questionable, because it was unable to detect a parallel augmentation in protein expression. Moreover, this phenomenon was noticed in the absence of a parallel increase in HO-1 and IL-1β expression, which suggests that the effect of TiO2 NPs on MMP-12 expression is independent of oxidative stress or IL-1β induction (Roulet *et al*., 2012). The physiological role of MMP-12-mediated proteolysis remains poorly understood and may be bind to remodeling of connective tissue during growth and development, and migration of macrophages into tissues (Gaggar et al., 2011).

The regulation of MMP expression in diseases of airway obstruction is multifactorial because many regulators including allergen challenge, smoke exposure, activation of inflammatory cells, and the underlying inflammation have been implicated (Greenlee et al., 2007; Churg et al., 2012). The mechanism of MMP activation is essentially the same for each family member via the cleavage of a 10-kD proenzyme peptide. In vivo activation of MMP may occur through several mechanisms. MMP can auto-catalyze the cleavage of the

propeptide, and other proteases, such as NE, MMP-7, and cathepsins, will also activate MMP. Recent studies have investigated the role of reactive oxygen species in MMP activation (Russell et al., 2002).

CONCLUSION

TiO_2 NP induce many alterations in lung structure after intra-tracheal instillation TiO_2 NP affected on MMP-12 expression in lung detected by immunohistochemistry after 4 days from instillation while it was raised after a month and 3 months from instillation, also TiO_2 affected on MMPs expression which was decreased the expression of *MMP-12* in the lung.

REFERENCES

Churg A, Wright JL (2005). Proteases and emphysema. *Current Opinion in Pulmonary Medicine*, *11*, 153–159.

Churg, A., Zhou, S., and Wright, J. L. (2012). Matrix metalloproteinases in COPD. *EuropeanRespiratory Journal*, 39(1), 197–209.

Cobos-Correa A, Trojanek JB, Diemer S, Mall MA, Schultz C (2009). Membrane-bound FRET probe visualizes MMP12 activity in pulmonary inflammation. *Nature Chemical Biology*, 5(9), 628–30.

Demedts IK, Brusselle GG, Bracke KR, Vermaelen KY, Pauwels RA (2005). Matrix metalloproteinases in asthma and COPD. *Current Opinion in Pharmacology*, 5(3 SPEC. ISS.), 257–263.

Gaggar A, Hector A, Bratcher PE, Mall MA, Griese M, Hartl D (2011). The role of matrix metalloproteinases in cystic fibrosis lung disease. *The Eur. Resp. J.* 38(3), 721–7.

Gill SE, Parks WC (2008). Metalloproteinases and their inhibitors: Regulators of wound healing. *International Journal of Biochemistry and Cell Biology*, *40*(6-7), 1334–1347.

Greenlee KJ, Werb Z, Kheradmand F (2007). Matrix Metalloproteinases in Lung: Multiple, Multifarious, and Multifaceted. *Physiological Reviews*, 87(1), 69–98.

http://nanopartikel.info/en/nanoinfo/materials/titanium-dioxide

Hunnunghak GM, Cho MH, Tesfaigzi Y, Soto-Quros ME, Avila L, Lasky-Su J, Celedon JC (2009). MMP12, Lung Function, and COPD in High-Risk Populations. *Sciences-New York*, 361(1812), 2599–2608.

Hussain S, Vanoirbeek JAJ, Luyts K, De Vooght V, Verbeken E, Thomassen LCJ, Martens JA, Dinsdale D, Boland S, Marano F, Nemery B, Hoet PHM (2011). Lung exposure to nanoparticles modulates an asthmatic response in a mouse model. *European Respiratory Journal*, *37*(2), 299–309.

Jasim FA, Suker DK, Abdullah S (2017). TiO2 nanoparticles induce lung fibrosis and proteinosis through influence on matrix metalloproteinase expression. Accepted in international journal of sciences. (under publishing)

Kaspiris A, Khaldi L, Chronopoulos E, Vasiliadis E, Grivas TB, Kouvaras I, Papadimitriou E (2015). Macrophage-specific metalloelastase (MMP-12) immunoexpression in the osteochondral unit in osteoarthritis correlates with BMI and disease severity. *Pathophysiology*, 22(3), 143–151.

Kobayashi N, Naya M, Endoh S, Maru J, Yamamoto K, Nakanishi J (2009). Comparative pulmonary toxicity study of nano-TiO2 particles of different sizes and agglomerations in rats: Different short- and long-term post-instillation results. *Toxicology*, *264*(1–2), 110–118.

Lavigne MC, Eppihimer MJ (2005). Cigarette smoke condensate induces MMP-12 gene expression in airway-like epithelia. *Biochemical and Biophysical Research Communications*, 330(1), 194–203.

Ma L, Zhao J, Wang J, Liu J, Duan Y, Liu H, Hong F (2009). The Acute Liver Injury in Mice Caused by Nano-Anatase TiO2. *Nanoscale Research Letters*, *4*, 1275–1285.

Morimoto Y, Oyabu T, Ogami A, Myojo T, Kuroda E, Hirohashi M, Shimada M, Lenggoro W, Okuyama K, Tanaka I.(2011). Investigation of gene expression of MMP-2 and TIMP-2 mRNA in rat lung in inhaled nickel oxide and Titanium dioxide nanoparticles. *Industrial Health*, 49, 344–352

Poulopoulos AK, Andreadis D, Markopoulos AK (2013). Expression of matrix metalloproteinases 9 and 12 in actinic cheilitis. *World Journal of Experimental Medicine,* 3(3), 43–9.

Roulet A, Armand L, Dagouassat M, Rogerieux F, Simon-Deckers A, Belade E, Nhieu JTV, Lanone S, Pairon JC, Lacroix G, Boczkowski J (2012). Intratracheally administered titanium dioxide or carbon black nanoparticles do not aggravate elastase-induced pulmonary emphysema in rats. *BMC Pulmonary Medicine*, 12:38.

Russell RE, Culpitt SV, DeMatos C, Donnelly L, Smithm M, Wiggins J, Barnes PJ (2002). Release and activity of matrix metalloproteinase-9 and tissue inhibitor of metalloproteinase-1 by alveolar macrophages from patients with chronic obstructive pulmonary disease. *Am.J. Respir. Cell Mol. Biol.*, 26(13), 602–609.

Valavanidis A, Vlachogianni T (2010). Nanomaterials and nanoparticle in the aquatic environment: Toxicological and ecotoxicological risks. *Science advances on Environment, Toxicology and Ecotoxicology issues*.

Wagner CJ, Schultz C, Mall MA (2016). Neutrophil elastase and matrix metalloproteinase 12 in cystic fibrosis lung disease. *Molecular and Cellular Pediatrics*,3(1), 25.

Zheng T, Zhu Z, Wang Z, Homer RJ, Ma B, Riese RJ, Elias JA (2000). Inducible targeting of IL-13 to the adult lung causes matrix metalloproteinase- and cathepsin-dependent emphysema. *Journal of Clinical Investigation*, *106*(9), 1081–1093.