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Influence of UV radiation on TiO_2 nanoparticles antibacterial behaviour

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ABSTRACT

Purpose: The influence of UV radiation on the antibacterial properties of titanium oxide nanoparticles was examined using yeast Saccharomyces cerevisiae strain for this purpose.

Design/methodology/approach: Nanopowders were made with sol-gel method. Surface morphology studies of the obtained materials were made using Zeiss's Supra 35 scanning electron microscope. In order to confirm the chemical composition of observed nanopowders, qualitative tests were performed by means of spectroscopy of scattered X-ray energy using the Energy Dispersive Spectrometer (EDS). The DLS (Dynamic Light Scattering) method was used to analyse the particle size distribution using the AntonPaar Litesizer 500 nanoparticle size analyser. Changes in particle size distribution at elevated temperatures were also observed. The antibacterial properties of titanium oxide nanoparticles were examined by subjecting the yeast sample to irradiation with an UV lamp.

Findings: Samples containing yeast Saccharomyces cerevisiae were irradiated with and without the addition of TiO_2 nanoparticles. A faster decrease in the colony count was observed compared to irradiated exposures without the addition of a suspension.

Practical implications: Presented materials can be used in the production of antibacterial coatings for surfaces occurring in public spaces such as schools, hospitals, public toilets for the simple and effective elimination of bacteria and fungi as a result of exposures.

Originality/value: The antibacterial properties of titanium oxide nanoparticles under UV radiation were confirmed.

Keywords: Titanium dioxide, Nanoparticles, Antibacterial properties

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BIOMEDICAL AND DENTAL MATERIALS AND ENGINEERING

1. Introduction

Nanotechnology is a science focused on objects and structures smaller than 100 nm in at least one direction. The study of these materials, thanks to the invention of the electron microscope, is no longer a major obstacle for scientists, but their practical applications are still in great demand. Nanotechnology is particularly appreciated in various fields of medicine. Materials with a structure fragmented to nanometric sizes, as well as those with nanoparticles, nanowires, nanotubes are particularly useful in orthopaedics and tissue engineering, as well as cardiology [1-3]. They owe this popularity to their extraordinary strength properties, increased abrasive and corrosion resistance obtained by depositing coatings a few nanometres thick, as well as a small response of the body in contact with them. Nanoparticles, which this work is devoted to, may indicate antibacterial effects under the influence of external factors. Researches ale being carried out on the use of several kinds nanoparticles in the areas of medicine and plant protection. Nanoparticles are gaining more and more recognition in these areas. Experiments involving ultraviolet (UV) radiation and microwaves for those materials are particularly promising. Under the influence of their interaction, the particles produce ROS (reactive oxygen species) can lead to cancer cells destruction. ROS is a compound that occurs naturally in the cells of the body, formed as a product of the metabolic processes. In basal amounts it is essential for the proper functioning of the body. As its concentration in cells increases, it becomes cytotoxic and ultimately leads to cell death (Fig. 1). Four compounds classified as ROS are divided: Superoxide ($O^{\bullet}_{2}$), Hydroxyl radical (OH•), Hydrogen peroxide (H_2O_2) and singlet oxygen ($^1O_2$) [4-11].

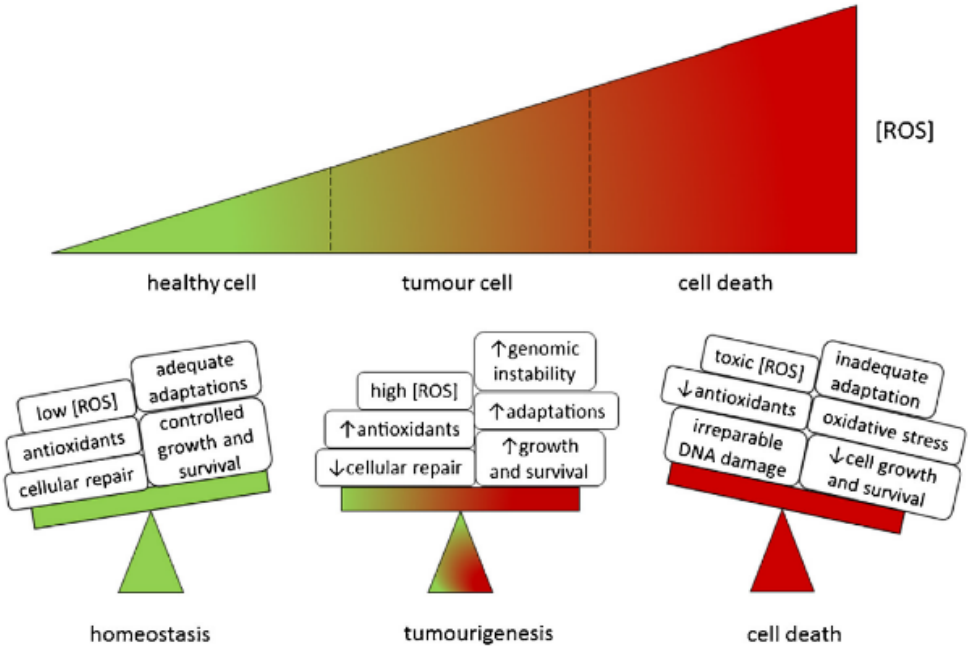

Fig. 1. ROS effect in cells [2]

Size is the most important attribute of nanoparticles for biomedical applications. They must be adequately small and well dispersed to fulfil their functions. The optimal size of nanoparticles having direct contact with the human body is from 6 to 30 nm. Smaller ones show little susceptibility to external conditions such as magnetic field or UV radiation. Larger particles will not penetrate the cells or intercellular spaces. The particle size allows reaching previously inaccessible areas of organisms, which allows for more effective distribution of drugs and other chemical substances. In addition, they also have properties that differ significantly from the solid materials. Due to such small dimensions, nanoparticles have a very large specific surface area, which is why their antibacterial effect is much more effective than in other materials. However, a large specific surface area increases the mutual interactions between

particles, which increases their tendency to agglomerate and after combining into agglomerates they lose their extraordinary antibacterial properties [12-21].

The main goal of the experiment was to produce titanium dioxide nanoparticles using the sol-gel method, which allows the particle size to be controlled in a simple way. The nanoparticles were then analysed to assess chemical composition and size. Finally yeast tests were made to confirm antibacterial properties of obtained materials under UV irradiation.

2. Materials and methods

During the work titanium dioxide nanoparticles were produced by the sol-gel method.

2.1. Synthesis of titanium dioxide nanoparticles

Titanium oxide nanoparticles were made using titanium isopropoxide as precursor and distilled water as hydrolysis catalyst. The desired pH value of the solution was adjusted by the addition of HNO_3. While stirring with a magnetic stirrer, both substances were mixed under room temperature. Cloudy suspension was formed, which was then heated to 60-70°C and held overnight. After that, the volume of the solution was reduced to approx. 50 cm^3. After the reaction had completed, the solution was dried in furnace. The resulting material was then annealed (Fig. 2).

The produced precipitates were next washed with ethanol and dried. As a result, a yellow-white nanopowder was obtained, which was further ground in an agate mortar (Fig. 3).

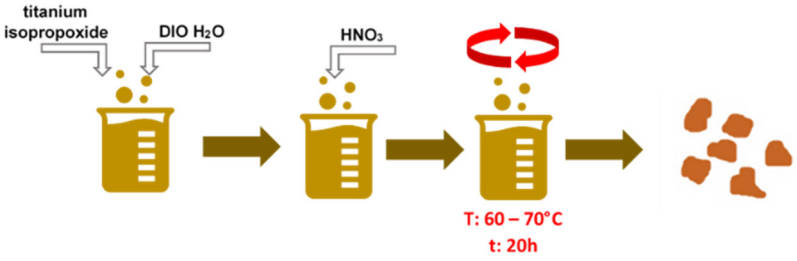

Fig. 2. Scheme of sol-gel method of TiO_2 nanoparticles synthesis

Fig. 3. The TiO_2 nanopowder obtained after grinding in an agate mortar

2.2. Characterisation techniques

To observe particle surface morphology, SEM imaging was performed using a Zeiss's Supra scanning electron microscope operated at 3 kV. In order to confirm the chemical composition of the obtained materials qualitative tests were performed by means of spectroscopy of scattered X-ray energy using the Energy Dispersive Spectrometer (EDS). The DLS (Dynamic Light Scattering) method was used to analyse the particle size distribution using the AntonPaar Litesizer 500 nanoparticle size analyser. The particle size at elevated temperature (25, 50 and 70°C) was also measured.

2.3. Measurement of TiO_2 antibacterial properties

The yeast sample of the Saccharomyces cerevisiae strain was cultured using a gelatine-based medium, starch and glucose solution. The samples were incubated at a temperature of about 40°C for 4 h and then kept at a temperature of about 23°C for 48 h. After this time, the number of colonies in the sample was examined. TiO_2 nanoparticles in an ethanol solution were added to a series of samples and

left for about 15 minutes. The second series of samples was also sprayed with the solution of studied nanoparticles and subjected to UV lamp 36 W for 5, 15, 20, 25 s and 1, 3, 5 min. The all samples were stained with an iodine solution and observed with light ZEISS Axio Vert.A1 microscope.

3. Results and discussion

In the SEM imaging (Fig. 4) agglomerates of nanoparticles with sizes up to 100 nm were registered.

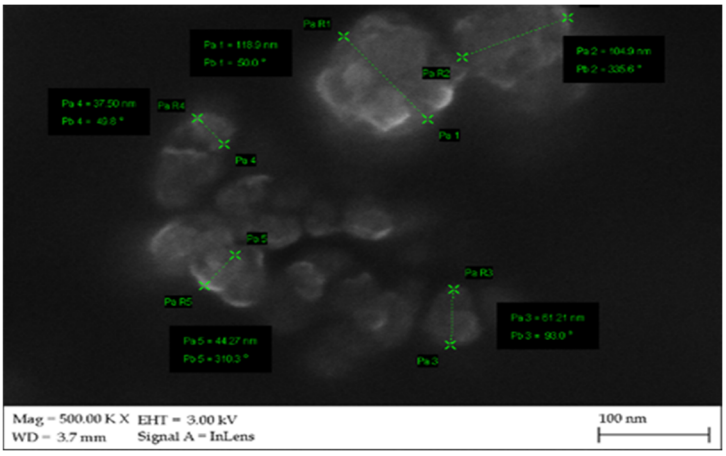

Fig. 4. SEM Images of TiO_2 nanoparticles agglomerates

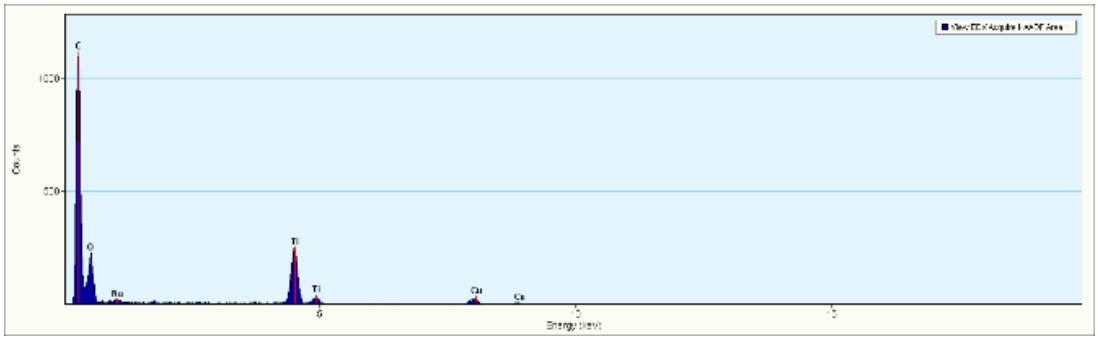

Fig. 5. EDS spectra of TiO_2 nanoparticles

The qualitative analysis of EDS (Fig. 5) confirmed the chemical composition of the material produced, no additional contamination of the samples was found. Cu on TiO_2 EDS spectre was caused by background.

The size distribution of nanoparticles was checked using the DLS method (Fig. 6). The highest proportion among the agglomerates of the nanoparticles has been shown to show those with a diameter of 80 to 125 nm.

Obtained nanoparticles were additionally subjected to the analysis of the size distribution as a function of temperature (Fig. 7). This study showed the large tendency of this material to agglomerate.

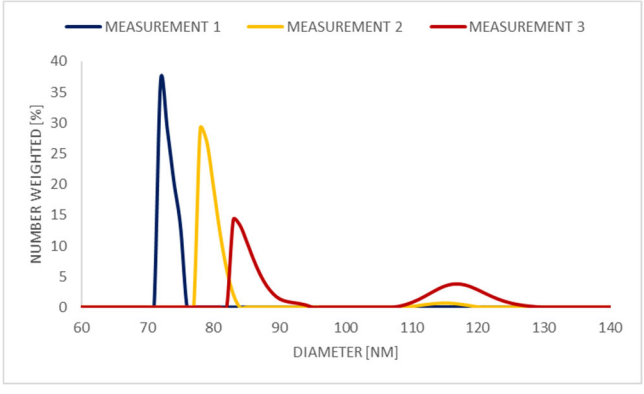

Fig. 6. Size distribution of TiO_2 nanoparticles

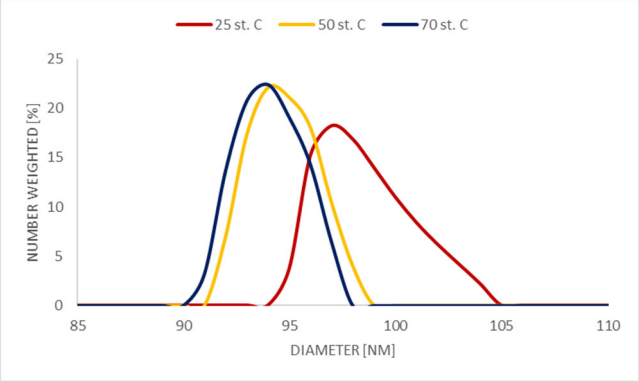

Fig. 7. Size distribution of TiO_2 nanoparticles in the function of temperature

After completing the morphological tests an experimenter was carried out to check the bactericidal properties of nanoparticles after UV irradiation. TiO_2 NPs were chosen because of their properties and best size. Samples containing yeast Saccharomyces cerevisiae were irradiated with and without the addition of TiO_2 nanoparticles. A faster decrease in the colony count was observed compared to irradiated exposures without the addition of a suspension (Fig. 8).

4. Conclusions

Nanoparticles were synthesized as a result of the experiment. Comparing the results obtained with the use of different research techniques, a strong tendency of particles to agglomerate was learned. The size analyser additionally rounds samples to the sphere, which affects the inflated result. The EDS study confirmed the chemical composition of nanoparticles. The yeast experiment showed a significant effect of TiO_2 nanoparticles on decreasing the number of colonies, which may confirm the good bactericidal effect of these structures under the influence of ultraviolet radiation. Significant doses of UV radiation are considered harmful to the body. In the case of conducted studies, however, it was shown that irradiation for only 30 s significantly reduces the number of yeast colonies. This is a much lower time than the exposure during the use of services using UV radiation (solarium, hybrid manicure). The antibacterial properties of nanoparticles may also be used to produce coatings that, when exposed to some external factors such as radiation or microwaves, remove bacteria. Such coatings will be used, for example, in public buildings: hospitals, offices, schools, public toilets.

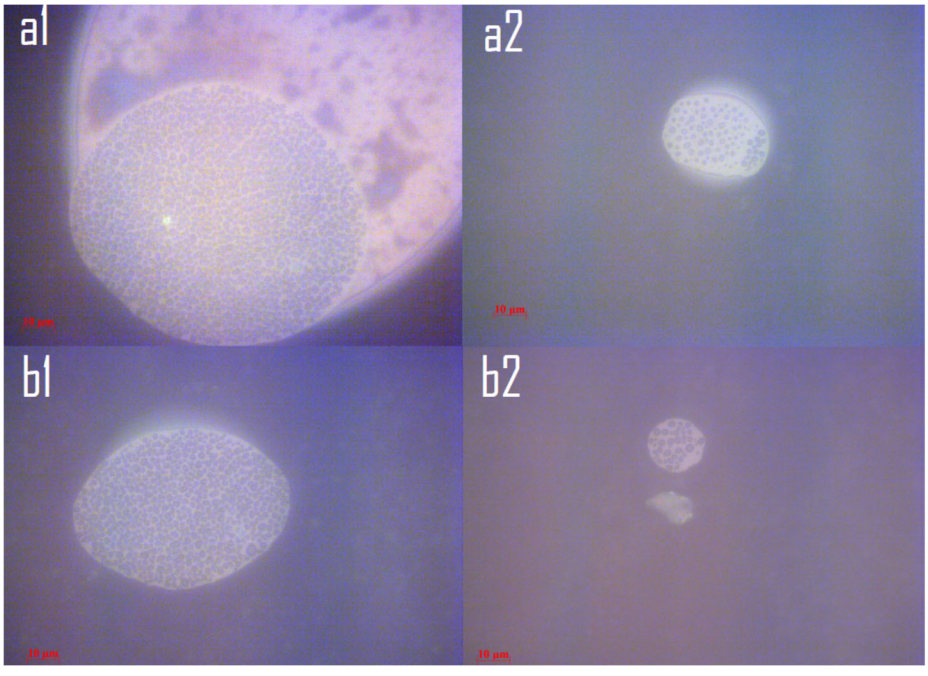

Fig. 8. Yields colony after 20 sec. long UV irradiation (a1 – without TiO_2 NPs, a2 – with TiO_2 NPs) and after 25 sec. long UV irradiation (b1 – without TiO_2 NPs, a2 – with TiO_2 NPs)

References

[1] K. Szmajnta, M. Szindler, Synthesis and properties of TiO_2, NiO and ZnO nanoparticles and their possible biomedical application, Archives of Materials Science and Engineering 98/2 (2019) 81-84, DOI: https://doi.org/10.5604/01.3001.0013.4612

[2] L.A. Dobrzański, The significance of the nano-structural components on the properties of the nano-engineering materials, Journal of Achievements in Materials and Manufacturing Engineering 88/2 (2018) 55-85, DOI: https://doi.org/10.5604/01.3001.0012.6150

[3] J. Palán, L. Maleček, J. Hodek, M. Zemko, J. Dzugan, Possibilities of biocompatible material production using conform SPD technology, Archives of Materials Science and Engineering 88/1 (2017) 5-11, DOI: https://doi.org/10.5604/01.3001.0010.7746

[4] R. Mittler, ROS Are Good, Trends in Plant Science 22/1 (2017) 11-19, DOI: https://doi.org/10.1016/j.tplants.2016.08.002

[5] J.N. Moloney, T.C. Cotter, ROS signalling in the biology of cancer, Seminars in Cell & Developmental Biology 80 (2018) 50-64, DOI: https://doi.org/10.1016/j.semcdb.2017.05.023

[6] S.I. Zandalinas, R. Mittler, ROS- induced ROS release in plant and animal cells, Free Radical Biology and Medicine 122 (2018) 21-27, DOI: https://doi.org/10.1016/j.freeradbiomed.2017.11.028

[7] H. Ma, L. Zhao, L. Guo, F. Chen, W. You, Roles of reactive oxygen species (ROS) in the photocatalytic degradation of pentachlorophenol and its main toxic intermediates by TiO_2/UV, Journal of Hazardous Materials 369 (2019) 719-726, DOI: https://doi.org/10.1016/j.jhazmat.2019.02.080

[8] A. Moriyama, J. Takahashi, I. Yamada, H. Iwahashi, Oxidative stress caused by TiO_2 nanoparticles under UV irradiation is due to UV irradiation not through nanoparticles, Chemico-Biological Interactions 294 (2018) 144-150, DOI: https://doi.org/10.1016/j.cbi.2018.08.017

[9] S. Mahshid, M. Askari, M. Sasani Ghamsari, Synthesis of TiO_2 Nanoparticles by hydrolysis and peptization of titanium isopropoxide solution, Journal of Materials Processing Technology 189/1-3 (2007) 296-300, DOI: https://doi.org/10.1016/j.jmatprotec.2007.01.040

[10] L. Fu, M. Hamzeh, S. Dodard, Y.H. Zhao, G.I. Sunahara, Effects of TiO_2 nanoparticles on ROS production and growth inhibition using freshwater green algae pre-exposed to UV irradiation, Environmental Toxicology and Pharmacology 39/3 (2015) 1074-1080, DOI: https://doi.org/10.1016/j.etap.2015.03.015

[11] J. Wang, Y. Guo, B. Liu, X. Jin, L. Liu, R. Xu, Y. Kong, B. Wang, Detection and analysis of reactive oxygen species (ROS) generated by nano-sized TiO_2 powder under ultrasonic irradiation and application in sono-catalytic degradation of organic dyes, Ultrasonic Sono-chemistry 18/1 (2011) 177-183, DOI: https://doi.org/10.1016/j.ultsonch.2010.05.002

[12] A.M. Świdwińska-Gajewska, S. Czerczak, Titanium dioxide nanoparticles – biological effects, Medycyna Pracy 65/5 (2014) 651-663, DOI: https://doi.org/10.13075/mp.5893.00096 (in Polish).

[13] X. Chu, L. Mao, O. Johnson, K. Li, J. Phan, Q. Yin, L. Lin, J. Zhang, W. Chen, Y. Zhang, Exploration of TiO_2 nanoparticle mediated microdynamic therapy on cancer treatment, Nanomedicine: Nanotechnology, Biology and Medicine 18 (2019) 272-281, DOI: https://doi.org/10.1016/j.nano.2019.02.016

[14] A.J. Haider, R.H. Al-Anbari, G.R. Kadhim, C.T. Salame, Exploring potential environmental applications of TiO_2 nanoparticles, Energy Procedia 119 (2017) 332-345, DOI: https://doi.org/10.1016/j.egypro.2017.07.117

[15] K. Kosmala, R. Szymańska, Titanium (IV) oxide nanoparticles. Preparation, properties and application, Kosmos: Problemy Nauk Biologicznych 65/2 (2016) 235-245 (in Polish).

[16] P. Rokicka-Koniczna, A. Wanag, A. Sienkiewicz, E. Kusiak-Nejman, A.W. Morawski, Antibacterial effect of TiO_2 nanoparticles modified with APTES, Catalysis Communications 134 (2020) 105862, DOI: https://doi.org/10.1016/j.catcom.2019.105862

[17] S.H. Hosseinali, Z.P. Boushehri, B. Rasti, M. Mirpour, K. Shahpasand, M. Falahati, Biophysical, molecular dynamics and cellular studies on the interaction of nickel oxide nanoparticles with tau proteins and neuron-like cells, International Journal of Biological Macromolecules 125 (2019) 778-784, DOI: https://doi.org/10.1016/j.ijbiomac.2018.12.062

[18] T. Ali, A. Ahmed, U. Alam, I. Uddin, P. Tripathi, M. Muneer, Enhanced photocatalytic and antibacterial activities of Ag-doped TiO_2 nanoparticles under visible light, Materials Chemistry and Physic 212 (2018) 325-335, DOI: https://doi.org/10.1016/j.matchemphys.2018.03.052

[19] N. Nithya, G. Bhoopathi, G. Magesh, C.D. Nesa Kumar, Neodymium doped TiO_2 nanoparticles by sol-

gel method for antibacterial and photocatalytic activity, Materials Science in Semiconductor Processing 83 (2018) 70-82, DOI: https://doi.org/10.1016/j.mssp.2018.04.011

[20] G. Machalska, M. Noworolnik, M. Szindler, W. Sitek, R. Babilas, Titanium dioxide nanoparticles and thin films deposited by an atomization method, Archives of Materials Science and Engineering 100/1-2 (2019) 34-41, DOI: https://doi.org/10.5604/01.3001.0013.6000

[21] M. Pawlyta, B. Sobel, B. Liszka, Estimation of the chemical specific surface area of catalytic nanoparticles by TEM images analysis, Journal of Achievements in Materials and Manufacturing Engineering 87/1 (2018) 5-12, DOI: https://doi.org/10.5604/01.3001.0012.0733