Team Results Document

NephroCat

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SensUs

1. Abstract: Summary for the SensUs website

Chronic kidney disease (CKD) affects over 850 million people worldwide, representing nearly 10% of the world's population [1]. In Spain, almost 15 % of patients undergoing routine blood and urine tests meet CKD diagnostic criteria [2]. The disease is characterized by a persistently reduced estimated glomerular filtration rate (eGFR) and/or an elevated urine albumin-to-creatinine ratio (UACR) [3]. Among available biomarkers, creatinine remains the most accessible and trusted indicator of kidney function [4].

However, early-stage CKD often goes unnoticed, undiagnosed, and under-monitored, delaying intervention until dialysis or transplantation become the only options [5]. This is particularly concerning in Spain which, despite being a global leader in organ transplantation [6, 7], still struggles with long waiting lists for kidney transplants [8].

Pre-dialysis patients represent a crucial window of opportunity: timely detection of declining kidney function can mean the difference between stabilizing the disease and progressing to irreversible kidney failure.

To address this gap, we propose a simple, low-cost electrochemical creatinine sensor for at-home use by pre-dialysis patients. This device would enable patients and clinicians to detect subtle but meaningful changes between routine blood tests, allowing for earlier treatment adjustments that could delay, or even prevent, the need for dialysis. Providing patients with reliable and convenient monitoring has the potential to transform how Spain and the world confronts this silent epidemic.

2. AP award: Biosensor developed for the Eindhoven Testing Event

2.1. Molecular recognition

Our biosensor does not rely on any molecular recognition element. Instead, it is based solely on the electrochemical properties of the sample, particularly its impedance response, which is the resistance of the solution to the flow of an alternating electrical current. Changes in creatinine concentration alter this impedance, enabling direct detection and quantification.

This design decision was guided by the specific constraints and goals of the SensUs competition, where continuous monitoring, wearability, durability, and reagent-free operation are essential. The inclusion of biomolecular components would increase complexity, cost, and the need for surface regeneration or replacement, making the device less suitable for long-term or continuous use in real-world conditions.

Our design is supported by existing literature [9] showing that bioelectrical impedance correlates with creatinine clearance, and may serve as a non-invasive, quick, and accurate method for estimating kidney function.

2.2. Physical transduction

The biosensor operates by measuring changes in the electrical impedance of the solution, which correlate with varying creatinine concentrations. A 1 kHz sinusoidal excitation signal is applied across the working and reference electrodes. The resulting current is transformed into a voltage signal through a transimpedance amplifier (MCP6004) and digitized via the Digilent Analog Discovery 2. The acquired data is processed using custom Python software (WaveForms API) to obtain impedance magnitude and phase.

2.3. Cartridge technology

The biosensor features a straightforward design, comprising a disposable screen-printed electrode (SPE), specifically the DropSens C223AT. This electrode integrates a gold working electrode, a gold counter electrode, and a silver reference electrode on a ceramic substrate. A microfluidic channel with an area of 64.8 mm^2 and a height of 0.14 mm, fabricated from polydimethylsiloxane (PDMS), is bonded to the electrode using ARcare® 90106NB adhesive to direct the fluid sample precisely over the electrode surface (**Figure S1–S3** from Appendix). The channel volume is approximately 9 µL. It incorporates a single inlet and outlet, both connected via Male Mini Luer tube tuck connectors (Fluidic 1579, microfluidic ChipShop). Flexible tubing, with an internal diameter of 0.8 mm and an external diameter of 1.58 mm, links the biosensor to the fluid handling system. The inlet is connected to a peristaltic pump responsible for sample injection, while the outlet channels the fluid to a waste reservoir,

ensuring controlled and continuous sample flow through the microfluidic pathway (**Figure 1**).

Through experimental testing, it has been demonstrated that continuous biosensing is achievable due to the displacement flow phenomenon, where the introduction of a interstitial fluid (ISF) sample at the inlet effectively pushes the previous sample out through the outlet (**Figure S4** from Appendix).

2.4. Reader instrument and user interaction

Custom Python software, built on the WaveForms library, demodulates the digitized waveform to separate amplitude and phase information. A calibration routine programmatically varies the equivalent channel resistance to emulate different creatinine concentrations, constructing a robust calibration curve. During operation, the system references this curve to compute creatinine levels from measured impedance changes.

Mechanically, the reader features a compact, benchtop footprint optimized for point-of-care deployment. Users insert a disposable microfluidic cartridge into a guided slot; no fluidic connectors or manual alignments are required. After sample introduction, automated measurement sequences initiate, and real-time results are visualized via an intuitive graphical user interface. The GUI displays calibrated concentration readouts, trend graphs, and diagnostic alerts. Streamlined software workflows minimize operator training, while a modular electronic design ensures maintainability and scalability for future assay expansion.

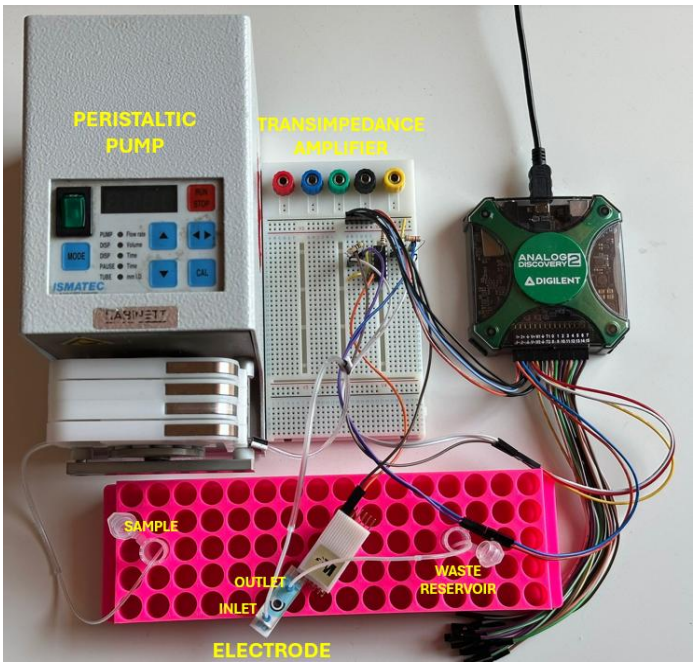


Figure 1. Cartridge setup showing the electrode, bonded microfluidic channel, inlet and outlet tubing, peristaltic. pump, waste reservoir, physical transduction mechanism.

3. IN award: Biosensor innovation

3.1. Wearable sensor

3.1.1. Technological novelty of wearable sensor

The core technological novelty of our biosensor lies in its reagent-free detection principle. It operates by electrochemically inducing a local pH shift in the ISF to protonate creatinine molecules. With a pKa of ~4.8 [10, 11], creatinine is mostly uncharged at physiological pH (~7.4). Lowering the pH below this value adds protons, giving creatinine a positive charge.

This charge shift alters the ionic environment at the electrode interface, specifically the electrical double layer, which modulates local impedance. Monitoring these impedance changes allows direct creatinine quantification without surface-bound molecular recognition elements that degrade over time.

The pH shift is achieved through local electro-acidification using a pair of auxiliary electrodes embedded in the microchannel: an inert platinum anode and an Ag/AgCl cathode. Applying a voltage drives water oxidation at the anode, generating protons and oxygen gas (**Eq. 1**):

$$2\,H_2O\,(l) \rightarrow\ O_2\,(g) + 4\,H^+ + 4\,e^- \quad (Eq.1)$$

This localized proton generation lowers the pH in the sensing zone without chemical reagents. The Ag/AgCl cathode balances the charge transfer with minimal hydroxide production, maintaining the acidified environment and ensuring efficient protonation of creatinine. The resulting charge-induced changes in the electrical double layer enable sensitive, label-free detection [12, 13, 14].

The sensor interface can be integrated into a wearable skin patch featuring a hydrogel microneedle array for passive ISF extraction. These microneedles wick fluid from the dermal layer using capillary action alone, without causing pain or bleeding. ISF is transported into the sensing zone via a displacement-flow microfluidic system, where each new sample physically replaces the previous one, eliminating the need for pumps or valves and preventing sample mixing or memory effects. The displaced sample is directed into a dedicated waste reservoir, ensuring clean and uncontaminated measurements for each sensing cycle.

Sensing occurs in a three-electrode electrochemical setup. The working electrode is sensitive to changes in the electrical double layer caused by the protonation-induced shift in local charge distribution. An Ag/AgCl reference electrode maintains potential stability, while the counter electrode completes the circuit. This transduction mechanism produces impedance and potential shifts that reflect creatinine concentration in real time.

Signal acquisition is carried out by a compact, battery-operated ESP32-based circuit integrating waveform generation (DAC), signal acquisition (ADC), and wireless communication (Bluetooth) (**Figure 2**). The system is controlled by C++ code optimized for embedded microcontrollers [15].

A key enabler of the platform's wearable functionality is its compact and modular architecture. All components — sensing electrodes, fluidics, electronics, and microneedles — are amenable to miniaturization without sacrificing performance. The absence of bulky reagents, pumps, or moving parts reduces the device's footprint, allowing integration into a skin-conformal patch just a few millimeters thick. Screen-printed electrodes on flexible substrates ensure mechanical compliance with skin, while the battery-powered ESP32 circuitry enables low-power, wireless operation over extended periods. This high degree of integration and autonomy makes the platform truly wearable, enabling continuous, unobtrusive creatinine monitoring in both clinical and home settings.

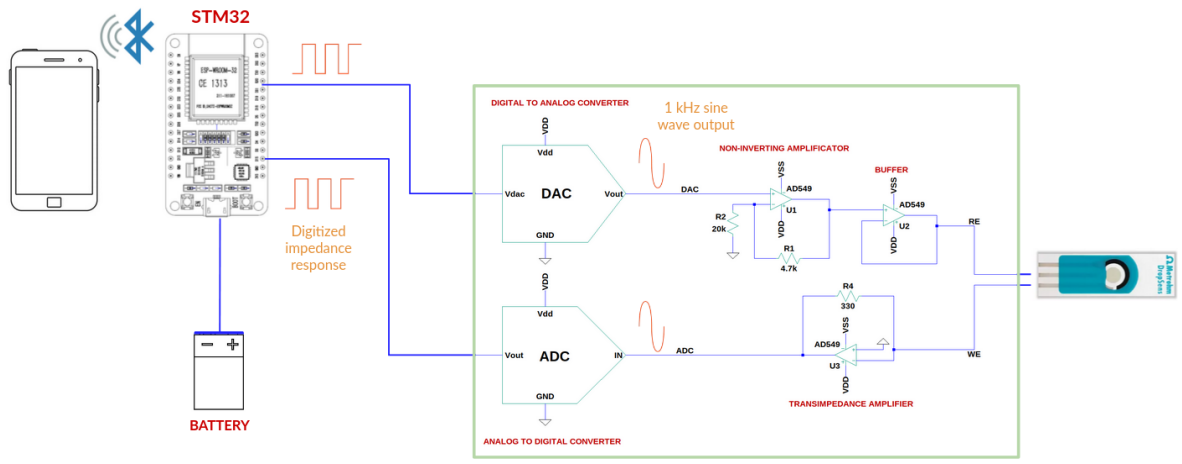


Figure 2. Compact architecture of the wearable creatinine sensing system. An STM32 microcontroller generates and reads electrochemical signals via DAC/ADC, with signal conditioning handled by amplifiers. Data is wirelessly transmitted to a mobile device via Bluetooth.

3.1.2. Technical feasibility of wearable sensor

The core sensing platform has been engineered with miniaturization and full system integration as primary design drivers. All key components — electrochemical sensing electrodes, signal processing electronics, and passive fluidics — are implemented in compact, low-profile formats, demonstrating the feasibility of embedding the entire system into a wearable skin patch.

The electronic readout, based on a battery-operated ESP32 microcontroller, integrates waveform generation, impedance measurement, and Bluetooth communication. The ESP32's low power consumption (<100 mW) and small form factor allow full integration into a compact enclosure, powered by a coin cell or thin-film battery.

Microfluidic handling is achieved through a valveless displacement-flow channel, enabling sample exchange without pumps or actuators. At the current stage, the sensor is validated using externally applied fluid samples. Integration of hydrogel microneedle arrays for passive ISF extraction is a planned extension supported by existing literature and commercially available materials. These microneedles offer a minimally invasive, reagent-free method for continuous fluid collection and are compatible with the demonstrated compact sensor layout. A hydrogel pad between the microneedles and skin would maintain fluid contact and prevent drying, while a medical-grade silicone adhesive around the periphery ensures secure placement and skin conformity during normal daily activities [16, 17] (**Figure S5 – S7** from Appendix). More details about the sensor can be found in Appendix C.

The electrochemical acidification system, consisting of a platinum anode and Ag/AgCl cathode for localized pH control, has been validated in benchtop setups and is technically compatible with miniaturized layouts. Its integration into the flexible patch format is in progress, with no anticipated materials or power limitations based on current results.

3.2. Reliability of sensor output

3.2.1. Technological novelty of reliability concept

The reliability of wearable biosensors is often compromised by degradation of recognition elements, reagent instability, and environmental drift [18]. Our system departs from traditional biochemical sensing methods by avoiding enzymatic or antibody-based layers and instead using a reagent-free, protonation-driven impedance transduction strategy. This eliminates a major source of variability, making the system inherently more stable over time.

At the core of our approach is an electrochemical acidification mechanism, a fully physical, non-biochemical signal transduction method that enables repeatable measurements without replenishing reagents or recalibrating enzymatic reactions.

A novel aspect of our reliability strategy is drift and calibration management without traditional reference fluids. Rather than requiring user or clinical recalibration, the system performs a fluid-only calibration step in which interstitial fluid with no added creatinine passes through the sensor. This provides a real-time baseline impedance reading under

identical physiological and hardware conditions. Comparing subsequent readings to this baseline allows tracking of signal shifts and early identification of drift.

Additional robustness comes from optimized impedance measurement. Through frequency sweeps, we identified a single optimal frequency, integrated into a displacement-flow microfluidic design where each new sample displaces the previous one without valves or pumps. This ensures only fresh fluid reaches the sensing area, preventing cross-contamination and memory effects common in static or recirculating systems. The passive nature of this flow is both innovative and critical for achieving stable, drift-free measurements in a wearable form factor.

The system operates without redundant sensors, chemical reagents, or specialized calibration kits. Reliability is embedded in both the physical architecture and the signal processing routine. This “robustness-by-design” approach, integrating simplicity from detection chemistry to calibration, enables consistent, drift-resistant performance, making the platform well suited for wearable, point-of-care, and home-based use.

3.2.2. Technical feasibility of reliability concept

The technical feasibility of our reliability concept was evaluated through bench experiments, signal characterization, and repeatability testing. The biosensor employs a three-electrode configuration with a screen-printed Ag/AgCl reference electrode, and a working electrode optimized for proton-modulated impedance detection of creatinine.

To assess stability and drift, we implemented a calibration procedure using creatinine-free interstitial fluid substitutes. This isolated the baseline impedance response and allowed verification of its stability under constant flow and repeated operation. Repeated passes of the baseline fluid produced nearly identical impedance values, with less than 5% variation across trials, confirming reproducibility and indicating minimal drift during typical operating cycles.

Measurement reliability was strongly influenced by the excitation frequency. A full sweep from 10 Hz to 10 MHz identified 260 Hz as the optimal frequency, balancing sensitivity to creatinine concentration changes, noise stability, and compatibility with microcontroller-based operation.

Each measurement was averaged over three to five acquisition cycles to reduce the effects of transient fluidic disturbances or electrode settling. The flow-through microfluidic design ensured that each reading was taken from a clean sample, avoiding memory effects or cross-sample interference.

Short-term repeatability tests were conducted by cycling creatinine-spiked solutions (30 µM to 300 µM) and comparing impedance responses. At 260 Hz, the calibration curve showed an R^2 of 0.997, demonstrating high linearity and confirming the robustness of the detection principle across a physiologically relevant range (**Figure S8** from Appendix).

These results validate the system's ability to produce reliable, repeatable outputs without reagent replenishment, surface reconditioning, or frequent recalibration. The capability to detect creatinine through purely physical properties while maintaining signal quality over repeated use demonstrates a high level of technical readiness for a wearable, low-maintenance sensor.

3.3. Original contributions

3.3.1. From the team

Our biosensor introduces several original features to enhance wearable integration and sensor output reliability. These include a reagent-free, protonation-based impedance sensing mechanism, hydrogel microneedles for passive ISF extraction, a displacement-based microfluidic system, and a calibration method using creatinine-free ISF baseline readings.

The idea of reagent-free sensing through pH modulation arose during internal brainstorming between wet-lab and electronics subgroups. In parallel, the wearable and fluid-handling design was developed by the microfluidics team based on literature and clinical insights.

After reviewing multiple approaches, the team independently selected the impedance-based sensing and displacement flow strategy based on internal criteria of robustness, cost, and simplicity. These ideas were further refined through benchtop testing, frequency sweeps, and fluidic design iterations to improve signal reliability and flow consistency.

All scientific testing, including calibration with creatinine-spiked and blank samples, was carried out by the team using custom circuits, WaveForms scripts, and Python code. While we received access to lab facilities and some technical feedback, no part of the concept development, design, or experimental validation was performed by people outside the team. All key innovations are the result of the team's original, independent work.

3.3.2. From the supervisor

The biosensor developed by NephroCat for creatinine detection presents a novel application and integration of known electrochemical principles toward a future wearable

sensing platform. The sensor stands out for its non-enzymatic, label-free, and regeneration-free detection method, relying on controlled local pH modulation within a microfluidic environment.

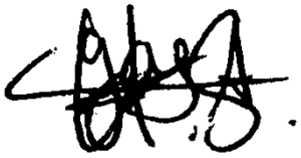
While electrochemical acidification is an established method, the team identified its potential for indirect recognition of creatinine, a less common approach for this analyte, especially in wearable contexts. The method involves protonation of creatinine through localized acidification, which leads to measurable electrochemical potential shifts at the electrode surface due to changes in the electrical double layer.

Team Contributions

- The concept of using protonation-based detection was conceived and developed by the team.
- They adapted and refined the system by tuning electrode configuration, fluidics, and potential control to ensure efficient protonation and stable signal output. They also developed the data analysis pipeline to quantify creatinine concentration.
- The team conducted the entire experimental validation, including sensor construction, calibration, and tests for sensitivity, specificity, and reliability.

This simple yet effective approach reflects the principle of Occam's razor: achieving fast, reliable, and low-cost detection without complex surface chemistry. Its microfluidic design also lays the groundwork for future integration into a wearable device.

Beyond technical development, the team demonstrated remarkable independence in setting up the project infrastructure. They secured lab access, coordinated with external collaborators for fabrication, and obtained financial support to cover material and prototyping costs. These efforts reflect strong initiative, resilience, and motivation.



Inês Salema Yangming Zhang Janet van der Graaf

Team Captains Team Supervisor

4. TP award: Translation potential

4.1. Customer interviews

We began by identifying key stakeholder groups relevant to a non-invasive creatinine sensor, focusing on both patients and healthcare professionals. While nephrologists and transplant specialists were our entry point, aligned with the competition scope, we used an iterative approach: insights from each interview helped us expand our network and adjust the profile of future interviewees.

This process led us to consult four nephrologists, and one specialist each in transplant medicine, cardiology, infectious diseases, and paediatrics, selected based on recurring clinical overlaps highlighted during earlier conversations.

On the patient side, we used input from doctors to identify relevant profiles. We interviewed six patients, including three with lupus-related kidney issues (some with transplant or dialysis history), one transplant recipient with congenital kidney malformation, one dialysis patient with hypertension and obesity as contributing factors, and one cardiac patient.

The interviews were carefully prepared and conducted following a structured and adaptable methodology. We made sure to clarify, at the first point of contact, that all responses would be kept confidential and used exclusively for research purposes.

Interview questions were tailored to the stakeholder profile. For patients, we focused on their personal experiences with kidney monitoring, emotional and logistical challenges, and how monitoring impacted their daily life. For doctors, the questions explored clinical decision-making, technical limitations of current methods, and the types of patients who would most benefit from more frequent or real-time monitoring. Interview questions and main takeaways for each stakeholder group are available in the Appendix A for reference.

The interviews with healthcare professionals revealed overall interest in the concept of continuous creatinine monitoring, particularly in scenarios where early intervention could reduce complications or hospitalizations. While the idea was well received, most clinicians emphasized that the sensor's applicability depends heavily on patient context and clinical setting.

Doctors generally welcomed the idea of continuous creatinine monitoring, recognizing its potential to reduce diagnostic delays and support faster intervention. Still, they emphasized that its usefulness depends heavily on the clinical context.

In stable patients, the current approach (routine blood and urine tests) is considered sufficient. Similarly, in hospital and ICU settings, where lab testing is frequent and

comprehensive, the sensor adds little value. Some specialists also noted that creatinine alone is often not enough for clinical decisions and must be interpreted alongside other biomarkers (such as cystatin C, proteinuria, or broader metabolic markers).

Despite these limitations, several promising applications emerged. Pre-dialysis patients were consistently highlighted as an ideal target group, where close monitoring could help detect deterioration in time to adjust treatment and possibly delay the need for dialysis. Post-transplant patients and those in home-based care with fast-track clinical pathways (e.g. myocardial infarction, stroke) were considered promising areas where early kidney function insights could influence treatment decisions.

Patient interviews revealed a range of monitoring experiences depending on disease stage, personality, and treatment context. While transplant recipients and stable lupus patients generally expressed confidence in current follow-up protocols, typically based on quarterly or semi-annual lab tests, most recognized that more continuous or accessible monitoring could have added value at critical stages.

Concerns about anxiety and data overload were raised by some patients, who felt that real-time data could become psychologically overwhelming if not properly explained and supported by clinical guidance. This reinforces the importance of identifying the right clinical context for using the sensor — ensuring it is applied where it adds value, rather than being used indiscriminately.

Across the interviews, there was also consensus on the need for less invasive, more convenient methods, particularly for children or during fragile stages of illness. At home-based usability, reduced dependence on hospital visits, and the ability to anticipate complications were cited as major potential benefits.

Overall, while both pre-dialysis and early post-transplant phases were identified as meaningful use cases, the clearest consensus — among both patients and clinicians — was that **pre-dialysis monitoring holds the greatest potential impact**. This phase is marked by gradual but critical decline, where continuous creatinine tracking could enable earlier interventions and possibly delay or avoid dialysis altogether. In contrast, although post-transplant patients require close monitoring, rejection is not detected through creatinine levels alone, reducing the value of a sensor focused solely on this marker.

4.2. Design of validation study

4.2.1 Conceptual Prototype and Relevant Use Case

The chosen clinical problem is the monitoring of patients in the pre-dialysis phase of CKD, a stage where renal function is progressively declining. Timely intervention during this

period is critical to delay or prevent the initiation of dialysis. Even small changes in creatinine levels can signal significant shifts in kidney performance [19], yet these are often not detected in time due to the limitations of standard intermittent blood testing.

Our proposed solution is a non-invasive, continuous, real-time wearable creatinine biosensor. The device integrates a painless microneedle array for interstitial fluid sampling with an impedance-based detection system (**Figure 3**), transmitting results wirelessly to a mobile application. The app displays creatinine trends, estimates in real-time creatinine levels, and issues alerts when clinically significant changes are detected.

This approach is well-suited to pre-dialysis care, where early identification of declining renal function can enable prompt medical adjustments — such as changes in medication, diet, or hydration strategies — potentially postponing the need for dialysis.

This use case is strongly aligned with stakeholder needs, as identified through clinician and patient interviews. Unlike stable chronic patients or those already undergoing regular in-hospital monitoring, pre-dialysis patients often fall into a monitoring gap, where follow-up is not frequent enough to prevent sudden deterioration. Offering a home-based solution in this context improves not only clinical outcomes, but also the quality of life for patients, by reducing the need for emergency interventions or hospitalizations.

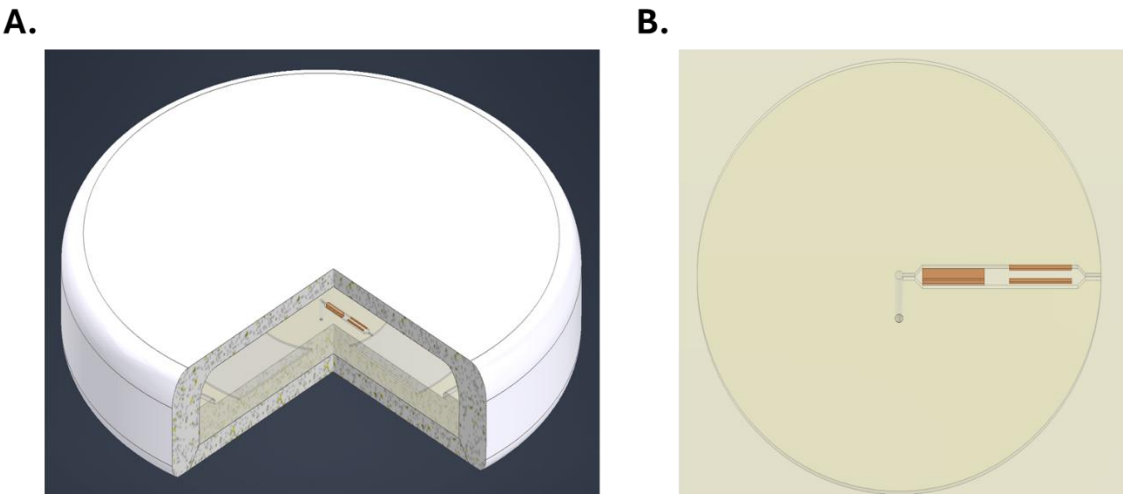


Figure 3. Wearable biosensor design and internal microfluidic structure. **A.** Sectioned view of the device showing internal microfluidics and electrodes. **B.** Close-up of the microneedle inlet, reaction chamber, and waste channel.

4.2.2 Design of a validation study

To demonstrate the feasibility and clinical relevance of the proposed solution, several key aspects must be carefully validated. First, the impedance-based detection system must

show reliable correlation with creatinine concentrations in physiologically relevant ranges, typically between 30 and 300 µM. This analytical sensitivity and accuracy is essential for the device to provide meaningful clinical information. Additionally, the signal must remain stable over time, particularly under continuous operation for periods extending to at least 72 hours, to ensure its applicability in real-world monitoring scenarios.

Beyond the technical signal quality, the usability of the device plays a crucial role. The wearable form factor must be comfortable, safe, and practical for patient use, especially considering the intended long-term home-based application. It is also critical that both patients and healthcare professionals can interpret the data meaningfully, allowing for clinical decisions to be made based on the trends and alerts provided by the app. Avoiding misinterpretations or unnecessary alerts is a priority to ensure that the system becomes a helpful tool rather than a source of confusion or anxiety.

The initial validation will focus on confirming these aspects through benchtop experiments and simulated use scenarios. Measurements will be performed using phosphate-buffered saline (PBS) and artificial interstitial fluid spiked with creatinine. Electrochemical impedance will be measured across a screen-printed three-electrode system using custom electronics, and readings will be benchmarked against standard laboratory values.

A small-scale clinical pilot study is planned in collaboration with the Hospital Clínic of Barcelona, targeting 5–10 pre-dialysis patients, pending ethical approval. The sensor will be used for 24–72 hours per subject, and impedance readings will be compared to blood and urine creatinine values collected during the same period. Patients and clinicians will be invited to complete a brief usability and satisfaction questionnaire, to assess comfort, perceived value, and trust in the system.

Although the sensor is still undergoing laboratory validation and has not yet been fully assembled in its final wearable format, the team anticipates potential challenges such as environmental drift, electrode degradation, or signal instability. To address these, we will refine the calibration routine, explore simplified signal processing algorithms, and work closely with engineering mentors and clinical collaborators to adapt the design based on early feedback.

This phased validation approach—starting with in vitro experiments and leading to clinical pilot testing—ensures that the solution evolves in response to evidence, while staying aligned with stakeholder needs and clinical realities.

5. Team and support

5.1. Contributions of the team members

Name	Role and contribution
Laia Colomé	Contributed to electronics, data analysis, innovation ideation and social media.
Gerard Grajera	Contributed to electronics, and social media.
Emma Pubill	Contributed to microfluidics development, experimental testing, and innovation ideation.
Joana Ros	Contributed to electronics, data analysis, innovation ideation and social media.
Inês Salema	Served as co-captain, contributing to microfluidics development, experimental testing, translational strategy, and data analysis.
Teresa Vela	Contributed to innovation ideation and social media.
Marc Verdaguer	Contributed to experimental testing, data analysis, and translational strategy.
Yangming Zhang	Served as co-captain, contributing to microfluidics social media development, experimental testing, translational strategy, and social media.

5.2. People who have given support

Name	Role	Contribution
Janet van der Graaf	Team Supervisor	Provided essential guidance and support throughout the project
Jordi Colomer	Team Coach	Offered overall guidance and technical advice on the electronics development
Romén Rodriguez	Team Coach	Contributed to the conceptual development and hosted experiments in his lab
Joan Bertomeu	Vice Dean for Academic Affairs	Provided institutional support and financial assistance for project
Òscar Castaño	Biomedical Engineering Master's Coordinator	Contributed to the institutional support and financial assistance for project
Javier Romón	Researcher Professor	Provided expert guidance on microfluidics and supported innovation development
Martín Ruíz	PhD Student	Provided the microfluidic channel and lab material
Jordi Fonollosa	Researcher Professor	Advised the team on expert-level data analysis
Matheus Provinciali	Innovation manager	Mentored the team on the translational and business-oriented aspects
Francisco Palacio	Researcher Professor	Coached the team on advanced electronics design in the final stages

5.3. Sponsors and partners

Organization	Contribution
University of Barcelona	Provided sponsorship, infrastructure, materials, and covered project expenses
StartUB!	Offered financial support and sponsorship throughout the project
Biosensors for bioengineering group at IBEC	Supplied materials and supported the fabrication of the microfluidic channels
Polytechnic University of Catalonia	Institutional support, including project visibility

6. Final remarks

We would like to sincerely thank everyone who supported us throughout the development of our biosensor — whether through technical advice, materials, funding, or workspace. Special thanks to the SensUs organization for their continuous support, feedback sessions, and financial aid, and to the Jury for dedicating their time to reviewing our work and listening to us in Eindhoven.

Despite having limited funding, a small team, and no direct academic specialization in the field, we are proud of what we achieved. The project was entirely extracurricular and built from scratch, and while our solution is simple, we believe it demonstrates that simplicity can be powerful — especially when it aligns with accessibility and continuous use.

Our results using professional impedance analyzers were promising and validated our detection concept. Although our custom hardware still needs refinement, this experience confirms the feasibility of a reagent-free, impedance-based creatinine biosensor for future applications. Improving the robustness of our reader will be the next step.

More than anything, this was an incredibly enriching challenge. It was the first time many of us experienced the full journey of engineering a real device — from ideation and lab work to hardware development and end-user feedback. We hope this is just the beginning for future Barcelona teams in SensUs.

Thank you to everyone involved — and see you next year.

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8. Appendix

Appendix A – Microfluid channel design

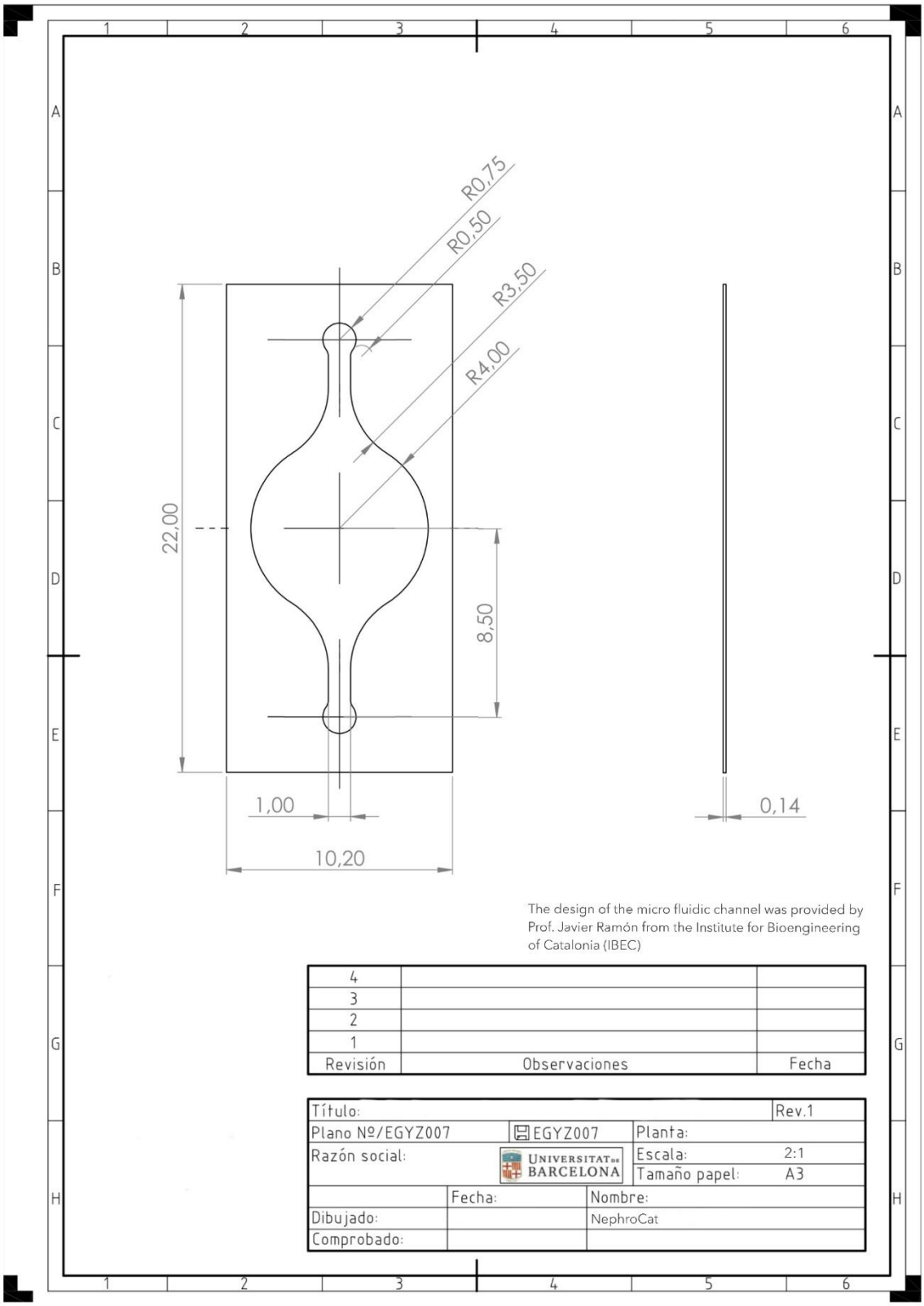

Figure S1. Microfluid channel design provided by PhD candidate Martín Ruíz from Professor Javier Ramón's group at the Institute for Bioengineering of Catalonia (IBEC).

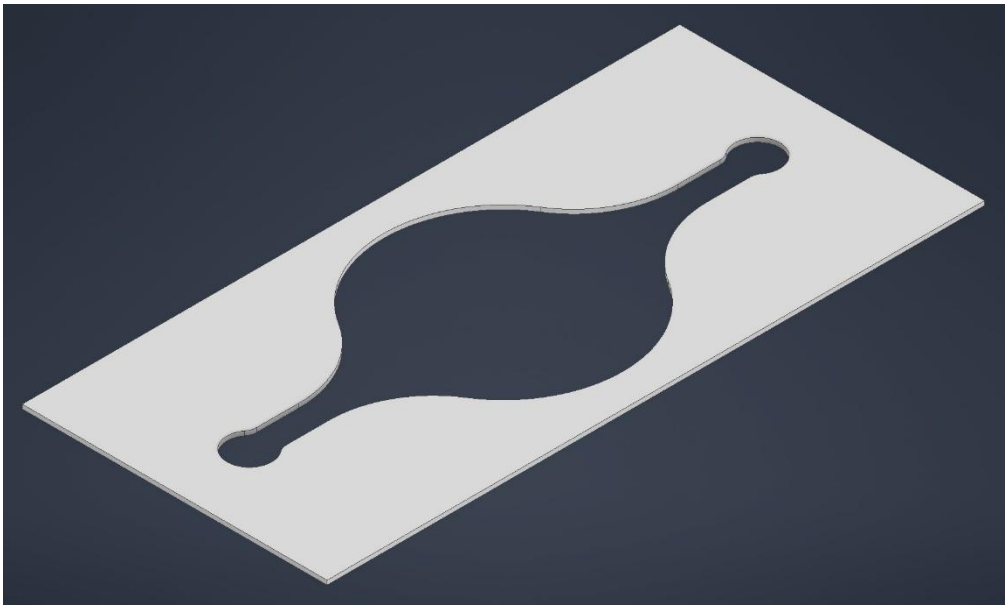

Figure S2. Three-dimensional (3D) model of the microfluid channel.

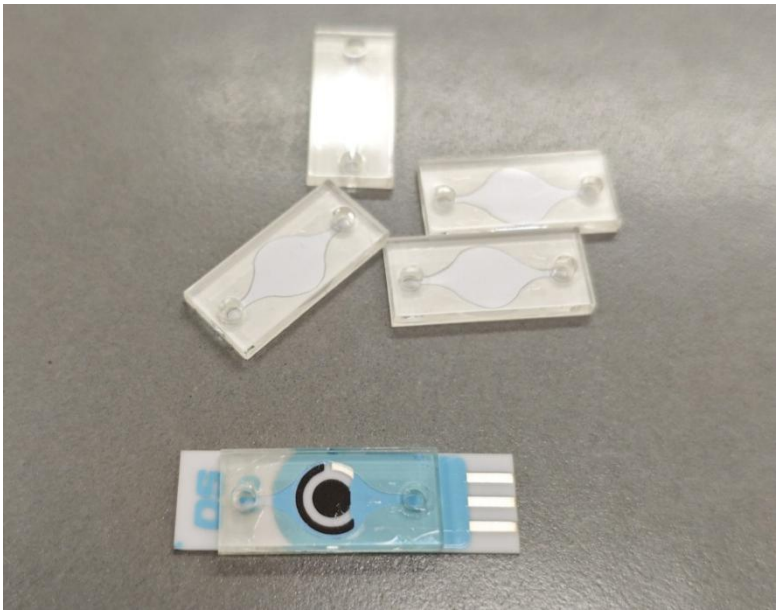

Figure S3. Microfluidic channel attached to an electrode surface.

Appendix B – Proof of concept of a continuous monitoring

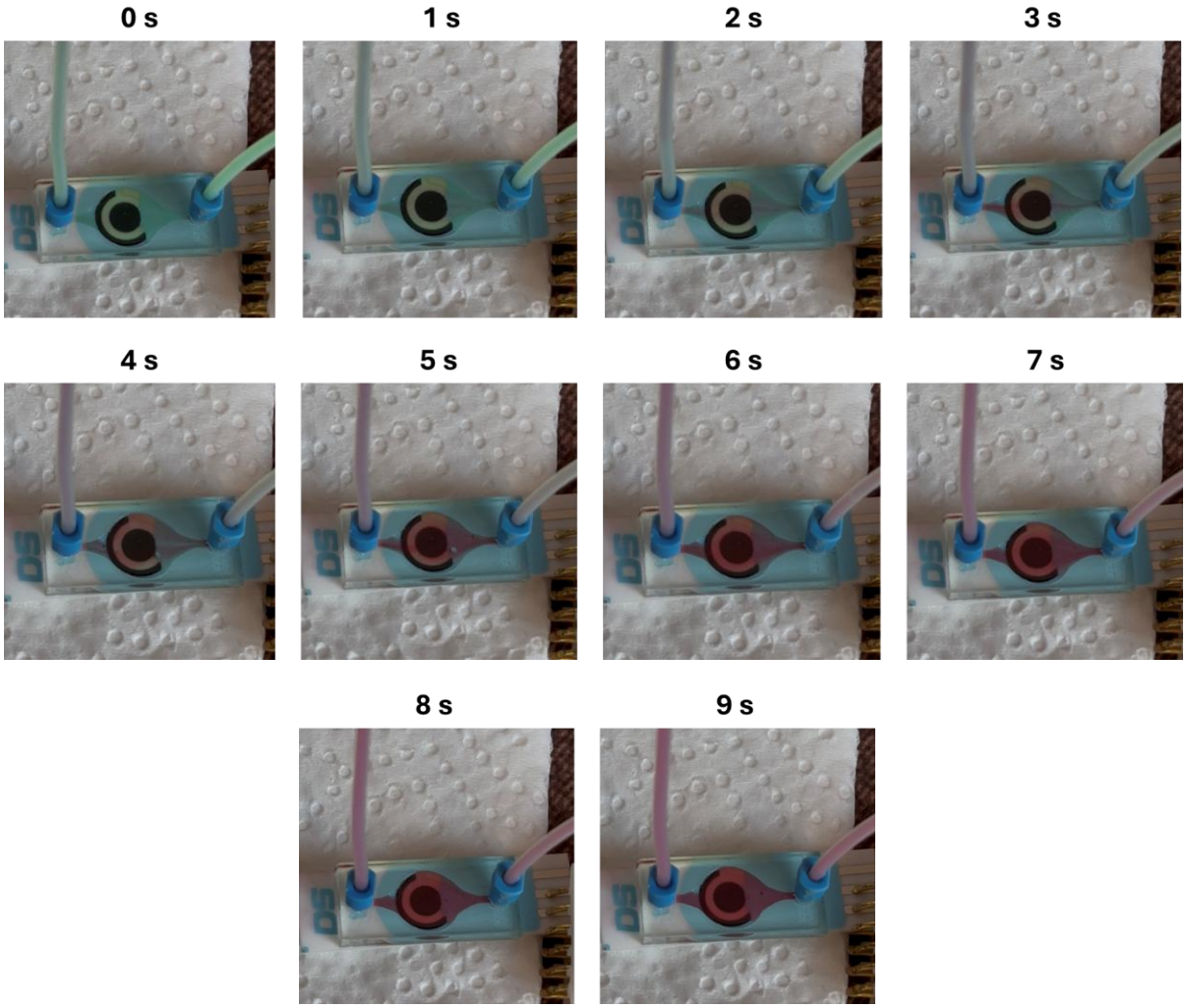

Figure S4. Time-lapse images as proof of concept for continuous monitoring, using two different water dye samples added sequentially: green (first) and red (second).

Appendix C – 3D model of the wearable sensor and dimensions

Dimensions and Key Parameters of the Prototype:

- **External housing diameter:** 42.4 mm
- **Total housing height:** 6.5 mm
- **Microchannel structure diameter:** 40 mm
- **Internal fluidic area diameter:** 13 mm
- **External microneedle diameter:** 0.25 mm
- **Internal microchannel diameter:** 0.1 mm
- **Reaction chamber:**
    - Width: 0.6 mm
    - Length: 5 mm
- **Electrode configuration in the reaction chamber:**
    - Electroacidification pair: one electrode on the upper surface and one on the lower surface.
    - Impedance measurement pair: two longitudinal electrodes located downstream of the acidification zone.
- **Waste reservoir:** annular shape, surrounding the fluidic area to optimize space usage.
- **PCB:** 36 mm diameter, positioned above the microfluidic structure and aligned with the electrodes.
- **Assembly:** circular sealed housing with a top cover, designed to protect the system and ensure user safety and comfort.

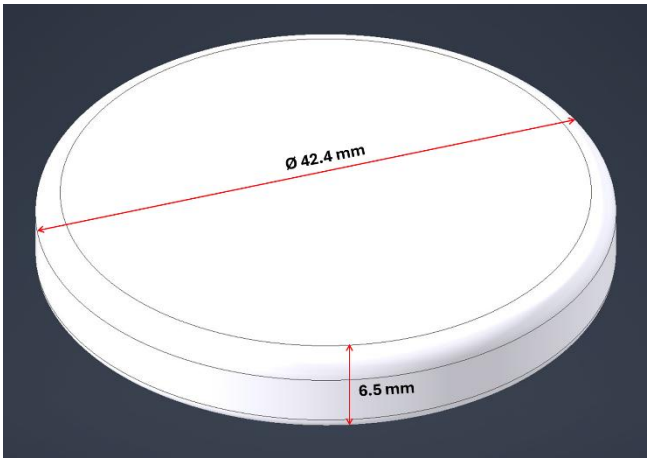

Figure S5. 3D model of the wearable sensor with all external dimensions.

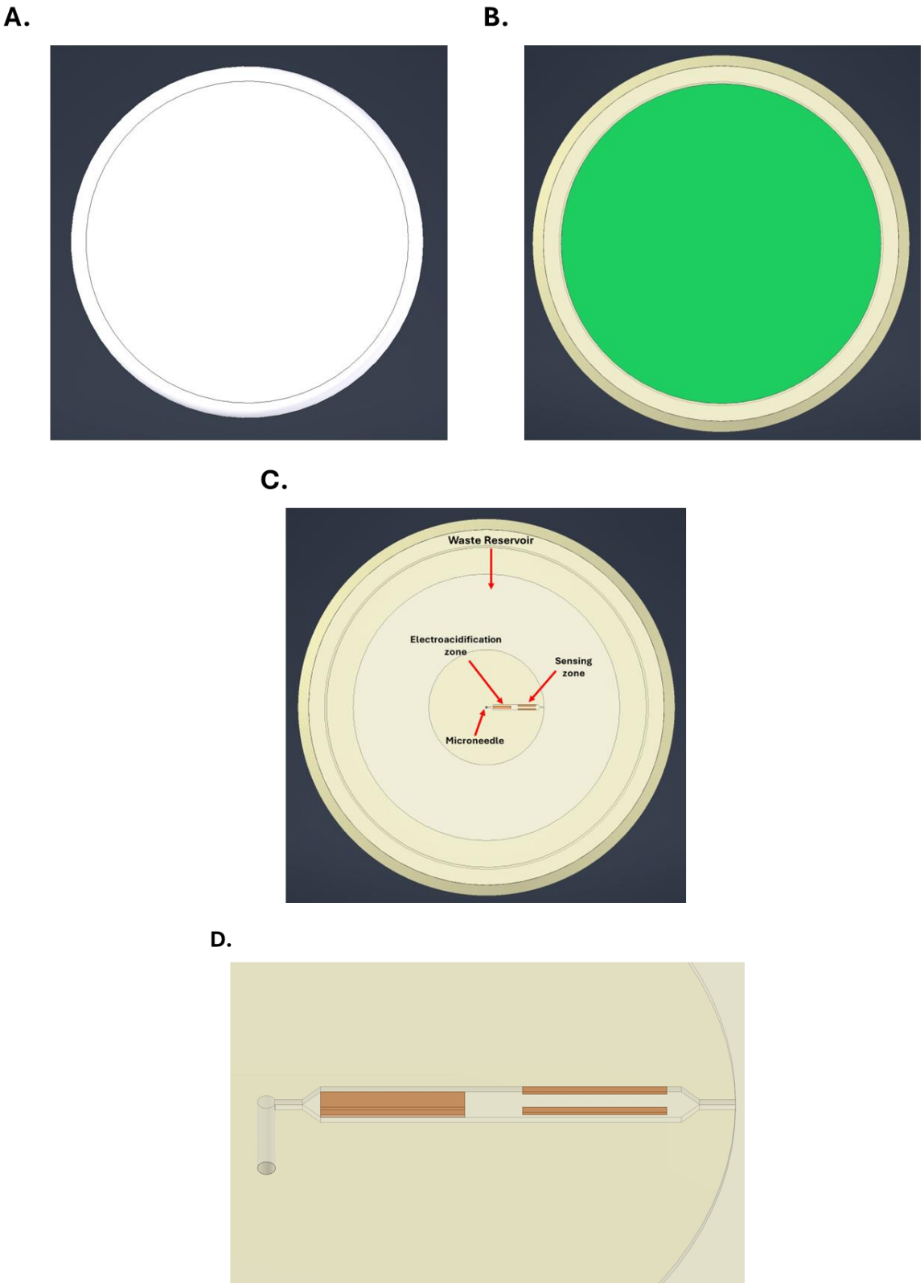

Figure S6. Uper view of the wearable sensor. **A.** Sensor with the shell. **B.** Sensor without the shell and showing the PCB location (green). **C.** Sensor without the shell and the PCB, showing the different parts of the microfluidic channel. **D**. Closer look to the microfluidic channel of the sensor.

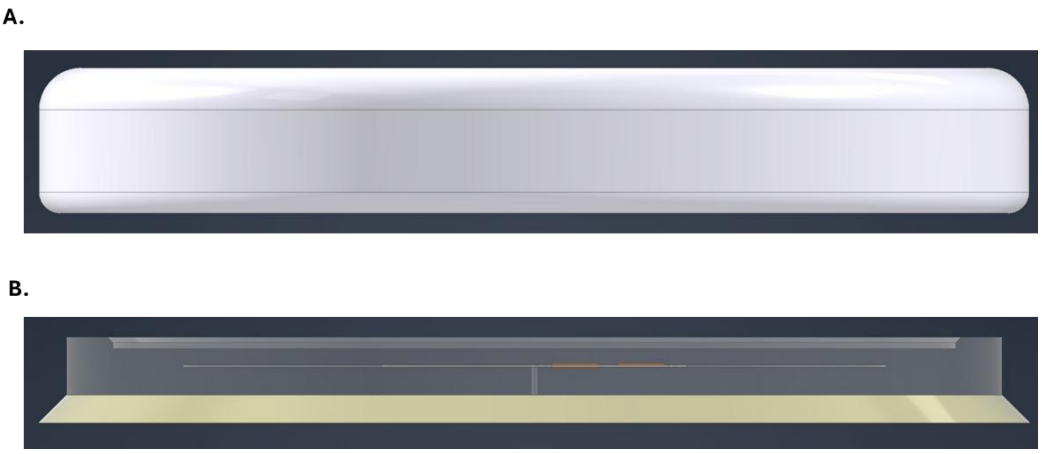

Figure S7. Side view of the wearable sensor. **A.** Side view with the sensor shell. **B.** Side view without the sensor shell.

Appendix D – Proof of concept of the sensor. Calibration curve

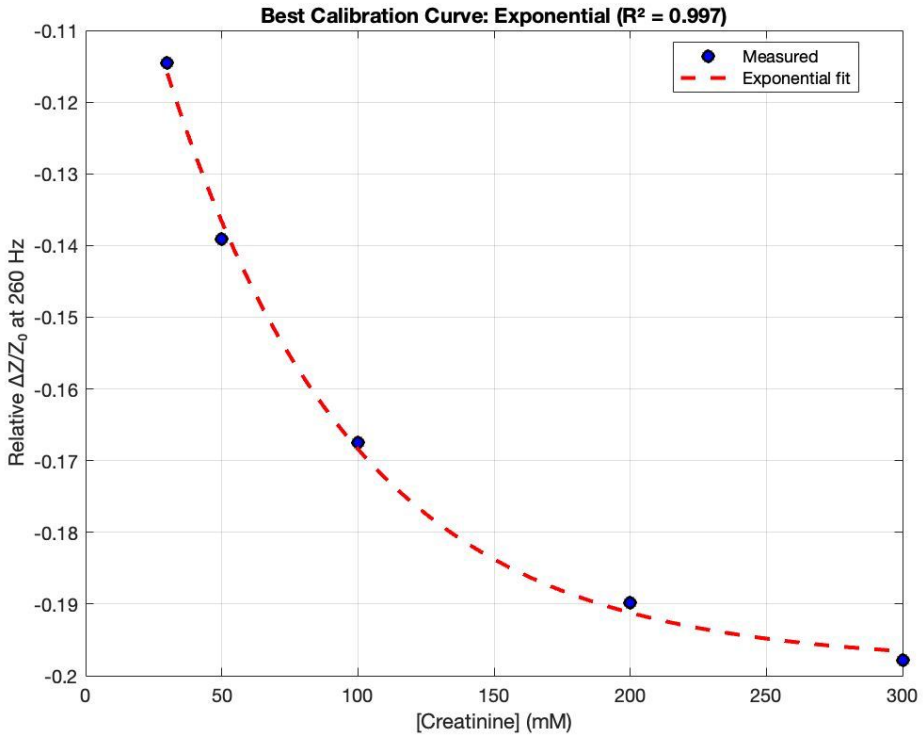

Figure S8. Calibration curve.

Appendix E - Customer Interviews

E.1 Customer Interviews Template

Objective: Build trust and explain the purpose of the interview without influencing responses, in order to understand which are the current problems with kidney monitoring.

Introduction: Hello, my name is _____, and I am part of a team researching kidney function monitoring. We want to better understand the challenges that patients/healthcare professionals like you face with current monitoring methods.

We will use your answers only for research purposes and we will keep them completely confidential. If there's anything you'd rather not answer, that's completely okay. Just let me know and we'll move on.

Questions for Patients:

Kidney function monitoring

– Can you describe your experience with kidney function tests? How often do you need them?

– What steps do you usually have to take to get your creatinine levels checked?

– Have you ever had trouble getting tested (for example: scheduling, costs, access to facilities)?

Understanding level of the patient

– How well do you understand what creatinine levels mean for your health?

– Has a doctor ever explained how changes in creatinine levels affect your condition?

– Do you feel you have enough information to manage your kidney health effectively?

– How did you know that you had kidney failure? How did the doctor explain it to you?

– What kind of measures did you have to take after the diagnosis?

Emotional and practical impact

– If you could change something about how kidney function is monitored, what would it be?

– How does waiting for test results affect your daily life?

– Do you feel confident that your current monitoring method provides you with a clear understanding of your kidney function, or do you feel uncertain about it despite it being monitored?

Questions for Doctors:

Current monitoring practices

– How do you usually monitor kidney function in your patients?

– How frequently do you request creatinine tests, and what factors influence this decision?

– What limitations do you see in the current testing approach?

– How do you balance the use of blood tests (like creatinine) with other indicators (e.g., urine output, GFR estimates) when assessing kidney function?

– How do you integrate patient-reported symptoms with test results in your monitoring strategy?

Challenges in monitoring and decision-making

– Have you had cases where a patient's condition worsened unexpectedly because their condition was not being monitored frequently enough?

– Do you feel that current monitoring methods allow for early detection of problems?

– Are there specific patient groups that would benefit from more frequent monitoring?

– Are there specific risk factors that lead you to monitor kidney function more frequently in certain patients?

– In your experience, has preventive monitoring helped in avoiding severe kidney complications?

– What are the main barriers to performing more regular kidney function tests?

– How often do you find discrepancies between a patient's test results and their actual clinical condition?

– Are there times when you hesitate to order more tests due to patient discomfort or cost concerns?

Limitations in kidney function monitoring

– How do limitations in kidney function monitoring affect patient care and treatment decisions?

– Do you think more frequent or continuous monitoring could reduce hospital admissions related to kidney issues?

– If you had access to real-time kidney function data, how would that affect your treatment decisions?

– In what ways do you think continuous kidney function monitoring could impact healthcare costs?

E.2 Customer Interviews Main Takeaways

- Doctor Luisa Lobato (Nephrologist)

One of the most promising applications seems to lie in the pre-dialysis phase and the domiciliation of care for chronic kidney patients. In these stages, real-time monitoring could help delay the need for dialysis, support tighter control over disease progression, and give patients more autonomy in managing their condition—while also reducing unnecessary hospital visits. In acute scenarios like stroke or myocardial infarction fast-track protocols, early knowledge of kidney function could also have immediate clinical impact, informing treatment choices and preventing complications related to renal vulnerability.

- Doctor Mireira Musquera (Surgery)

Although she is a specialist in kidney transplantation, this doctor highlighted that pre-dialysis stages may actually be more relevant for continuous or wearable monitoring than the post-transplant period. In her view, creatinine is not the primary biomarker used to detect transplant rejection, so real-time creatinine tracking would offer limited added value after transplantation. By contrast, in pre-dialysis patients, where decisions about starting dialysis or adjusting treatment are highly dependent on subtle changes in renal function, such monitoring could provide critical insights, enable earlier interventions, and support patients at home during a particularly delicate phase.

- Patient X (anonymous)

As a patient living with lupus and chronic kidney disease, this individual emphasized that real-time kidney monitoring would have been especially valuable during critical phases, such as the conservative treatment period before dialysis and the high-risk months following her kidney transplant. While she noted that not everyone would want constant data—*'some people become obsessed with fear of rejection'*—she believed that having access to such information could empower patients to better manage their health, detect complications earlier, and even delay the need for dialysis through tighter control and prevention.