Transforming brain monitoring with bioresorbable wireless sensing

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INTRODUCTION

The ability to continuously and accurately monitor intracranial physiological indices is crucial for the diagnosis and management of various neurological conditions, including traumatic brain injury, hydrocephalus, and cerebrovascular disorders. However, conventional approaches involving wired instruments with percutaneous leads are fraught with challenges, including the risk of infection, restriction on patient movements, and potential surgical complications during insertion and removal. In a recent study, an interdisciplinary team led by Professors Jianfeng Zang, Xiaodong Chen and Xiaobing Jiang proposed an innovative solution—an injectable, bioresorbable, and wireless sensor for ultrasonic monitoring of intracranial signals.[1]

KEY FINDINGS AND INNOVATIONS

Wireless bioelectronic devices are often hindered by detection range, signal quality, and size constraints within the human body.[2–4] Overcoming these challenges has been a long-term pursuit in the field of medical sensing and monitoring. Tang et al.[1] proposed a new approach leveraging the unique properties of soft acoustic metamaterials.[5] They demonstrated the concept of a metagel sensor, which combines hydrogel as the base material with periodically aligned air columns to create a specific acoustic reflection spectrum (Figure 1A). Their approach minimizes infection risk through minimally invasive sensor injection, which enhances patient mobility with wireless monitoring and eliminates the need for surgical removal due to the bioresorbable nature of the sensor. The core principle of this metagel sensor lies in its ability to deform in response to changes in the physiological environment, causing shifts in the peak frequency of the reflected ultrasound waves. These frequency shifts can be wirelessly detected by an external ultrasound probe, eliminating the need for percutaneous leads or complex electronics within the implant itself. The metagel can wirelessly and accurately measure pressure changes in the range 0–20 mmHg and a broad temperature range spanning 28–43°C (Figures 1B and 1C).

What's more important is the ability of the metagel sensor to independently detect intracranial pressure, temperature, pH, and flow rate, with a detection depth of up to 10 cm. Moreover, it exhibits nearly complete biodegradation within 18 weeks after implantation. The unique advantages of the sensor stem from its small size ($2 \times 2 \times 2$ mm^3), enabling minimally invasive delivery through a puncture needle, as well as its full biodegradability, circumventing the need for surgical removal. Unlike previous approaches that relied on conventional electronics or complex communication systems, the metagel sensor is elegant in design and easy to deploy in clinical settings. The authors have demonstrated impressive results in both rodent and porcine models, demonstrating the metagel sensor's performance in line with conventional wired benchmarks.

CHALLENGES AND LIMITATIONS

While the results presented in this study are promising, it is important to acknowledge the challenges and potential limitations that may arise in the translation from animal studies to human trials and eventual widespread clinical adoption. Rigorous testing and evaluation will be necessary to ensure safety, efficacy, and scalability of the metagel sensor technology in diverse *in vivo* conditions. Additionally, regulatory hurdles and ethical considerations will need to be carefully addressed to pave the way for responsible and equitable deployment of this innovative technology.

Furthermore, the decoupling and accurate interpretation of multiple physiological signals from the metagel sensors may present challenges, particularly in complex clinical scenarios where environmental factors and interferences may be present. The authors have proposed a promising decoupling scheme based on simultaneous monitoring of multiple metagels, which may require further refinement and validation in real-world settings.

FUTURE OUTLOOK AND RECOMMENDATIONS

It is exciting to see the potential synergies between this innovative sensing technology and the rapidly evolving field of transient implants. The interdisciplinary collaboration between materials science and engineering, sensing technologies, and minimally invasive intervention will undoubtedly accelerate further discoveries and novel approaches for patient care with due consideration of accessibility and healthcare economics.

It can be anticipated that further development and rapid translation of this new technology can lead to tangible clinical applications. The metagel sensor is a perfect example of realizing the vision of personalized, minimally invasive, and continuous healthcare monitoring, enabled by multidisciplinary approaches. I am sure the team already has concrete plans in place to combine advanced data processing and machine learning techniques to make the sensor even

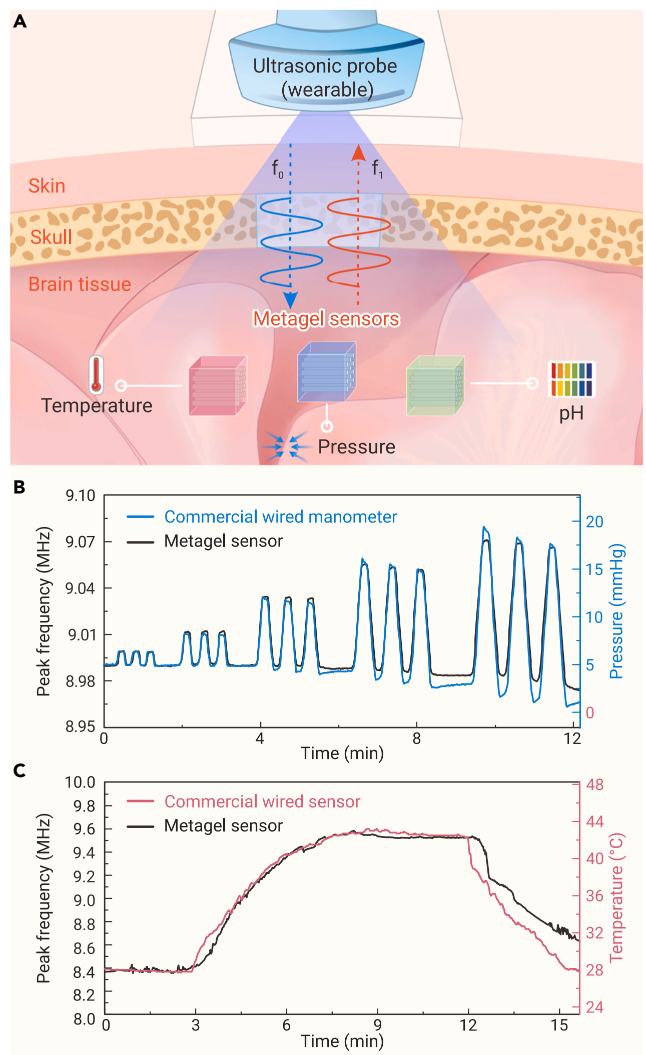

Figure 1. Metagel-ultrasonic sensing (A) Schematic of sensing mechanism. (B and C) Pressure and temperature sensing performance of metagel sensors (image courtesy of Tang et al.[1]).

smarter. By combining real-time physiological data with intelligent algorithms, predictive models, and wearable ultrasound devices, it is possible to unlock further possibilities for early detection, personalized treatment, and proactive health management.

Meanwhile, the potential applications of this technology could be exciting. Imagine a scenario where a surgical robotic, equipped with integrated imaging and sensing capabilities, could precisely implant these metagel sensors at targeted intracranial locations during a minimally invasive procedure. Post-operatively, the implanted metagels could wirelessly transmit real-time physiological data to a wearable ultrasound device, enabling continuous and remote monitoring of the patient's intracranial conditions. This continuous monitoring could be crucial for making therapeutic decisions, including adjusting intracranial pressure or administering targeted treatments based on the detected physiological parameters. Beyond intracranial applications, the metagel sensor could potentially be adapted for monitoring various physiological parameters in other organs or tissues, opening up new avenues for minimally invasive diagnostics, targeted therapies, and perioperative monitoring. The integration of metagel sensors with wearable or implantable devices could also enable continuous monitoring in ambulatory settings, which could be particularly valuable for patients with chronic conditions or those at risk of developing certain disorders, enabling proactive and personalized care.

CONCLUSION AND DISCUSSION

The work by Tang et al.[1] represents a step forward in the field of wireless implantable sensors, with potentially far-reaching implications for patient care. Their metagel sensor technology has elegantly addressed long-standing challenges in intracranial monitoring, offering a minimally invasive, wireless, and biodegradable solution with multiparametric sensing capabilities. The small size and wireless nature of the metagel sensor could potentially reduce healthcare costs associated with traditional approaches, making advanced monitoring solutions more accessible to a broader population.

As we look to the future, the convergence of innovative sensing technologies like this new metagel sensor with advanced data analytics holds the promise of transforming perioperative monitoring. By fostering interdisciplinary collaborations and addressing regulatory and ethical considerations, it is possible to unlock the full potential of this new technology and drive transformative improvements in patient outcomes and quality of life.

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DECLARATION OF INTERESTS

The author declares no competing interests.