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Biomedical Engineering COMMENTARY

Making the invisible audible: Soft biodegradable implants redefine deep-tissue sensing

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Monitoring physiological signals deep inside the body has long been a technological and conceptual challenge. Pressure, temperature, and mechanical strain within organs often precede overt symptoms and guide clinical decision-making, yet they remain difficult to access continuously and noninvasively.[1] Conventional imaging offers snapshots rather than real-time dynamics, while implantable sensors introduce new constraints related to invasiveness, rigidity, long-term safety, and wireless communication.

Implantable sensors are often sold as a simple promise: place a device next to the organ of interest and physiology will speak for itself. In practice, the message gets lost long before biology does. Passive, battery-free implants based on resonant inductor-capacitor (LC) circuits are attractive precisely because they can be small, soft, and biodegradable—but they also tend to be geometrically fragile: signal quality collapses when the reader is too far, when alignment drifts, or when the implant rotates in a living, moving body.[2] That is why many demonstrations still look "surgical"—carefully positioned, tightly constrained, and measured under forgiving benchtop geometries.

Recent research may push this technology toward a more realistic clinical scene: a soft, biodegradable, wireless sensing platform that maintains reliable readout over long distances (up to 16 cm) and across variable positions and angles while supporting pressure, temperature, and strain modalities.[3] Their core message is not only that biodegradable implants can work—but that they can be read in the messy geometry of deep tissue (Figure 1).

FROM "COUPLING-LIMITED" TO "CLINIC-LIKE" READOUT

Passive resonant implants communicate by coupling to an external reader coil; the sensed variable shifts resonance, and the reader infers that shift. The Achilles' heel is that coupling is exquisitely sensitive to distance and orientation, so the same implant can appear to change simply because the patient (or the organ) moves. This problem becomes severe in deep tissue, where centimeters matter and alignments are rarely controllable.

The new work attacks the bottleneck where it hurts most: the readout physics. The authors introduce a "pole-moving sweeping" readout scheme, developed within a coupled-mode theoretical framework, that aims to preserve measurement fidelity under weak and perturbed coupling rather than assuming near-field, well-aligned operation. Unlike conventional resonance-tracking approaches that rely primarily on detecting an amplitude peak, the method reshapes the phase-frequency response of the coupled system during frequency sweeping. As the excitation frequency scans across resonance, the effective pole of the system dynamically shifts in the complex plane, generating a trackable phase signature even when the amplitude response becomes weak under loose coupling conditions.

This strategy effectively converts the readout problem from simple peak detection to pole tracking, which can remain identifiable despite variations in distance, orientation, or alignment between the implant and the reader. Such robustness is particularly valuable in deep-tissue environments, where geometric relationships change continuously with posture, respiration, and organ motion. At the same time, the approach does not eliminate all constraints: extremely weak coupling, strong electromagnetic interference, or rapid environmental fluctuations may still limit signal fidelity. Framing these factors explicitly helps clarify the engineering envelope within which long-distance biodegradable telemetry can realistically operate.

FOLDING MECHANICS INTO ELECTROMAGNETICS

Readout alone is not enough if the implant itself cannot survive the mechanical reality of tissue. A second enabling element is a folded structure that couples mechanical compliance with electromagnetic function, balancing softness with the geometry needed for stable wireless response.

This is an underappreciated design point in biodegradable devices: materials selection often receives most attention, but geometry frequently determines whether the device is tolerant of bending, compression, and shifting interfaces. The folded architecture effectively makes mechanical flexibility part of the electromagnetic design space—an approach that could generalize to many passive implants where robustness is limited not by the sensing element but by how the resonator behaves when deformed.[4]

LARGE-ANIMAL VALIDATION AS A TRANSLATIONAL "STRESS TEST"

The most convincing argument for translational relevance is the choice of model and scenario. The platform was tested *in vivo* in the abdominal cavity of horses, where deep-tissue conditions and uncontrollable geometry are closer to clinical reality than the usual small-animal demonstrations. In this setting, the system reliably captured deep-tissue pressure and temperature, and additional *ex vivo* experiments supported accurate strain monitoring without strict positional control.

This matters because many biodegradable, battery-free platforms still rely on proximity or constrained alignment to work. The direction here is clear: if a biodegradable implant is meant to disappear, it should not require a permanent "dance partner" (precise reader placement) to be clinically useful.

WHY THIS ADVANCE LANDS NOW

Across bioresorbable electronics, recent progress has been remarkable—miniaturization, multimodal sensing, and clever materials stacks. Yet clinical adoption remains gated by practicalities: safe removal (or no removal), patient comfort, long-term stability during the therapeutic window, and reliable data under everyday motion.

Passive bioresorbable systems have already shown strong value in specific niches (for example, continuous local chemical monitoring, such as pH sensing after surgery, and battery-free therapeutic platforms). What Lan et al. add is a step toward geometry-agnostic telemetry—a capability that can unlock broader indications where you cannot dictate alignment, including abdominal, musculoskeletal, and potentially obstetric or post-operative monitoring, where the "best" reader position changes with posture and time.

WHAT STILL STANDS BETWEEN DEMO AND DEPLOYMENT

Several challenges are now crisply defined by this work and will likely determine how quickly such soft biodegradable implants move from demonstration to deployment. First, degradation-aware calibration is unavoidable. Because bioresorbable devices evolve chemically and mechanically over time, changes in geometry, conductivity, or dielectric properties can lead to resonance frequency drift, variation in quality factor, and attenuation of signal amplitude. These device-induced shifts may partially overlap with the signatures of genuine physiological changes, complicating signal interpretation during long-term monitoring. Future systems may therefore require strategies that explicitly disentangle degradation from physiology—for example, through reference resonators, differential sensing architectures, or model-based calibration frameworks that incorporate degradation kinetics into the sensing transfer function. Establishing such approaches will be important for ensuring reliable physiological readout throughout the functional lifetime of transient implants.[5] Second, multiplexing in real anatomy remains a major translational hurdle. Clinical monitoring rarely relies on a single sensor; instead, it involves distributed measurements across multiple anatomical sites or physiological modalities. Future

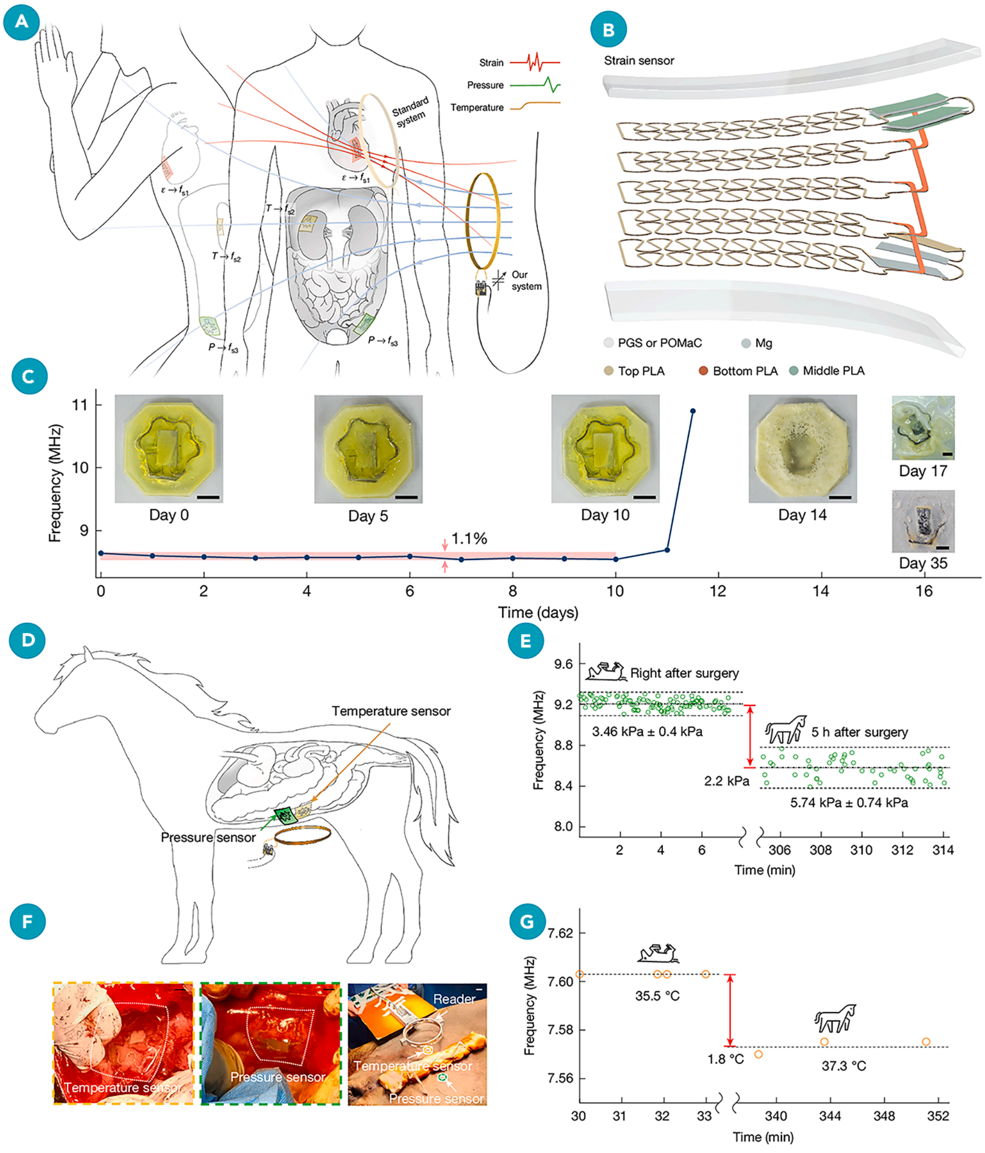

Figure 1. A soft, biodegradable wireless sensing system designed to decouple physiological readout from strict spatial alignment, enabling reliable monitoring in deep, moving tissue (A) Soft, biodegradable, wireless sensing platform used in a clinical environment, where distance and angle cannot be controlled. (B) Explosion diagram of the strain sensor. (C) Daily results of readout frequency and typical photos of the pressure sensor during the degradation process in phosphate buffered saline (PBS). (D) The placement of the reader and the pressure and temperature sensors for *in vivo* monitoring of pressure and temperature inside the abdominal cavity of a horse. (E) The signals of readout frequency caused by intra-abdominal pressure. (F) Images of the sutured pressure and temperature sensors with 5 × 5 cm encapsulation and the monitoring process with the horse in a supine position. (G) The signals of readout frequency caused by core body temperature variation.

implementations may therefore require scalable addressing strategies—such as frequency-division multiplexing or coded sensing schemes—to enable simultaneous readout of multiple implants. However, introducing multiple resonant devices within the same electromagnetic environment raises additional challenges, including spectral overlap, inter-sensor crosstalk, and signal ambiguity during dynamic motion. These issues may be further complicated by the heterogeneous electromagnetic properties of biological tissues, which can modify coupling conditions as organs move or deform. Addressing these factors will be essential for translating single-device demonstrations into robust multisensor physiological monitoring systems. Third, reader ergonomics and clinical workflow will be decisive: "wide-angle" telemetry only matters if it comes with portable readers, rapid acquisition, and minimal operator burden; in this regard, the availability of open phase-frequency acquisition code offers a practical foothold for standardization and reproducibility. Finally, safety, byproducts, and the regulatory narrative must be treated as integral engineering constraints, as the promise of biodegradability is not merely that the device functions but that it functions and then disappears safely—requiring rigorous characterization of degradation products, inflammatory responses, and failure modes under worst-case coupling and real-world use conditions.

OUTLOOK

Soft biodegradable implants are often framed as a materials revolution. This paper persuasively argues that the revolution will be equally about systems: the co-design of mechanics, electromagnetics, and signal inference so that deep-tissue physiology can be accessed without requiring a perfectly staged experiment. By showing long-distance, wide-angle readout and validating it in a large animal, Lan et al. narrow the gap between what bioresorbable electronics can do in the lab and what they must do in the clinic. If the next decade of bioresorbable devices is to look like medicine rather than a physics demo, platforms will need to be judged by an unforgiving metric: whether they still perform when geometry is uncertain, the body is moving, and "ideal alignment" is nobody's job. More broadly, advances in biodegradable materials, wireless readout physics, and system-level integration may gradually transform transient implants from short-term monitoring tools into more sophisticated medical platforms. Coupled with developments in flexible electronics, programmable biointerfaces, and closed-loop therapeutic technologies, future biodegradable systems may not only sense physiological signals but also interact with them—forming intelligent transient devices that monitor, interpret, and respond to biological states deep within the body. In this sense, the work by Lan et al. hints at a broader shift from isolated sensing demonstrations toward integrated transient bioelectronic systems capable of operating reliably in realistic clinical environments.

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DECLARATION OF INTERESTS

The authors declare no competing interests.

REFERENCES

1. Kang, S.K., Murphy, R.K.J., Hwang, S.W. et al. (2016). Bioresorbable silicon electronic sensors for the brain. *Nature* **530**:71–76. DOI:10.1038/nature16492
2. Boutry, C.M., Beker, L., Kaizawa, Y. et al. (2019). Biodegradable and flexible arterial-pulse sensor for the wireless monitoring of blood flow. *Nat. Biomed. Eng.* **3**:47–57. DOI:10.1038/s41551-018-0336-5
3. Lan, Y., Li, S., Guo, H. et al. (2026). Soft biodegradable implants for long-distance and wide-angle sensing. *Nature* **649**:366–374. DOI:10.1038/s41586-025-09874-3
4. Rogers, J.A., Someya, T. and Huang, Y. (2010). Materials and mechanics for stretchable electronics. *Science* **327**:1603–1607. DOI:10.1126/science.1182383
5. Li, C., Guo, C., Fitzpatrick, V. et al. (2019). Design of biodegradable, implantable devices towards clinical translation. *Nat. Rev. Mater.* **5**:61–81. DOI:10.1038/s41578-019-0150-z