Gold Nanoparticles and DNA, a Revolutionary Duo for Medicine: Nanoconjugates in the Fight with Cancer and Other Diseases

The nanoconjugates, known as nanobeacons and nano-flares, open up new horizons for rapid and accurate disease diagnosis and targeted therapies.


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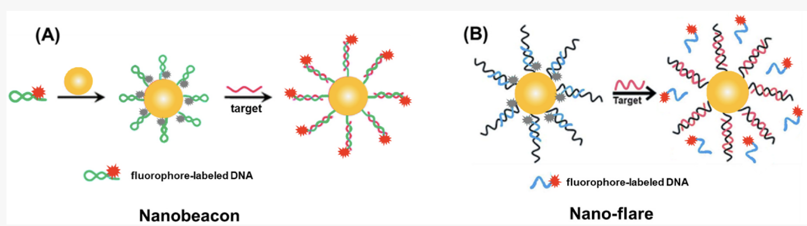

Schematic representation of the most common fluorophore-DNA-AuNPs composite nanomaterials: nanobeacon (A) and nano-flare (B).

CLUJ-NAPOCA, ROMANIA, September 18, 2025 /EINPresswire.com/ -- An innovative study published in the prestigious journal Trends in Analytical Chemistry by a team of Romanian and French researchers—Ana-Maria Crăciun, Simion Aștilean, Monica Focșan, and Marc Lamy de la Chapelle—has highlighted the remarkable potential of gold nanoparticles (AuNPs) conjugated with fluorophore-labeled DNA. This detailed research explores how these nanoconjugates, known as nanobeacons and nano-flares, open up new horizons for rapid and accurate disease diagnosis, as well as for the development of targeted therapies.

For over a decade, scientists have been exploring ways to link nanoparticles to biological entities to obtain nanoconjugates with superior and controlled properties. Gold nanoparticles are particularly attractive due to their chemical stability, ease of synthesis, high biocompatibility, and unique optical characteristics related to the Surface Plasmon Resonance (SPR) phenomenon. Under certain conditions, AuNPs can either amplify the fluorescence signal (Metal-Enhanced Fluorescence - MEF) or effectively quench it through a process called Fluorescence Resonance Energy Transfer (FRET).
An ingenious detection mechanism: From quenching to amplification

The authors describe two main approaches:

Nanobeacons: These systems use a single strand of DNA (ssDNA) with a rod-loop structure, labeled with a fluorophore at one end and linked to an AuNP at the other. In the initial state, the rod-loop structure keeps the fluorophore close to the AuNP, quenching the fluorescence through the FRET mechanism. When the nanoprobe encounters a target DNA or RNA molecule, the loop opens and the distance between the fluorophore and the AuNP increases, restoring the fluorescent emission.

Nano-flares: These consist of an AuNP functionalized with a DNA sequence that hybridizes with a fluorescent "reporter," i.e., another DNA sequence labeled with a fluorophore. When a target molecule binds to the DNA on the AuNP, the fluorescent reporter is "desorbed" and the fluorescence signal is released.
Both mechanisms make the fluorescence intensity directly proportional to the concentration of the target molecule, allowing quantitative detection.

Extensive applications in diagnostics and beyond

The study highlighted the performance of these nanoconjugates in a wide range of biosensor applications:
DNA/RNA detection: This technology enabled rapid and sensitive detection of DNA sequences, RNA-metabolizing enzymes (RNase A), and genetic mutations. The sensitivity achieved is impressive, with limits of detection (LOD) of 10 pM for DNA and 0.73 fM for RNase A. An MEF-based approach has even managed to detect concentrations as low as 97.2×10^{-18} M, paving the way for ultra-early diagnosis. Furthermore, CRISPR/Cas12a-based nanosensors can detect the BRCA-1 gene, a marker of breast cancer, with a sensitivity of 0.34 fM in just 30 minutes.

Detection of biological molecules and hazardous compounds: These systems have demonstrated remarkable efficiency in identifying biomarkers associated with diseases, such as ATP, whose concentration is closely linked to conditions such as Parkinson's disease or malignant tumors. Fluorescent nanoprobes have also been used to detect Hg^{2+} ions in aqueous solution and organophosphorus pesticides (OPPs) in real samples, demonstrating their potential in environmental monitoring.

Imaging-guided therapies: Nanobeacons have proven to be not only diagnostic tools but also therapeutic (theranostic) platforms. One study demonstrated how anti-Kras nanobeacons can target, detect, and inhibit a mutant Kras gene in gastric tumors in mice, resulting in a drastic reduction in tumor size and metastases. Fluorescent imaging confirmed the ability of these nanoconjugates to localize and selectively act on tumor cells without affecting healthy organs.

Real-time monitoring of cellular mechanisms

Another crucial application is the real-time monitoring of cellular processes, such as mRNA transport or gene silencing. Nanobeacons have been used to track gene silencing in zebrafish embryos, demonstrating their ability to localize molecular events in living tissues. Such tools are vital for understanding disease mechanisms and developing new therapeutic strategies, particularly in the fight against cancer.

A look into the future
Despite impressive successes, researchers emphasize that further efforts are needed to overcome limitations such as probe stability in complex biological environments and autofluorescence issues. However, the progress made is proof that these hybrid materials have enormous potential to revolutionize medicine and diagnostics. The combination of AuNPs with fluorescent DNA paves the way for much more sensitive and specific biosensor platforms, which will soon become indispensable tools in modern science.

The findings of this study are promoted by UBB Core, The Career Guidance for Researchers Center from ”Babeș-Bolyai” University in Cluj-Napoca, Romania.

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