

Safe-by-Design nanotechnology for safer cultural heritage restoration

Humanity cultural heritage is vast, and it includes archeological areas, antique and modern works of art (e.g. paintings, statues), books, monuments, and frescos. Some of these works of art are subjected to environmental stressors like air pollution and microbial activity. Degradation is often shown as loss of cohesion of constituting materials, causing cracks in frescos surface and loss of paint particles, as well as loss of stone material from monuments and statues.

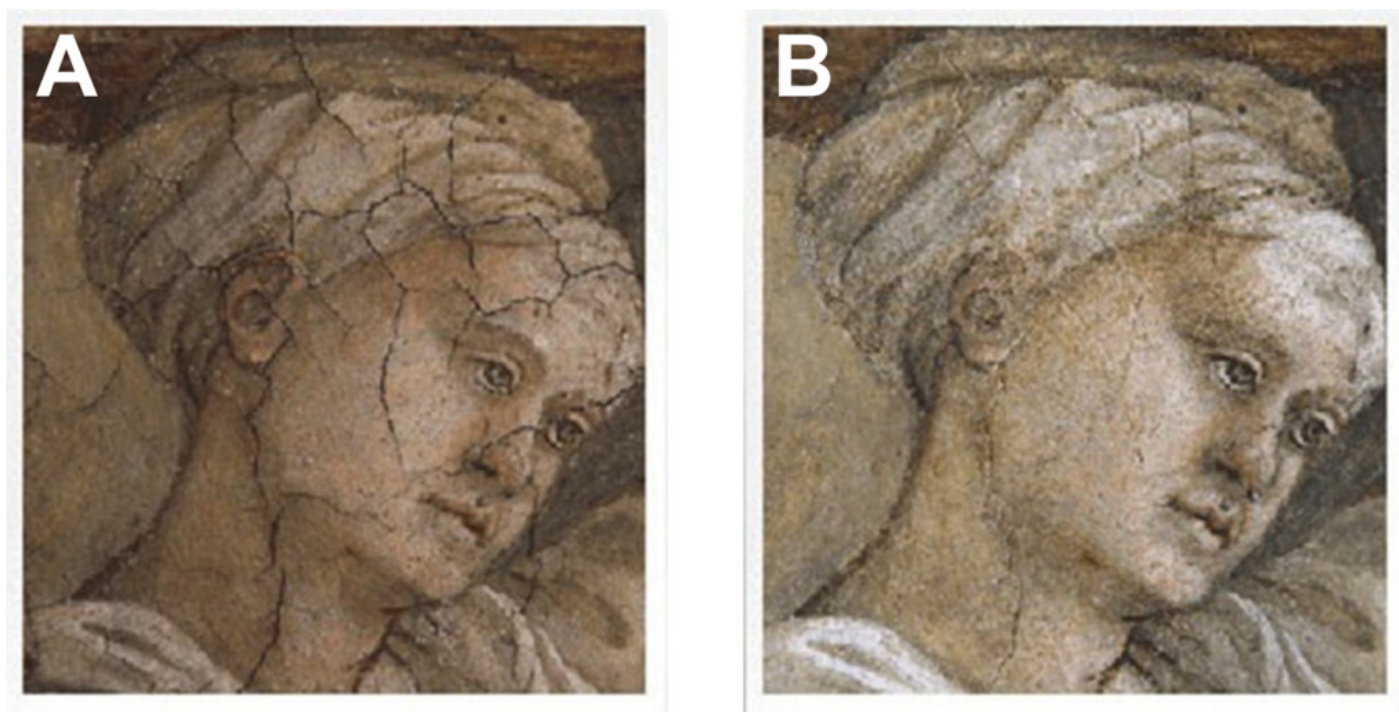


Fig. 1. Effect of consolidation process on works of art. (A) before treatment; (B) after consolidation.

One important phase in works of art restoration is consolidation, which is defined as “the application of binding material to improve cohesion of loose and friable media or substrates to their supports” (Fig. 1). Consolidation is a physical stabilization of the work of art aiming at binding constituting materials, and ensuring both any further treatment procedure and its stability over time. Among the products used by professional restorer, different organic consolidants have been applied. However, the use of organic volatile solvents poses health risks for restorers, as well as for the work of art itself such as risk of accelerated chemical degradation and permanent colors modification. These side effects led to the development of a new generation of consolidants, based on nanoparticles. Nanoparticles are very small particles, with a dimension comprised between 1 nm and 100 nm. To give an idea of proportions, a nanoparticle can be as small as 10,000 times the

diameter of a human hair. Due to their small dimensions, these materials show new interesting properties, making “normal” materials potentially useful for many applications. In this case, silica (SiO_2), which is the main component of sand and it is used to produce ceramics and glass, as nanoparticle can be effectively used to consolidate stone and paintings. As for any new material, there are concerns for the safety of users and the environment. Nanoparticles can potentially be inhaled or come into contact with the skin, enter into blood stream and reach internal organs. In our work we tried to answer a very important question: Is there a way to make safer and at the same time more effective consolidation materials? The question is a way to express the concept of Safe-by-Design, which means integrating safety concerns into the innovation process. From a practical point of view, it consists into designing-out from the product the harmful properties, for example modifying chemical composition or proposing safer use conditions.

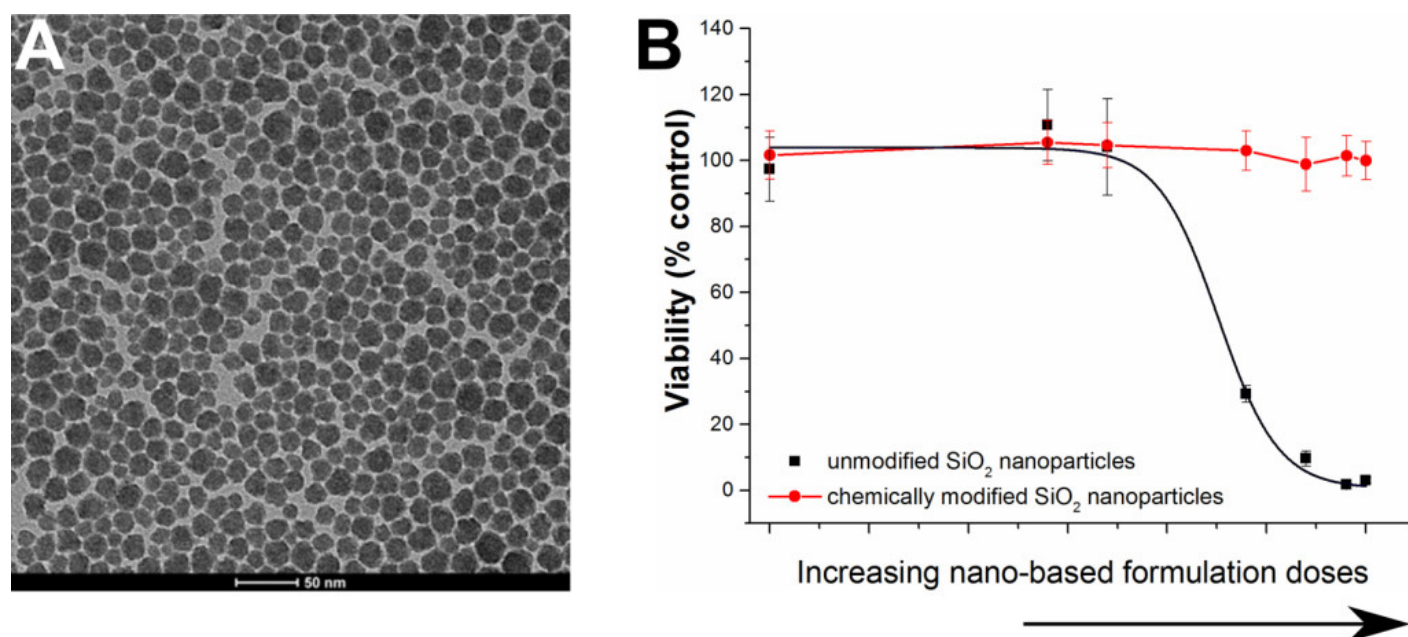


Fig. 2. (A) Representative TEM image of nanostructured SiO_2 consolidants; (B) toxicity of SiO_2 nanoparticle-containing consolidants.

In this research, three different commercially available nanotechnology-based formulations were selected, taking into account different chemical compositions: unmodified silica, chemically modified silica, and nanolime. The three formulations were characterized following standardized approaches for determining shape and measuring particle size distribution and surface charge. Toxicity evaluation on *in vitro* cell models of potential exposure routes and internal target organs (i.e. lungs, skin, and kidney) showed that chemically modified SiO_2 nanoparticles did not induce any toxic effect. On the contrary, bare and unmodified SiO_2 nanoparticles showed toxic effects at working concentrations on all *in vitro* models used (Fig. 2). Since microbial activity is involved in works of art degradation, we compared antibacterial efficacy of these formulations on bacteria

usually present on paintings and monuments. At working concentrations, both types of nanoparticles inhibit bacterial growth. Unmodified SiO₂ nanoparticles act specifically against Gram-positive bacteria (e.g. *Staphylococcus aureus*), while chemically modified SiO₂ nanoparticles act on Gram-negative bacteria such as *Escherichia coli*.

This study highlighted that formulation containing chemically modified SiO₂ nanoparticles is the most promising nano-based material for consolidation, in terms of efficacy and safety. Small changes in nanoparticle features, like surface chemical modification, deeply affect biological behavior of nanotechnology. This underlines the importance of tailoring nanomaterial physico-chemical properties with the aim to preserve functionality reducing risks, in fully agreement with Safe-by-Design approach.

Christian Micheletti, Federico Benetti

ECSIN-European Center for the Sustainable Impact of Nanotechnology, Rovigo, Italy

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[Cytotoxicity and antibacterial activity of a new generation of nanoparticle-based consolidants for restoration and contribution to the safe-by-design implementation.](#)

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