Gold Nanoparticles Optimize the Specificity of DNA Binding

The polymerase chain reaction (PCR) has revolutionized biology since its invention in the 1980s. Commonly used for DNA amplification, it is also employed in DNA detection in optoelectronic DNA biosensors. However, PCR specificity is still unsatisfactory. In a study reported in the August 12 issue of *Angewandte Chemie International Edition* (p. 4989; DOI: 10.1002/anie. 200590108), H. Li of Shanghai Jiao Tong University, J. Lv of the Chinese Academy of Sciences, and their colleagues have used gold nanoparticles to avoid nonspecific PCR reactions and enhance the binding of single-stranded DNA while preventing the binding of double-stranded DNA. Gold nanoparticles were studied due to their wide use in the field of biomaterials because of their nontoxic, biocompatible properties, and their ability to undergo surface functionalization. Gold nanoparticles also have unique optoelectronic properties.

According to J. Hu of Shanghai Jiao Tong University, he and his co-workers tested 10 nm gold nanoparticles free of additives in concentrations of 0.2–1.0 nM. The researchers used colloidal gold nanoparticles synthesized with a citrate stabilization process. They performed PCR with a 283 base-pair target sequence from a λ-DNA template, and the products were examined using agarose gel electrophoresis. The researchers found that nonspecific binding of DNA was enhanced at concentrations of 0.2–0.8 nM, but was inhibited at concentrations of 1.0 nM. This high speci-

Carbon Nanotubes Used for Cancer Cell Destruction and Drug Delivery

Biological cells are transparent to near-infrared light (NIR) in the wavelength range of 700–1100 nm. However, single-walled carbon nanotubes (SWNTs) show strong optical absorption in this spectral window. Furthermore, SWNTs have been used to safely deliver cargos across cellular membranes without cytotoxicity. Tying these facts together, Nadine Wong Shi Kam, Hongjie Dai, and co-workers at Stanford University have shown how SWNTs can be used to deliver molecular cargos as well as selectively destroy cancer cells inside living cells by optically stimulating them. The optical stimulation can be used to release the cargos, which can then destroy cancer cells, or to kill the cancer cells by heat transfer from bare optically-stimulated SWNTs. They report their results in the August 16 issue of the *Proceedings of the National Academy of Sciences* (p. 11600; DOI: 10.1073/pnas.0502680102).

SWNTs functionalized with a fluorescent-labeled DNA, functionalized by various phospholipids (PL), and functionalized with one or two PL-polyethylene glycol-folic acid (PL-PEG-FA) molecules acting as cargos were used in the study. HeLa cells (an adherent cell line) were used for the cell cultures and were subjected to incubation treatment in SWNT solutions. An 808-nm diode laser source (beam size ~3 cm and power density up to 3.5 W/cm^2) was used for the optical stimulation in the NIR regime. It was shown that SWNTs internalized within living cells act as tiny NIR "heaters." Short-time excitation triggered endosomal rupture and the release of molecular cargos from within the nanotubes, which then could freely diffuse across the nuclear membrane into the nucleus. The cells themselves were not harmed. Longer-term radiation induced extensive cell death, likely due to localized heating of the SWNTs within the cells.

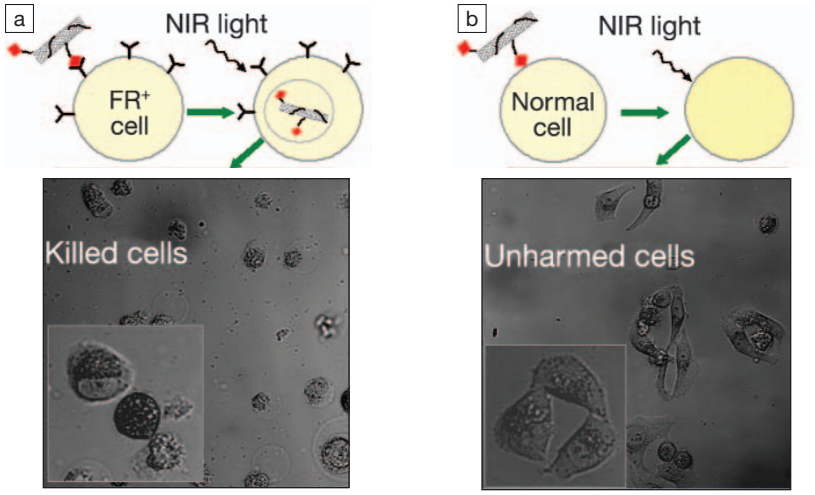

Figure 1. Selective targeting and killing of cancer cells. (a) (top) Schematic illustration of selective internalization of PL–polyethylene glycol–folic acid–single-walled carbon nanotubes (PL-PEG-FA-SWNTs) into folate-overexpressing (FR+) cells via receptor-binding and then near-infrared (NIR) 808 nm laser radiation. (bottom) Image showing death of FR+ cells (10–15 μm) with rounded cell morphology after NIR radiation at 1.4 W/cm^2 for 2 min. Magnification is ×20. (Inset) Higher-magnification image shows details of the killed cells. (b) (top) Schematic illustration showing no internalization of PL-PEG-FA-SWNTs into normal cells without available FRs. (bottom) Image showing that normal cells (10–15 μm) with no internalized SWNTs are unharmed by the same laser radiation condition as in (a). Magnification is ×20. (Inset) Higher-magnification image shows a live normal cell in stretched shape.

Some of the cells were also cultured with folic acid depleted from the solution. This results in an overexpression of folate receptors (FRs) on the cell surfaces (FR+ cells). FRs are common tumor markers that are observed at high levels on the surfaces of various cancer cells. Both the FR+ cells as well as normal cells without abundant FRs were exposed to the PL-PEG-FA-SWNTs (folic-acid–functionalized SWNTs) and then radiated with the 808 nm laser for 2 min at 1.4 W/cm^2. Extensive cell death was observed for the FR+ cells, whereas the normal cells remained intact due to the selective uptake of the SWNTs by FR+ cells (see Figure 1). This suggests that SWNTs can be selectively internalized into cancer cells with specific tumor markers and the NIR radiation can then be used to selectively trigger or activate cell death without harming normal cells, said the researchers.

The researchers also said that the only other nanomaterial used to destroy cells through the absorption of NIR light is the Au nanoshell, which requires more optical power than the SWNTs to cause cell destruction by heating.

The researchers said that their study demonstrates the potential for exploiting the intrinsic optical properties of SWNTs for drug delivery and cancer therapy.

GOPAL RAO

https://doi.org/10.1557/mrs2005.227 Published online by Cambridge University Press

ficity can only be attributed to the presence of gold nanoparticles, according to the researchers, since there was no specificity when only the medium in which the gold particles were suspended was used. Furthermore, the researchers said, the nanoparticles enabled PCR amplification at lower annealing temperatures than current techniques allow without compromising specificity.

The single-stranded DNA binding protein SSB selectively binds to single-stranded DNA, but not to double-stranded DNA. The researchers said that the optimizing effect of gold nanoparticles is greater than that of SSB that is commercially available. Gold nanoparticles bind more strongly to single-stranded DNA than double-stranded DNA because double-stranded DNA has a higher surface charge density, and anionic DNA strands do not bind to the negatively charged surfaces of citrate-stabilized nanoparticles. The researchers also said that adenine, thymine, guanine, and cytosine—the bases of which DNA is composed—contain nitrogen atoms that display high affinities to gold. These bases are more exposed in single-stranded DNA than double-stranded DNA, which means that there is a higher interaction between the gold nanoparticles and the DNA bases, the researchers said. They furthermore reported that the rigidity of the double-stranded DNA prevents the DNA from wrapping around the nanoparticles, but the more bendable single-stranded DNA readily wraps around them. The researchers said that this technique may find application in many other PCRs that require high specificity or high yields.

MARÍA PÍA ROSSI

Cobalt-Adsorbed Polypyrrole Film on Carbon Nanoparticles Shows Promise as Non-Noble-Metal Catalyst

Billions of dollars per year are currently being invested in fuel cell research and development worldwide. Currently, several materials-related issues, such as an alternative to Pt catalysts, must be addressed before fuel cell technology is able to supplant natural resources like oil as primary energy sources. M. Yuasa, A. Yamaguchi, H. Itsuki, K. Tanaka, M. Yamamoto, and K. Oyaizu of the Tokyo University of Science in Japan have investigated carbon nanoparticles with cobalt polypyrrole coatings as non-noble-metal catalysts for fuel cell electrodes. According to their study, reported in the August 23 issue of *Chemistry of Materials* (p. 4278; DOI: 10.1021/cm050958z), the cobalt atoms are coordinated by four nitrogens and the structure is maintained even after heat treatment at 700°C. The researchers have found an increase in catalytic activity after the high-temperature heat treatments.

M. Yuasa and co-workers used fluid-bed electrolysis to deposit polypyrrole (PPy) coatings on high-surface-area carbon black particles (BET surface area, ~800 m^2/g). Carbon black (CB) is a common support used for platinum-based catalysts. The PPy-coated CB particles were then suspended in a solution of cobalt acetate in CH_3OH, which was then refluxed to allow formation of cobalt ions at the respective sites. Current–voltage measurements, extended x-ray absorption fine structure spectroscopy, x-ray diffraction, and x-ray photoelectron spectroscopy were used to measure the catalytic activity and structure of the CoPPy/CB composite.

A significant feature of the CoPPy/CB catalyst synthesized using this procedure is a positive shift in the O_2 reduction potential after annealing in an inert atmosphere up to 700°C without deposition of metallic cobalt. The researchers said that the difference in catalytic activity may be attributed to the mechanism in which the catalyst reduces O_2. Yuasa and co-workers said that the reduction of O_2 by the heat-treated catalyst occurs by a four-electron reduction involving the bridging of O_2 with two adjacent cobalt centers. Conversely, as-synthesized CoPPy/CB catalysts are believed to reduce O_2 by two electrons involving only a single cobalt center. The researchers said carbon nanoparticles with PPy-modified

https://doi.org/10.1557/mrs2005.227 Published online by Cambridge University Press