JSPS-Royal Society Funded Bilateral Project: Green syntheses of nanoparticles for optical biomedical applications

The grant aimed to develop a collaboration with Dr Tanaka's group in Tokyo (Tokyo Institute of Technology) to develop the green synthesis of nanoparticles for optical applications biology and medicine. The applications would include developing various nanoparticle-based sensors. My group has expertise in nanoparticle characterisation and their applications. The Tanaka group has expertise in peptides and other biomolecules. Peptides can be used to control the synthesis of nanoparticles to control morphology and size in mild conditions, i.e. aqueous environment without heating or strong reducing agents. Controlling nanoparticle size and shape determines the optical properties of nanoparticle. For example, for gold nanoparticles, increasing the aspect ratio shifts the surface resonance plasmon to the near-infrared, which subsequently can be used for bio-imaging (e.g. photoacoustics). Or, in the case of semiconductor materials, constricting the size to a few nanometres creates quantum confinement which enables the fluorescent emission to be tuned to narrow wavelength ranges which could be used for imaging or sensing. Given, my groups interest in these two examples, we took looked at these two systems separately. Firstly, to control gold to produce NIR absorbance, and secondly for to produce peptide binders for QDs with targeting.
Through multiple visits between our laboratories, we establish key findings from the relatively short study. In the first project, we studied peptide binders to CdTe/CdS Quantum dots (QDs). For biological applications, the QD surface needs to be conjugated to biological molecules. We screened for CdTe/CdS QD-binding peptides from a phage display library as linkers for simple and bio-friendly QD modification. Among five QD-binding peptide candidates, a series of truncated peptides designed from two high-affinity peptides were subjected to an array-based binding assay with QDs to assess their functional core sequences and characteristics. Linking these isolated, shortened peptides with an antibody-binding peptide created dual-functional peptides that are capable of QD surface functionalisation by antibodies. Consequently, the dual-functional peptides could mediate anti-CD9 antibody functionalisation onto CdTe/CdS QD surface; CD9 protein imaging of cancer cells was demonstrated. Second, a peptide-based three-dimensional probe called "peptide matrix" inspired by the antibody paratope region, was fabricated on a surface plasmon resonance (SPR) sensor chip to enhance the sensitivity of detecting the explosive 2,4,6-trinitrotoluene (TNT). We developed the concept of the peptide matrix structure. This robust three-dimensional structure displays multiple binding sites which can efficiently associate with each TNT molecule. The peptide matrix had a dissociation constant (KD) of 10.1 nM. In the third project, we performed biomineralisation using peptides for one-pot synthesis of gold nanoparticles with selected optical properties. As the biomineralised AuNPs were captured on each peptide spot, analysis of the images provided information on their collective optical properties. Different peptides tuned the optical properties by modulating the size and shape of the AuNPs. In the fourth project, we extended the work from the TNT sensing to create a QD optical TNT sensor. While the sensitivity was much lower, it provided a much simpler detection mechanism which would be more applicable to on fieldwork.

In summary, the exchange was very productive with four joint papers being published already and more to follow. The students (and academics) all benefited scientifically and culturally. We hope to find other funds to continue our collaboration. – Dr Kevin Critchley.