# Enabling preventive medicine and improving patient care via aptamer-based molecular monitors

openaccessgovernment.org/article/enabling-preventive-medicine-and-improving-patient-care-via-aptamer-based-molecular-monitors/197428

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August 27, 2025

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## As health systems put greater focus on preventive, personalized care, Netzahualcóyotl Arroyo-Currás tells us about the broad benefits of Continuous Molecular Monitors (CMMs) in providing insights into biomolecular markers that facilitate early disease detection

Imagine waking up and placing a smart patch on your skin. The patch is an adhesive device embedded with painless, microscopic microneedle sensors. As you go about your day, eating, exercising, working, or studying, the patch quietly monitors your health. But it is not just tracking your steps or heart rate. It analyses a wide range of biomolecular markers in real time. These molecular insights can tell you how your body is doing and whether it's time to visit your doctor for preventive care. The patch can help detect diseases at their earliest stages, before symptoms appear, when treatment is most effective. It can also help fine-tune medication dosages based on real-time molecular data, maximizing benefits while minimizing side effects. This may sound like science fiction, but it is a future that I believe is rapidly approaching.

### Moving towards preventive, personalized care

Modern healthcare is undergoing a fundamental shift from reactive treatment to proactive, preventive care. This transformation is driven by the recognition that early detection and frequent monitoring can reduce the burden of chronic illness, improve outcomes, and lower healthcare costs. At the heart of this shift are technologies that provide real-time insight into the molecular state of the human body. Continuous Molecular Monitors (CMMs) are a promising class of biosensors designed to track biomolecular changes in vivo with appropriate temporal resolution. Unlike traditional diagnostics, which rely on occasional lab tests, CMMs offer uninterrupted surveillance of key biomarkers, enabling timely interventions and personalized treatment.

## The benefits of Continuous Molecular Monitors (CMMs)

A well-known example of this approach is the continuous glucose monitor (CGM), which has revolutionized diabetes care. By providing real-time glucose readings, CGMs empower patients and their clinicians to make informed decisions, reduce complications, and vastly improve quality of life. This success story highlights the broader potential of CMMs in managing a wide range of diseases. Central to these technologies are molecular recognition elements that detect specific biomolecules. Historically, antibodies and enzymes have played key roles in biosensing due to their specificity and catalytic capabilities. However, antibodies often suffer from thermal instability and manufacturing variability, while enzymes coupled to electronic interfaces are limited in the range of metabolites they can detect.

In recent years, aptamers – short, single-stranded nucleic acids that fold into unique three-dimensional structures – have emerged as powerful alternatives. Aptamers are selected through a process called SELEX (Systematic Evolution of Ligands by EXponential enrichment), which identifies nucleic acid sequences with high affinity and specificity for a target. They are resistant to temperature and pH changes, can be chemically modified, and are less likely to trigger immune responses. Critically, their interactions can be reversible, enabling real-time monitoring of dynamic changes in analyte concentration, making them ideal for integration into real-time CMM platforms.

At the core of an aptamer-based CMM is a recognition-transduction interface. Aptamers are chemically attached to a sensor surface, where binding to a target induces a conformational change that alters a measurable physical property, such as light emission or electrical current. This signal is digitized and analyzed in real time. This strategy is integrated into wearable or implantable devices that sample dermis interstitial fluid, blood, or other biological matrices. My laboratory focuses on electrochemical sensing, where aptamer binding modulates electron transfer between a redox-active tag and an electrode, producing a measurable current. This method is compatible with miniaturized electronics and has been shown to monitor molecules continuously in various body parts, including blood, brain, liver, bladder, dermis, and cerebrospinal fluid in animal studies.

Recent advances in flexible electronics, additive manufacturing, and wireless communication have enabled the development of fully integrated aptamer-based CMMs. These devices can continuously sample biofluids through microneedles, maintain aptamer functionality over days, and transmit data wirelessly to cloud platforms for remote monitoring. Prototype devices have already demonstrated real-time monitoring of drug levels and metabolites in animal models. These systems pave the way for personalized medicine, where treatment is dynamically adjusted based on molecular feedback. However, several challenges remain. Biofouling, or the accumulation of biological material on sensor surfaces, can degrade performance. Strategies to mitigate this include surface coatings, microfluidic flushing, and disposable sensor elements. Signal drift over time is another concern, which can be addressed through internal standards, recalibration algorithms, and robust aptamer design.

Multiplexing sensors to monitor multiple biomarkers simultaneously requires careful design to avoid cross-reactivity and interference, while miniaturization demands innovations in materials, power management, and wireless communication. Regulatory and ethical considerations are also critical. Aptamer-based CMMs must undergo rigorous clinical validation and meet safety and efficacy standards. This includes demonstrating analytical performance, conducting clinical trials, and navigating regulatory pathways. Data privacy and security are paramount, given the sensitive nature of continuous health data.

The true power of CMMs lies in their ability to provide detailed, moment-by-moment information about the body’s chemistry, such as how medication levels change throughout the day. When combined with Machine Learning and predictive analytics, this data could help identify early signs of disease and support closed-loop therapeutic systems, where drug delivery is controlled as a function of molecular levels of the drug itself and other biomarkers in the body. Future platforms may integrate aptamer-based CMMs with electronic health records, telemedicine, and clinical decision tools, creating a seamless ecosystem for proactive care.

## Future possibilities for CMMs

Looking ahead, aptamer-based CMMs could become foundational tools in a new era of precision health. Patients could wear discreet biosensors that continuously monitor key biomarkers. Clinicians could receive alerts before symptoms appear, enabling early intervention. Therapies could be dynamically adjusted based on molecular feedback. Population-level data could inform public health strategies and disease prevention.

Overall, this vision has the potential of representing a fundamental shift in how we understand and manage health: it would support healthcare that is predictive, preventive, personalized, and participatory (also known as P4 medicine), helping forecast and prevent illness, tailoring treatment to individuals, and involving patients in their own care.

In summary, aptamer-based CMMs may offer a transformative opportunity to detect disease earlier, personalize therapy, and empower patients, thus increasing the length and quality of life. The success of CGMs has already shown the value of continuous sensing for medicine. Aptamers, with their specificity, stability, and versatility, are poised to extend this model across a wide range of clinical applications. As aptamer-based systems mature, they may not only improve individual outcomes but also contribute to population health and biomedical discovery. Ultimately, they could help usher in a new healthcare paradigm that is smarter, more responsive, and truly centered on the patient.

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