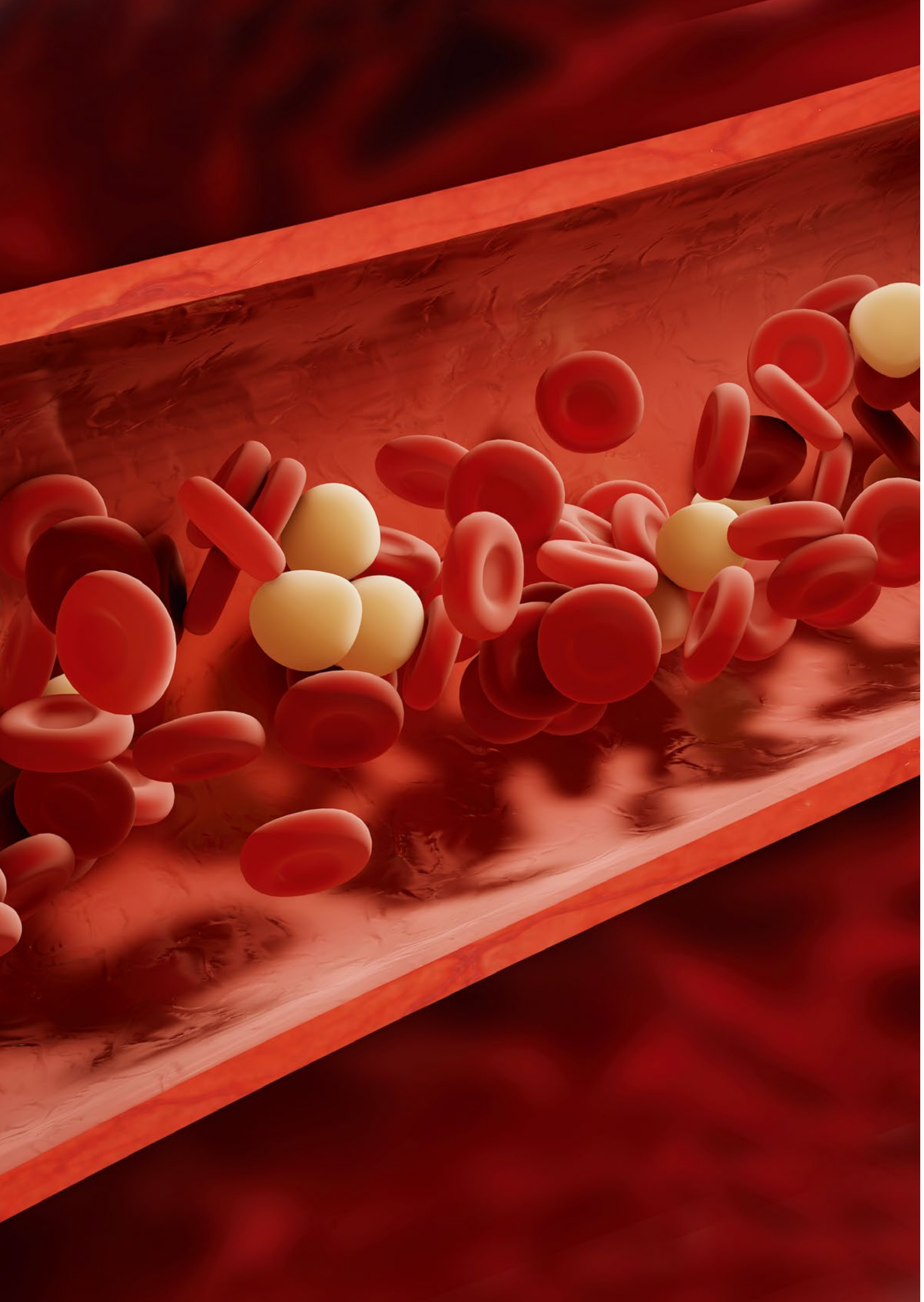

Modelling and characterisation of microcapsules

Dr Salsac's research focuses on the dynamics and mechanical behaviour of microcapsules and their subsequent interactions under the presence of an external flow when placed in suspension. This is an exciting field with potent applications to biofluids and vascular mechanics (e.g., flow of red blood cells in the microcirculation), and to the encapsulation of active substances (e.g., pharmaceuticals, cosmetics). The ability to model and characterise artificial microcapsules could hold the key to optimising drug delivery to specific cells or tissues.

Microencapsulation is the process of enclosing a core substance within a micrometric-sized particle. Microcapsules are liquid droplets protected by a thin, deformable membrane with elastic properties whose size can vary from a few micrometres to millimetres for the largest ones. The reticulated membrane governs the deformation of the capsule when it is placed in suspensions, and controls the exchanges between the internal and external fluids.

THE IMPORTANCE OF MICROCAPSULES

Micro-encapsulation is a prominent means of protecting a liquid internal medium and allowing its subsequent controlled release if desired – through adaptation of the membrane's mechanical properties and porosity. Even though this is a well-known technique – in fact, the first microencapsulation procedure was published back in 1931 – recent technological developments have allowed microencapsulation to become a very significant part of scientific research with a number of industrial applications.

CHALLENGES FOR AN OPTIMISED USE OF MICROCAPSULES

Undoubtedly, the most challenging aspects of generating efficient microcapsules is to ensure their stability, and control their deformation in external fluid environments. This requires controlling the deformability of the capsules as well as their dynamics when in suspension.

Owing to the strong fluid–structure interactions with the confined fluid flows, the capsules can be deformed in a complex way under the formidable hydrodynamic stresses. In order to deeply understand their dynamics, there is a need to generate numerical models that predict the behaviour of capsules under hydrodynamic stress,

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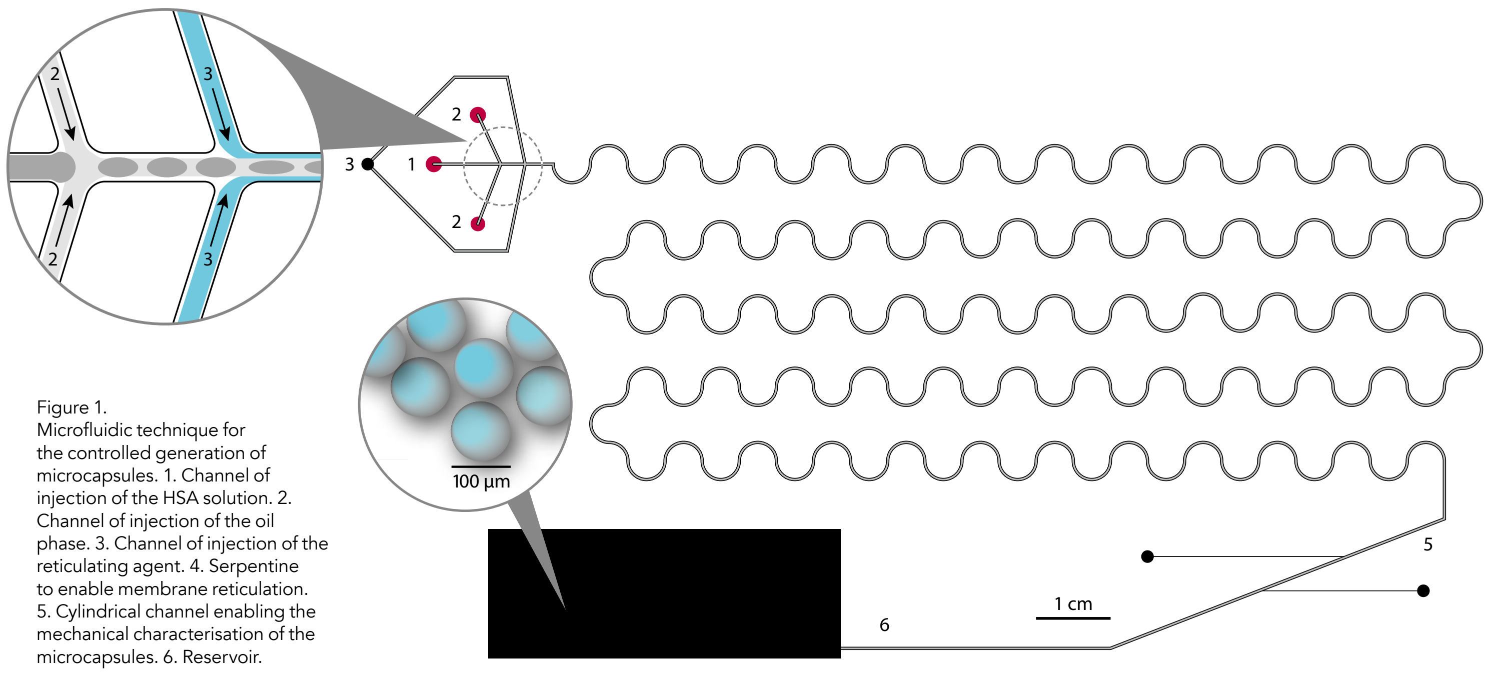


Figure 1.
Microfluidic technique for the controlled generation of microcapsules. 1. Channel of injection of the HSA solution. 2. Channel of injection of the oil phase. 3. Channel of injection of the reticulating agent. 4. Serpentine to enable membrane reticulation. 5. Cylindrical channel enabling the mechanical characterisation of the microcapsules. 6. Reservoir.

and to conduct microfluidic experime
capsule suspensions flowing in micro

The other challenge is to design tech
to characterise the mechanical prope
of entire capsule populations and ens
that they have the desired behaviour
each application. Micropipette aspira
or indentation by atomic force micros
have the drawback of necessitating m
manipulations on individual particles,
is cumbersome.

The development of microfluidics has
to new techniques of characterisation
be devised: the membrane resistance
is determined from the flow of capsule suspensions in microchannels, provided one can numerically model the capsule deformation under the exact same flow conditions as those prevailing in the microsystem.

This concept of combining highly complex numerical modelling with microfluidic experiments is exactly what Dr Anne-Virginie Salsac's work in the Biomechanics & Bioengineering Laboratory of Université de Technologie de Compiègne intends to achieve. This will, in turn, allow for the design and fabrication of microcapsules, specifically customised to satisfy the demands of each industrial application.

Figure 2.
Spherical capsule flowing in a cylindrical or square-section tube at equal flow rates.

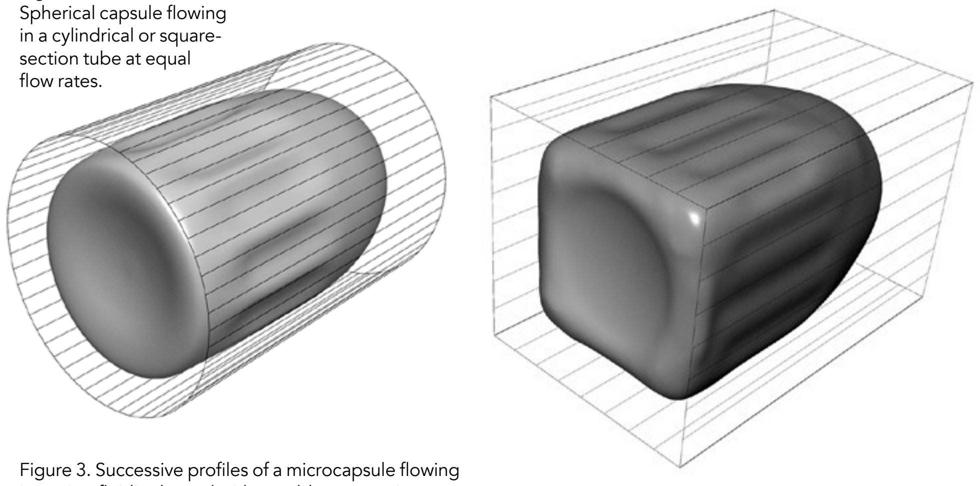
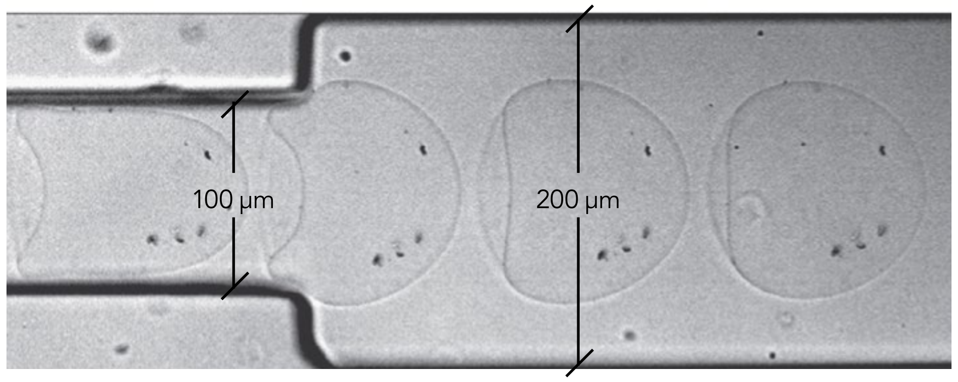


Figure 3. Successive profiles of a microcapsule flowing in a microfluidic channel with a sudden expansion



MICROCAPSULE FABRICATION USING MICROFLUIDICS

With the possibility of using photolithography to create microfluidic systems with an infinite number of designs, new techniques of microcapsule production have been designed. Dr Salsac's group has developed a microfluidic technique (Figure 1) that allows for the fabrication of finely calibrated microcapsules, both in terms of size and mechanical properties.

It relies on a flow-focusing system to first generate droplets, around which a membrane is then produced by cross-linking. Cross-linking refers to the formation of bonds between molecules that can be polymers, proteins, etc. The degree of membrane reticulation is defined by the mean velocity of the suspending fluid, and by the length of the serpentine channel, in which the drops circulate and react under the effect of the reticulating agent injected through the second flow-focusing system.

MODELLING OF MICROCAPSULES' MOTION IN HYDRODYNAMIC FLOW

To study the motion of microcapsules in confined or infinite flow conditions, Dr Salsac and her group develop numerical models that have the capacity to predict the deformation of microcapsules according to their intrinsic physical properties and provide measurements of non-measurable quantities, such as the stress level in the membrane, to evaluate the risk of rupture.

The team has developed and implemented second-order finite element-boundary integral (FE-BI) methods that allow for the modelling of initially spherical or anisotropic capsules, and of their flow in infinite or confined environments such as the microfluidic pores shown in Figure 2. Using shell elements, they have, for the first time, modelled the effects of the finite thickness of the capsule wall and compared the results to ones predicted by the zero-thickness membrane models.

Dr Salsac's pioneering research in the characterisation of microcapsules has the capacity to provide the scientific community with a greater insight on a field that has many industrial applications

CHARACTERISATION OF MICROCAPSULES

Dr Salsac's group have developed an innovative method for characterising the deformability of a population of microcapsules, as opposed to existing techniques that can only characterise individual ones. This microfluidic method allows cross-linked microcapsules to flow into a cylindrical microchannel, where deformation takes place. Consequently, and by means of a fast camera mounted on a microscope, both the deformation and the speed of the microcapsule can be measured. The deformed shape is then compared to developed models, predicting deformations under the same flow conditions.

Similarly, the group has developed other microfluidic-based techniques of characterisation. Using a microchannel which includes a sudden expansion from a rectangular to a square cross-section, they have, for instance, measured the viscoelastic properties of protein-reticulated microcapsules (Figure 3). The viscoelasticity is determined from the characteristic time of relaxation of the capsule after the expansion.

In the Biomechanics & Bioengineering Laboratory of Université de Technologie de Compiègne, Dr Salsac's team is currently performing pioneering research on the characterisation and modelling of microcapsules. Looking to the future, Dr Salsac's investigations have the capacity to provide the scientific community with a greater insight into a field that has many industrial applications.

Q&A

Why did you first become interested in this area of research?

Being specialised in biofluids applied to vascular mechanics, I am interested in the understanding of the blood flows from microcirculation to the haemodynamics in large blood vessels. Microcapsules, which are models of natural cells, provide an insight into the behaviour of red blood cells and open the way to the study of blood microcirculation.

What applications are there for microcapsules in general?

Over the last decades, small-scale encapsulation has become ubiquitous. Besides its classical use in cosmetics and personal care products, it is at the source of innovative applications, many of them appearing in the fields of biotechnologies (encapsulation of drugs for drug therapy or cells for artificial organ generation), food industry (encapsulation of aromas, nutrients, or active substances to produce neutraceuticals), agriculture (encapsulation of fertilisers) or energy storage (encapsulation of phase-change substances for new insulation technologies).

Can you give an example of how the knowledge gained from your research could be applied?

The beauty is that the research combines very fundamental aspects (advanced numerical models of the complex fluid-structure interactions of micro-objects) and very practical applications: for instance, it enables prediction of the behaviour of microcapsules upon injection, and determination of their mechanical properties using in batch technologies.

International collaborations constitute a real strength and a source of mutual enrichment

You are the Visiting Professor at Queen Mary University, London and completed your PhD in the US. How important is international collaboration to your work?

International collaborations are particularly crucial to our community, as it consists of a limited number of groups working worldwide on the numerical and experimental modelling of microcapsules. They constitute a real strength and a source of mutual enrichment.

What are the next steps for this research?

The next step is to further study the processes of release of the encapsulated medium and its interactions with the capsule flow and deformation.

Detail

RESEARCH OBJECTIVES

Dr Salsac's research focuses on the dynamics and mechanical behaviour of microcapsules and their interactions with an external flow when placed in suspension. Her latest research has looked at modelling and characterising microcapsules under hydrodynamic stresses.

FUNDING

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- Marc Leonetti, Julien Deschamps, Marc Georgelin (Aix Marseille Université, France)
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BIO

After graduating from UC San Diego in 2005 with a PhD in Biofluids, Anne-Virginie Salsac spent two years at University College London as a Lecturer. She was recruited by the CNRS in 2007 and joined the Biomechanics and Bioengineering Laboratory at UTC (France). In 2014, she was nominated Visiting Professor at Queen Mary University of London.

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