



Sistemi e Tecnologie Industriali Intelligenti
per il Manifatturiero Avanzato
Consiglio Nazionale delle Ricerche

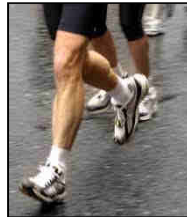
Finissaggi tessili antibatterici

Alessio Varesano, Claudia Vineis
CNR-STIIMA, Biella

Antibiotic resistance is one of the most critical health issues to human health in the world. The emergence has stimulated intensive research in many fields, including the development of antibacterial fabrics and novel broad-range biocides for textiles.

Antimicrobial finishes are used in many textile products, such as:

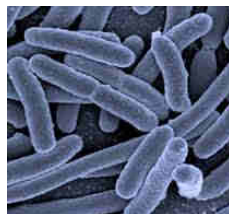
- **Sportswear** and **outdoor apparels**
- **Undergarments**
- **Shoes**
- **Furnishings** and **upholstery**
- **Hospital linens**
- **Wound care wraps**
- **Towels** and **wipes**.



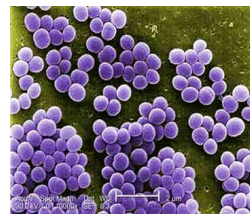
Other applications are for **antibacterial filter** applications (biotechnology processes, water purification, clean rooms, operating theatres, high volume air-conditioning systems, ...).

Antibacterial test in STIIMA Biella biological lab

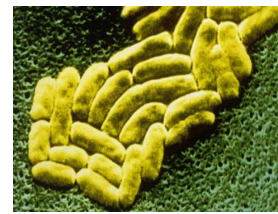
- Standard test method for determining the antimicrobial activity of antimicrobial agents under dynamic contact conditions (ASTM E 2149-2013);
- Antibacterial finishes on textile materials: assessment of (AATCC 100-2012);
- Determination of antibacterial activity – Agar diffusion plate test (EN ISO 20645).



Escherichia coli
(Gram-negative)



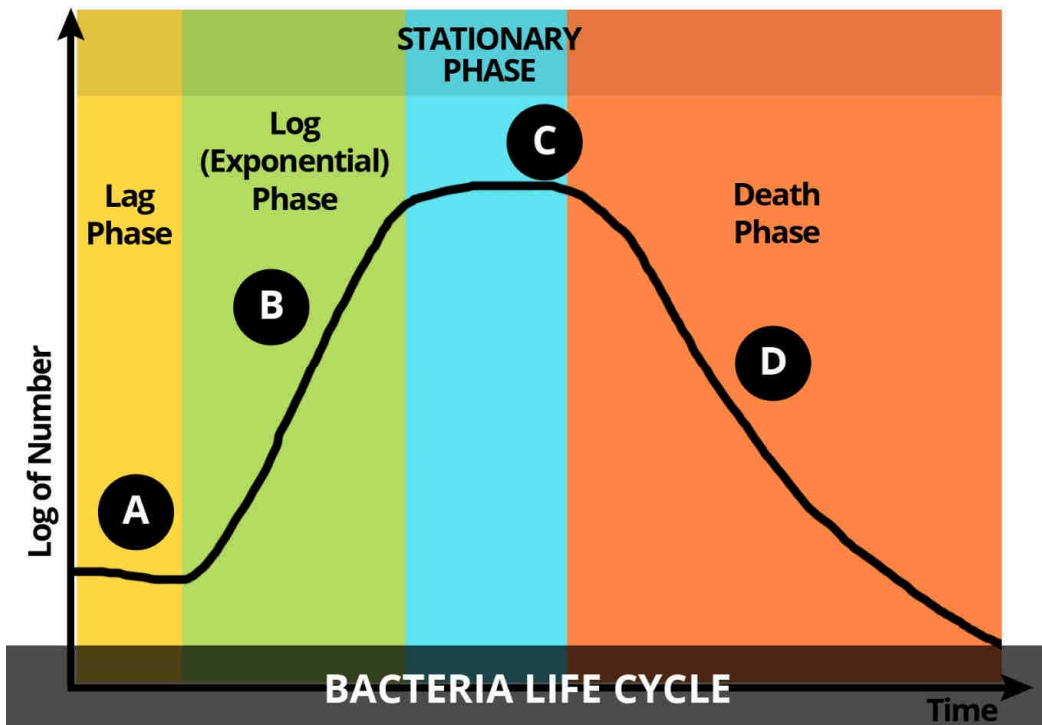
Staphylococcus aureus
(Gram-positive)



Klebsiella pneumoniae
(Gram-negative)

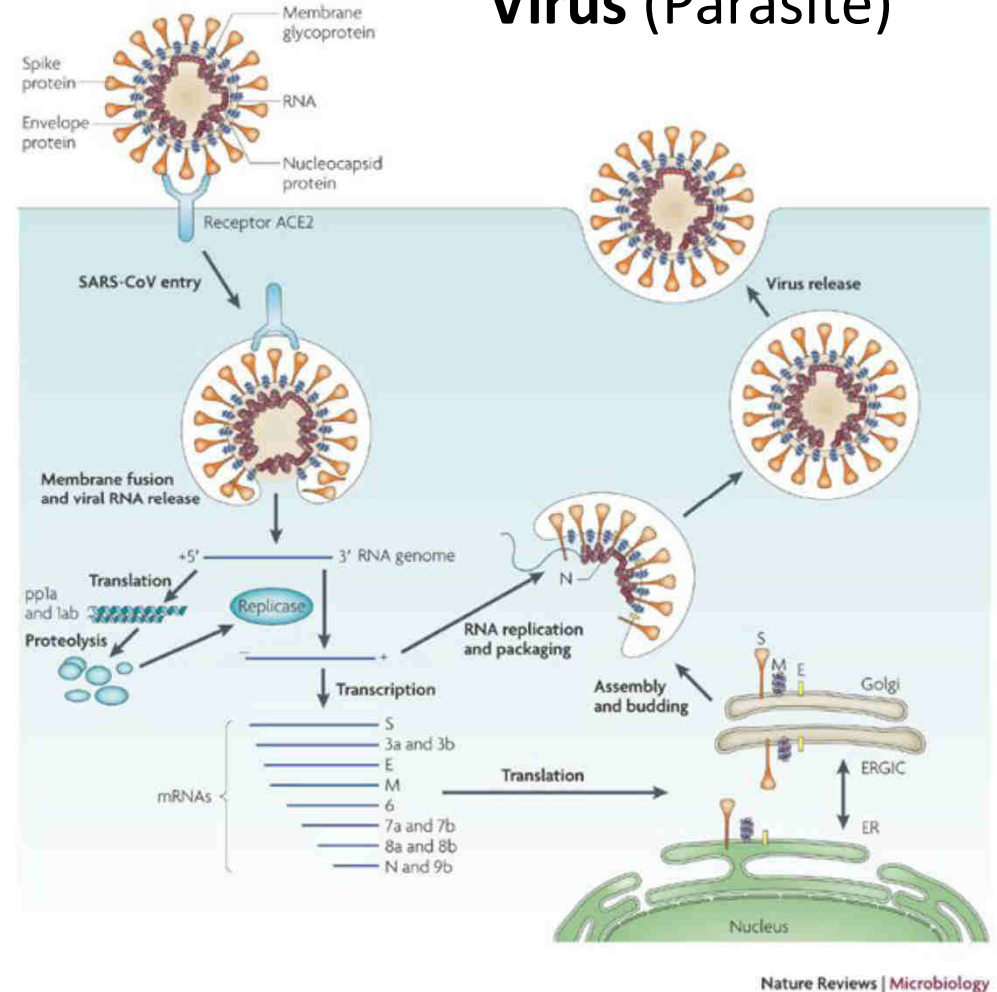
Bacteria

Bacteria are living micro-organisms forming a biomass which exceeds that of all plants and animals on Earth.

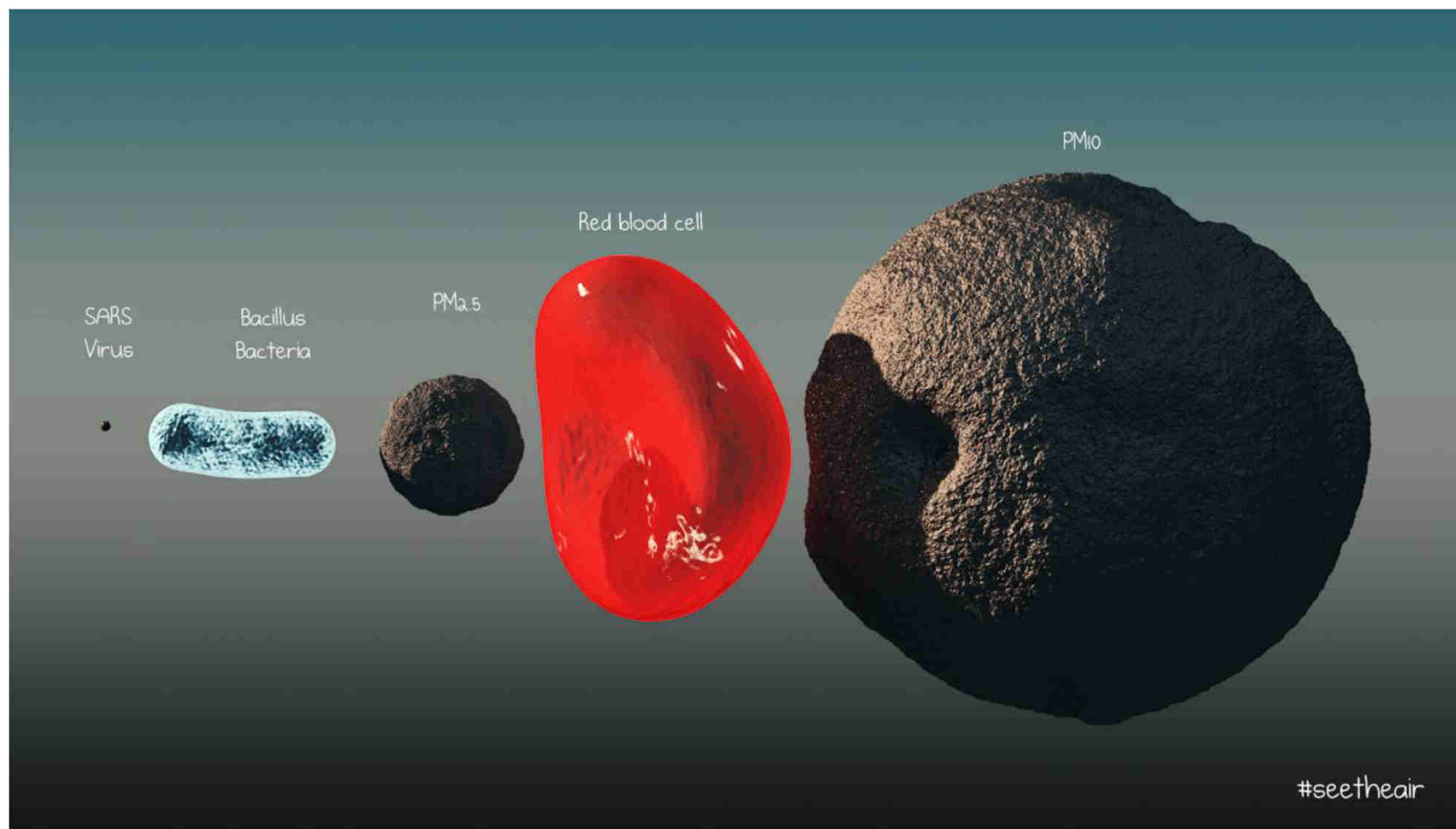


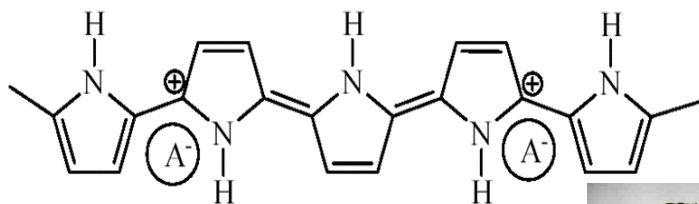
Alessio Varesano - STIIMA Biella

Virus (Parasite)

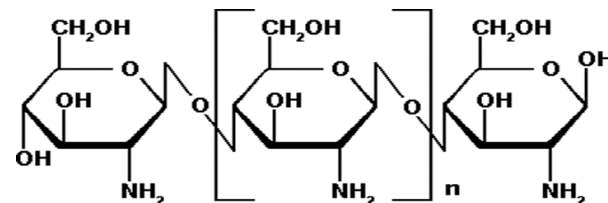


Size comparison

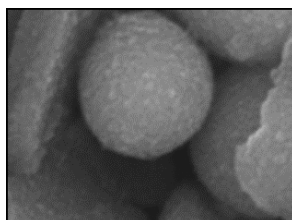
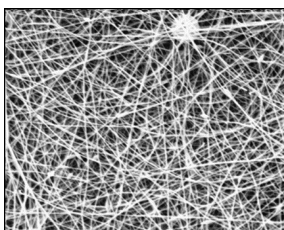




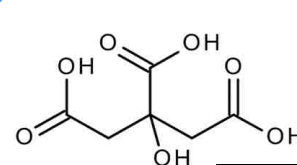
In situ deposition on textile materials of **polypyrrole**



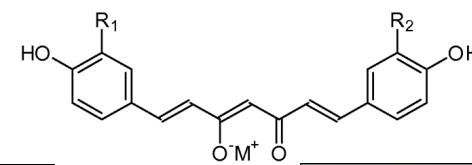
UV-cured **chitosan** filters for water depuration and antimicrobial textiles



Electrospun **keratin nanofibres** for biomedical devices and with **TiO₂** and **Ag** for military safety against NBC



Citric acid

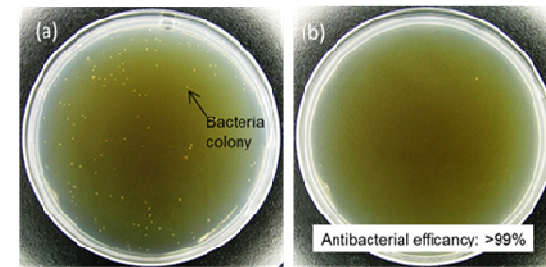


Curcumin



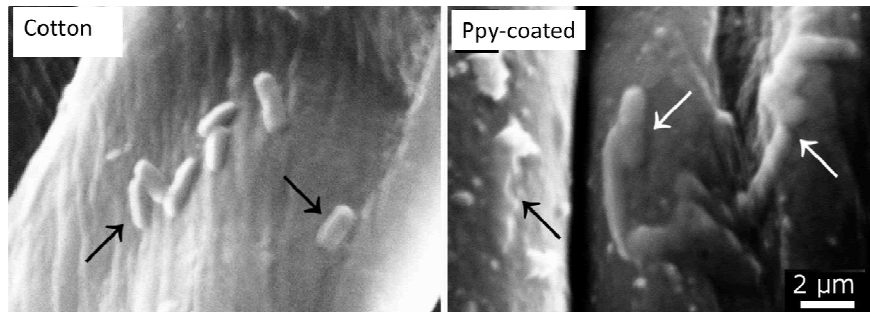
Chemically bound **natural biocides** on surfaces

Sample (amount of PPy)	Bacterial Reduction % (<i>S. aureus</i>)
Untreated fabric (0 % wt.)	16
PPy-coated fabric (2 % wt. PPy)	18
PPy-coated fabric (3 % wt. PPy)	95
PPy-coated fabric (9 % wt. PPy)	100
PPy-coated fabric (25 % wt. PPy)	100



Colony counting: a) untreated cotton; b) PPy coated samples

Bacteria reduction is 100% also against *Escherichia coli* and *Klebsiella pneumoniae* (at 9 % wt. of PPy)



Bacteria on untreated cotton fibres had typical and regular bacterial shapes indicating that the *E. coli* survived on the fibre surface.

On the contrary, the shape of *E. coli* cells was altered on PPy-coated fibres.

In particular, bacteria appeared flattened probably due to the leakage of intracellular components from bacterial cells.

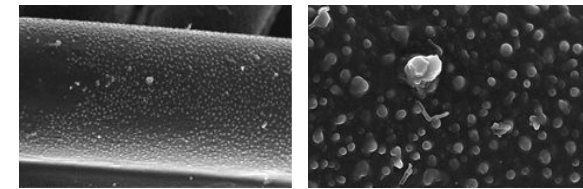
Useful also against NBC (Nuclear Biological Chemical) agents, because bacteria reduction is 100% against *Bacillus subtilis* (simulating *Bacillus anthracis*)



“Pre-commercial lines for production of surface nanostructured antimicrobial and anti-biofilm textiles, medical devices and water treatment membranes” (Grant no. 720851, start: 01/01/2017)



STIIMA Biella activities: production of water nanoparticles dispersions of antibacterial polypyrrole suitable for textile finishing by continuous coating processes (spraying and ultrasound)



PPy nanoparticles were deposited on polyester fabrics by an ultrasound-assisted deposition process

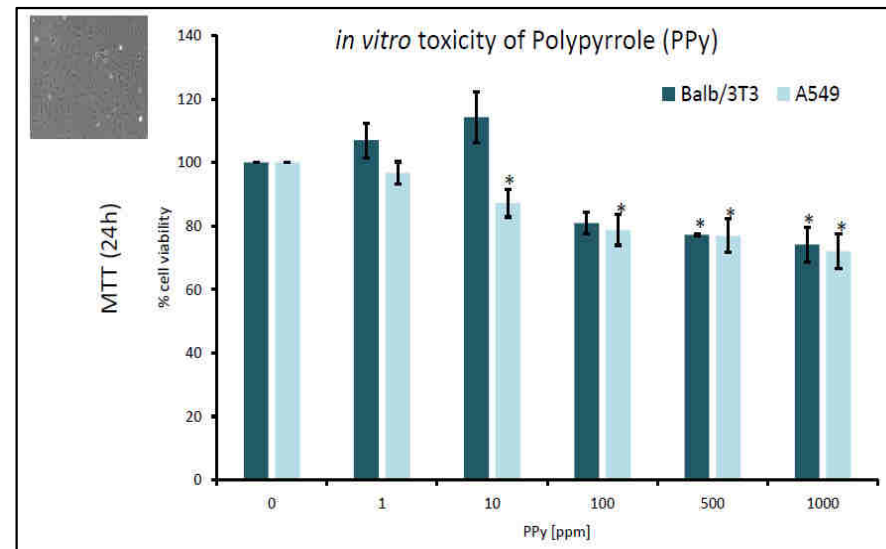
PPy amount evaluated by colorimetric analysis and antibacteria reductions of treated fabrics.

Samples	PPy (g/m ²) ^a	Bacteria reduction			
		<i>S. aureus</i>		<i>E. coli</i>	
		log	%	log	%
Uncoated	-	0.10	20.6	0.10	20.6
3146	0.62±0.15	1.65	97.8	0.10	20.6
3147	1.42±0.27	1.25	94.4	0.30	49.9
3148	2.61±0.18	1.80	98.4	0.95	88.8
3149	4.33±0.13	7.00	99.99999	7.35	99.999996

^a Datascolor

Excellent bacteria reduction

Antibacterial tests showed better biocidal activities for fabrics treated with great amount of polypyrrole

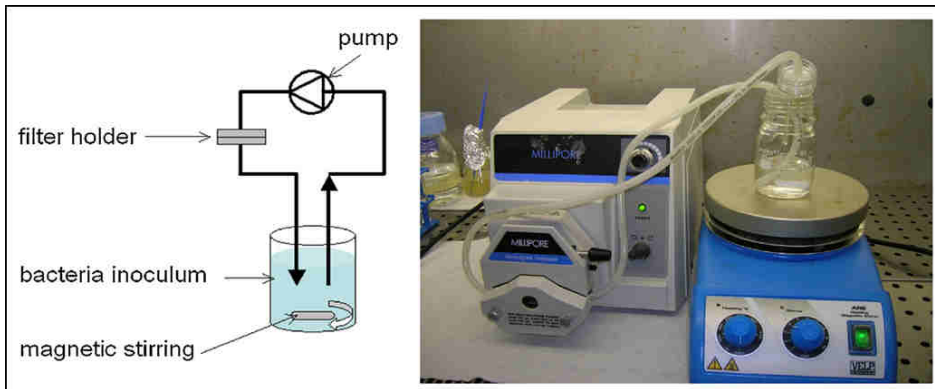


- Polypyrrole is:
- **non-cytotoxic**
 - **non-corrosive for skin**
 - **non-irritant**

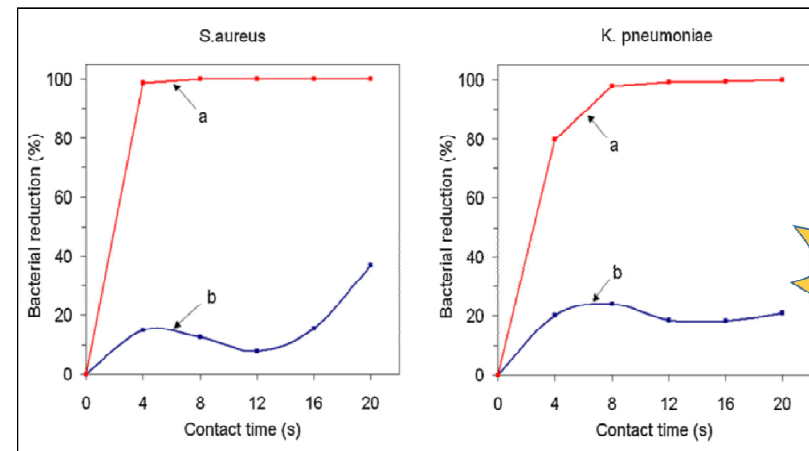
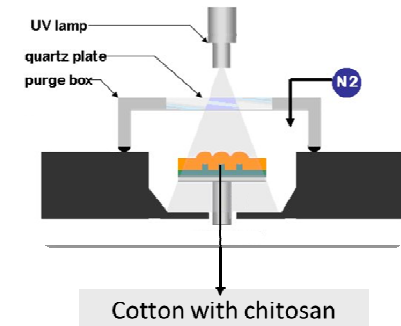
Fast and cheap water decontamination filtration process to eliminate microorganisms

In collaboration with
Politecnico di Torino

Cotton gauzes were coated with **chitosan** using an UV-curing process and compared with **cationized** samples by introduction of quaternary ammonium groups.



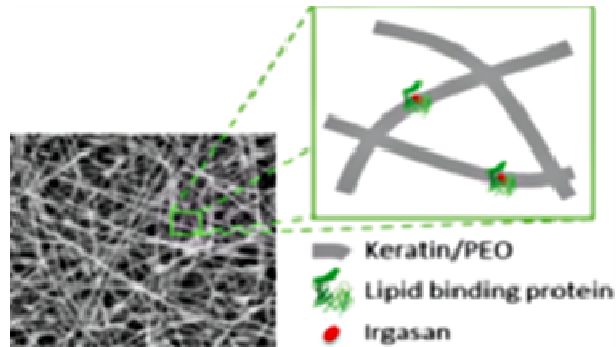
Treated gauzes were **tested in static and dynamic conditions**, as water filter for biological disinfection against both Gram-negative and Gram-positive bacteria.



a) Chitosan coated
b) Cationized

Fast biocidal
action of
chitosan!

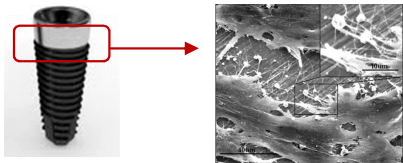
Best results were related to *S. aureus*, where 99% of reduction was obtained at the first sampling, corresponding to a contact time of 4 s. At the same contact time, 80% reduction was obtained against *K. pneumoniae*, nevertheless 98% bacterial reduction was reached after 8 s of contact, already an interesting time.



Sample	Contact time [h]	<i>E. coli</i> reduction [%]	<i>S. aureus</i> reduction [%]	
Keratin + BABP	24	0	0	No biocidal action
Keratin + BABP-IRG (7%)	1	<20	<20	Slow release of IRG through the nanofibers
Keratin + BABP-IRG (7%)	24	85	97	

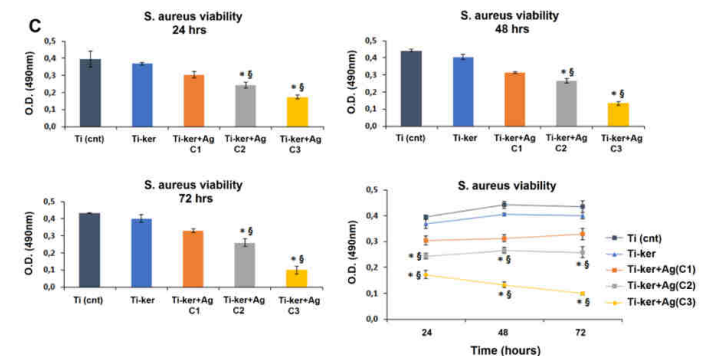
Nanofibers with a host/guest complex in the keratin/PEO matrix were prepared. The host was a lipid binding protein and the guest was an insoluble bactericidal molecule, **irgasan**, bound within the protein internal cavity. The obtained nanofibers exhibit excellent antibacterial activity toward Gram positive and negative bacteria, even with a moderate protein/irgasan cargo.

Peri-implantitis is still a serious clinical scenario, in which the success of implants, and tissue healing, are severely limited by inflammation caused by bacterial infection. To address this difficulty an innovative surface modification technology has been proposed.



Cells growth onto keratin nanofibers without damaging them

Deposition of **keratin nanofibers on titanium surfaces** by electrospinning, and their enrichment with silver by means of immersion in **silver nitrate** solutions. The modified surfaces were found to counteract bacterial contamination (in a dose-dependent manner), maintaining biocompatibility and the ability to support and improve fibroblast adhesion and proliferation.





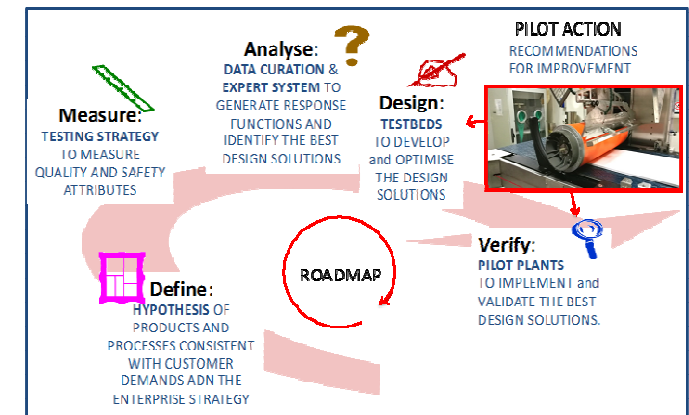
Anticipating Safety Issues at the Design Stage of NANO Product Development

Call: H2020 NMBP-15-2019: Safe by design, from science to regulation: metrics and main sectors (RIA)

CNR Coordinator – Expected starting date: 01/02/2020

	Material	Products	Incorporation process
VC1	Inorganic NPs (TiO ₂ , ZnO, Ag, CuO, SiO ₂), polymeric antimicrobial agents, dispersing matrices, capping or cross-linking additives	Air purifier Antibiotic resistant part Antimicrobial textile	ROLL TO ROLL SPRAY COATING DIP-COATING / DIP-PADDING INKJET PRINTING
		Designer	Manufacturer
VC2	Synthetic and natural polymers based NCs, nano-SiO ₂ based microcapsules, active phases, dispersing additives and matrices	Anti-aging cream Antimicrobial solution Antimicrobial textile	MIXER REACTOR SPRAY-FREEZE DRIER
		Designer	Manufacturer

*Process designer

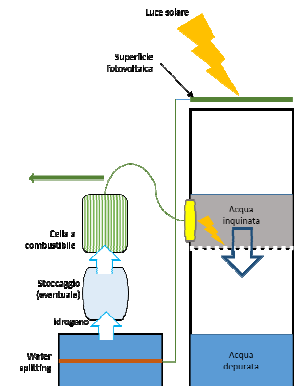


Sistema per la decontaminazione e lo Sviluppo di energia dall'ACQUA (SOS-ACQUA)

Call: Piano Nazionale della Ricerca Militare (PNRM) 2018

CNR Coordinator (Partner: Policlinico Militare di Roma)

Low-cost nanotechnology solutions for **water purification** and **clean energy generation** (hydrogen) to develop a field mobile system.



- D.O. Sanchez Ramirez, A. Varesano, R.A. Carletto, C. Vineis, I. Perelshtein, M. Natan, N. Perkas, E. Banin, and A. Gedanken, “Antibacterial properties of polypyrrole-treated fabrics by ultrasound deposition”, **Materials Science & Engineering C**, vol. 102, pp. 164–170, 2019.
- F. Truffa Giachet, M. Periolatto, D.O. Sanchez Ramirez, R.A. Carletto, A. Varesano, C. Vineis and R. Bongiovanni, “Stability of UV-cured chitosan coating on cotton gauze for water filtration”, **Journal of Industrial Textiles**, 48 (8), 1384-1396, 2019.
- M. Periolatto, F. Ferrero, C. Vineis, A. Varesano and G. Gozzelino, “Novel Antimicrobial Agents and Processes for Textile Applications”, In: Ashok Kumar (Ed.), “Antibacterial Agents”. **INTECH**, Croatia, Cap. 2, pp. 18-37, May 2017.
- A. Cochis, S. Ferraris, R. Sorrentino, B. Azzimonti, C. Novara, F. Geobaldo, F. Truffa Giachet, C. Vineis, A. Varesano, A.S. Abdelgeliel, S. Spriano and L. Rimondini, “Silver-doped keratin nanofibers preserve a titanium surface from biofilm contamination and favor soft-tissue healing”, **Journal of Materials Chemistry B**, vol. 5, pp. 8366-8377, 2017.
- S. Tomaselli, D.O. Sanchez Ramirez, R.A. Carletto, A. Varesano, C. Vineis, S. Zanzoni, H. Molinari, L. Ragona, “Electrospun lipid binding proteins composite nanofibers with antibacterial properties”, **Macromolecular Bioscience**, vol. 17, art. 1600300, 2017.
- S. Ferraris, F. Truffa Giachet, M. Miola, E. Bertone, A. Varesano, C. Vineis, A. Cochis, R. Sorrentino, L. Rimondini, S. Spriano, “Nanogrooves and keratin nanofibers on titanium surfaces aimed at driving gingival fibroblasts alignment and proliferation without increasing bacterial adhesion”, **Materials Science & Engineering C**, vol. 76, pp. 1-12, 2017.
- A. Varesano, C. Vineis, C. Tonetti, G. Mazzuchetti, V. Bobba, “Antibacterial property on Gram-positive bacteria of polypyrrole-coated fabrics”, **Journal of Applied Polymer Science**, 132(12) 41670, 2015.
- Periolatto, F. Ferrero, C. Vineis, A. Varesano, “Antibacterial Water Filtration by Cationized or Chitosan Coated Cotton Gauze”, **Chemical Engineering Transactions**, AIDIC, Vol. 38, 2014.
- A. Varesano, C. Vineis, C. Tonetti, D.O. Sánchez Ramírez, G. Mazzuchetti, S. Ortelli, M. Blosi, A.L. Costa, “Multifunctional hybrid nanocomposite nanofibers produced by colloid electrospinning from water solutions” , **Current Nanoscience**, vol. 11(1), pp. 41-48, 2015.
- F. Ferrero, M. Periolatto, C. Vineis, A. Varesano, “Chitosan coated cotton gauze for antibacterial water filtration”, **Carbohydrate Polymers**, vol. 103, pp. 207–212, 2014.
- A. Varesano, C. Vineis, A. Aluigi, F. Rombaldoni, C. Tonetti, G. Mazzuchetti, “Antibacterial efficacy of polypyrrole in textile applications”, **Fibers and Polymers**, 14, 1, 36-42, 2013.
- **Patent** n. 102015000070808 del 10/11/2015. S. Ferraris, S. Spriano (POLITO), A. Varesano, C. Vineis (ISMAC), V. Guarino, L. Ambrosio (IPCB), L. Rimondini, A. Cochis (UNIPO).



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Thank you

Alessio Varesano (alessio.varesano@stiima.cnr.it)

Claudia Vineis (claudia.vineis@stiima.cnr.it)

CNR-STIIMA, Corso Giuseppe Pella 16, 13900 Biella