Team Results Document

Glomero

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Copenhagen, 08.08.25

SensUs

1. Abstract: Summary for the SensUs website

Chronic kidney disease (CKD) is a progressive and irreversible decline of renal function, with kidney transplantation being the preferred treatment for end-stage cases. Post-transplant monitoring is crucial, particularly the tracking of biomarkers such as creatinine. However, current practices rely on frequent blood tests and hospital visits, leading to discomfort for patients and suboptimal monitoring due to cost and logistics. Herein, we present the conceptualization and early validation of a wearable biosensor for continuous, minimally invasive monitoring of creatinine in interstitial fluid. The device utilizes molecularly imprinted polymers (MIPs) combined with creatinine-copper complex to enable selective, scalable, low-cost and easy to store solution compared to conventional enzyme-based biosensors. Epidermal interstitial fluid is collected using a microneedle patch, minimizing discomfort without compromising sensor performance. The NFC-based wireless power supply allows battery-free operation, ensuring reliable measurements while maintaining the device's compact and user-friendly design. Our preliminary results demonstrate the feasibility of our sensor, highlighting its potential to become a standard home-based point-of-care tool for the 18,000 annual kidney transplant patients residing in the EU. Every year, our solution could save 140 million euro in EU healthcare costs, reduce clinician burden and improve patient outcomes while being at home with their loved ones.

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

Serum creatinine levels are correlated with kidney transplant failure, making continuous monitoring essential (Younespour et al., 2016). However, detecting low-abundance small molecules in interstitial fluid (ISF) remains challenging (Lee et al., 2023).

2.1. Molecular recognition

Our approach utilizes molecularly imprinted polymers (MIPs) for affinity-based creatinine detection. MIPs' abiotic nature confers greater stability compared to biological counterparts like enzymes, enabling long-term dry storage of sensors at room temperature (BelBruno, 2019). MIPs are synthesized by electropolymerizing the monomer β-cyclodextrin together with redox-active methylene blue, enabling direct detection of creatinine upon binding (see Figure 1(a)) (Lee et al., 2023; Tsai & Syu, 2005). This synthesis is cost-effective and easily scalable. Although, to the best of our knowledge, no MIP-based biosensor is currently available on the market, they are well established in academic research (Pereira et al., 2019).

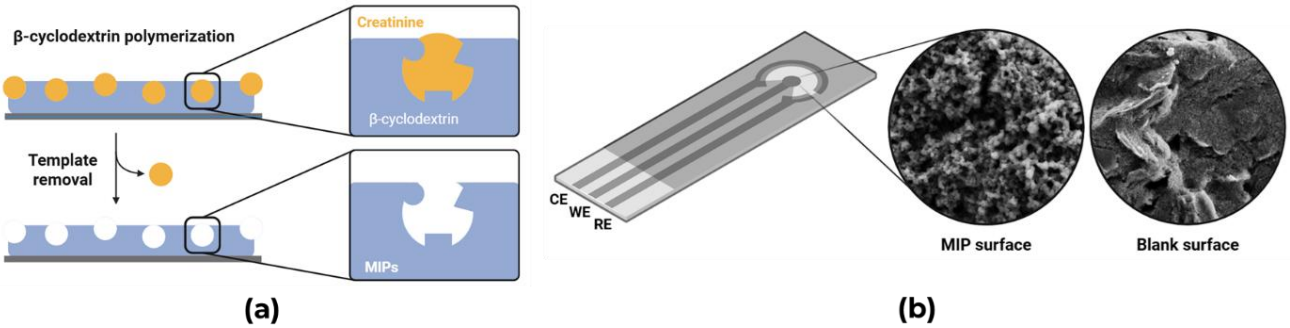

Figure 1: (a) Principle of the MIP technology. (b) Schematic of the three-electrode system. On the right, SEM images of the WE surface with MIPs and a blank WE surface.

2.2. Physical transduction

Our sensor is based on electrochemical transduction for the measurement of creatinine on a three-electrode system with the counter (CE) and working electrode (WE) made of screen-printed carbon and reference electrode (RE) made of silver. A schematic of the three-electrode system is shown on Figure 1(b). As creatinine is not electroactive on its own, we investigated the use of a widely studied strategy for creatinine measurement in the clinic: the conjugation of creatinine with copper. This copper-creatinine complex exhibits characteristic voltametric peaks corresponding to the reduction and oxidation of copper, enabling a highly sensitive creatinine detection using electrochemical methods (Montoya-Cano et al., 2025; Nontawong et al., 2019; Raveendran et al., 2017). Experiments using MIPs with varying creatinine concentrations showed a linear trend between 30 and 300 µM, as shown on Figure 2(a). Additionally, experimenting with copper using CV showed a

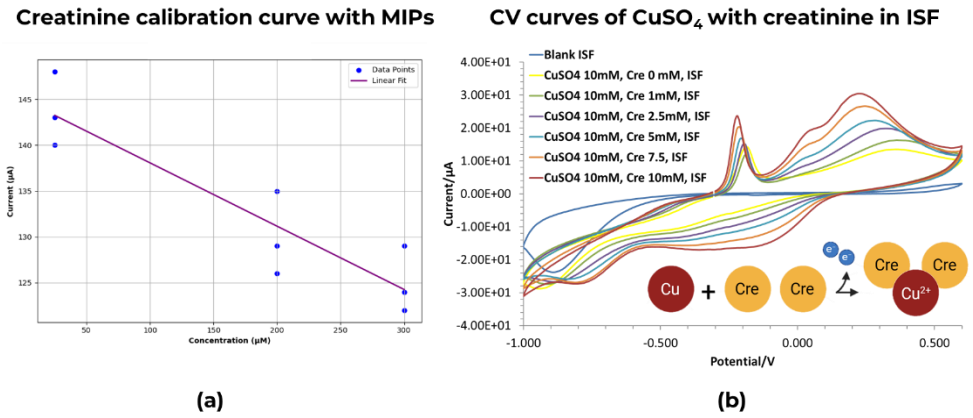

Figure 2: (a) Creatinine calibration curve obtained with electrodes covered with MIPS. (b) CV curves of $CuSO_4$ interacting with varying concentrations of creatinine in ISF. A schematic of the chemical interaction between creatinine and copper is shown below the CV curves.

noticeable increase in current with higher concentrations of creatinine due to an increase in electrons being released, shown on Figure 2(b).

2.3. Cartridge technology

The cartridge is a modular unit housing a sensing chip, fluidic channels, and sample handling components. The 3D-printed chip includes a flow cell with inlet and outlet ports, and an integrated electrode array for electrochemical detection. A secondary component slides in to secure the electrode. A 1.7 mm tube connects the sample port to the inlet, while another links the outlet to a motor-controlled syringe that withdraws fluid in increments of one-third of the sample volume. ISF samples are drawn through the sample port and pulled across the flow cell into the waste syringe. Between samples, air flushes the channel to reduce carryover and improve accuracy.

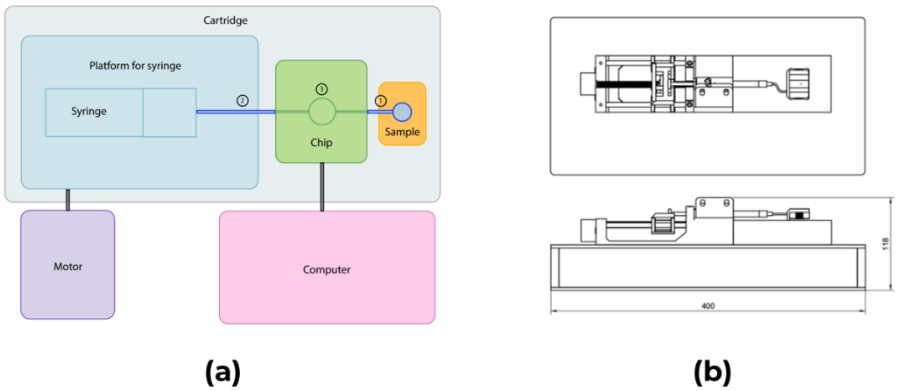

Figure 3: (a) Schematic of the cartridge system. 1 and 2 are connecting 1.7mm tubes, and 3 is the flow cell. (b) Schematic showing the technical views of the syringe platform, including the connection to the chip.

2.4. Reader instrument and user interaction

The biosensor uses a compact potentiostat (Sensit Smart, PalmSens) controlled by a Python script that automates calibration, electrochemical readings, and determination of creatinine concentration. Results are displayed in a user-friendly interface with both numerical and graphical outputs. Currently operated via a computer, the setup is compatible with smartphones, supporting future adaptation for mobile, point-of-care use.

3. IN award: Biosensor innovation

Our sensor is for patients recovering from kidney transplantation, who require frequent creatinine checks in the first six months post-surgery (see Translational Potential section for details). Current monitoring involves hospital visits and blood draws, creating both physical discomfort and mental burden for patients. Our approach enables safe, at-home monitoring to ease these problems and fit comfortably into the daily life of patients.

Figure 4: AI Model of wearable

3.1. Wearable sensor

To address these challenges, we developed a small upper-arm patch (see Figure 4) for quick, painless at-home creatinine measurement. It uses gold-coated microneedles coated with molecularly imprinted polymers (MIPs) to access interstitial fluid without puncturing blood vessels (Kim et al., 2019). Figure 5a shows the patch on the skin with microneedles penetrating the epidermis to reach interstitial fluid. An NFC-based integrated circuit is connected to the microneedles. It includes a potentiostat and performs cyclic voltammetry when the reader/smartphone sends a wake-up command wirelessly via NFC protocol (Krorakai et al., 2021). In figure 5b, creatinine binding to the MIP layer changes the electrochemical signal, which is processed in the chip and sent to the smartphone (figure 5c) for immediate display. As patients only need 1–2 measurements per day, the sensor is optimized for on-demand use, reducing complexity while meeting user needs.

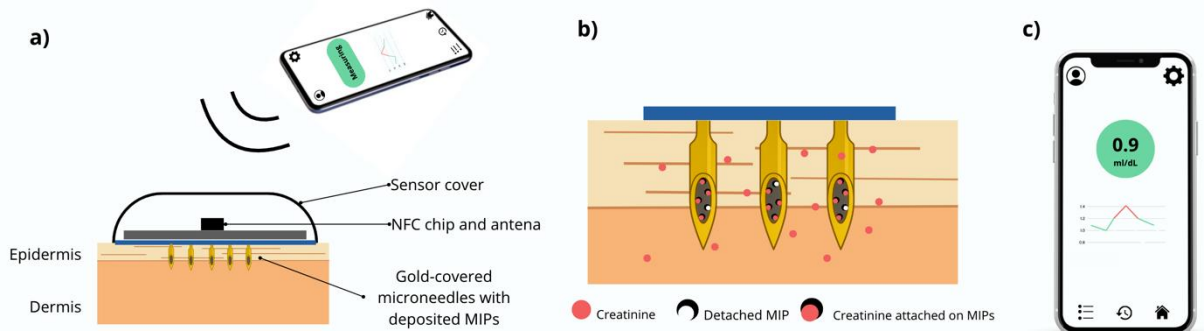

Figure 5: (a) Overview of whole sensor system. (b) Zoom-in of microneedles showcasing functionality. (c) User interface on reader/smartphone that displays data in a graphical way.

3.1.1. Technological novelty of wearable sensor

The novelty of our wearable biosensor lies in the integration of three components: microneedle arrays, MIPs as the biorecognition element, and an NFC-enabled integrated circuit that handles both signal generation and data transmission. The MIP layer is engineered to selectively bind creatinine as described in section 2.1. The

microneedle array is fabricated to include distinct regions functioning as the working, counter, and reference electrodes, enabling a full three-electrode configuration in a compact format (Tehrani et al., 2022). While microneedles and MIPs have individually been explored in academic research, to the best of our knowledge, our wearable system is the first to combine MIPs with microneedles for creatinine detection. This creates a novel and integrated biosensing platform tailored for chronic kidney disease patients.

3.1.2. Technical feasibility of wearable sensor

Microneedle Array

The microneedle array was 3D printed using a masked stereolithography (MSLA) printer with *Prusament Resin Model Transparent Green*, a plant-based resin. Since this resin is non-conductive, we coated specific regions of the microneedle array with gold sputtering using a mask to enable electrochemical sensing and MIP deposition (Duente et al., 2024). This fabrication method is fast, scalable, and low-cost—making it highly suitable for wearable sensor production. An example of our printed microneedle array (without gold coating) is shown in Figure 6. To finalize the electrochemical interface, these gold-coated regions will serve as the base for MIP deposition and signal transduction.

Figure 6: (a) 3D printed microneedles without gold under optical microscope, (b) whole 3D printed array, (c) The integrated circuit SIC4341

Powering, measurement and Signal Transmission

The integrated circuit SIC4341 (figure 6c) was demonstrated to be used for cyclic voltammetry (Krorakai et al., 2021). In our application we would like to use microneedle arrays as electrodes for cyclic voltammetry. This proof of connect has been demonstrated in (Kim et al., 2019). For the transmission of the data, we will use a circular screen-printed antenna soldered to the chip. The software from the chip manufacturer will perform the necessary calculations for concentration estimation on the reader/smartphone (Krorakai et al., 2021). The calibration curve will be calculated as described in section 2.4.

3.2. Reliability of sensor output

The potential sources of variability or unreliability include complete or partial damage of the needles, MIPs peeling off or being destroyed during skin penetration, and insufficient powering of the sensor during measurement. Therefore, the team has focused on two critical aspects: mechanical stability of the microneedles with MIPs during skin penetration, and enabling reliable powering of the device. To achieve this, the microneedles were designed with a sharp point for easy penetration, and a cavity where the MIP will be protected (Figure 7). The NFC powering method will ensure a good, reliable transfer of power for the performance of cyclic voltammetry without relying on batteries or rechargeable parts.

3.2.1. Technological novelty of reliability concept

The core innovation in our reliability approach is the unique shape and structure of the 3D-printed microneedles, designed specifically to preserve MIP functionality and structural integrity during skin insertion. The combination of geometry, material, and coating supports both mechanical resilience and stable voltametric response. While NFC-based powering is not new, integrating it into this reliability strategy is novel, eliminating battery degradation and power instability that cause drift in other biosensors (Lazaro et al., 2023).

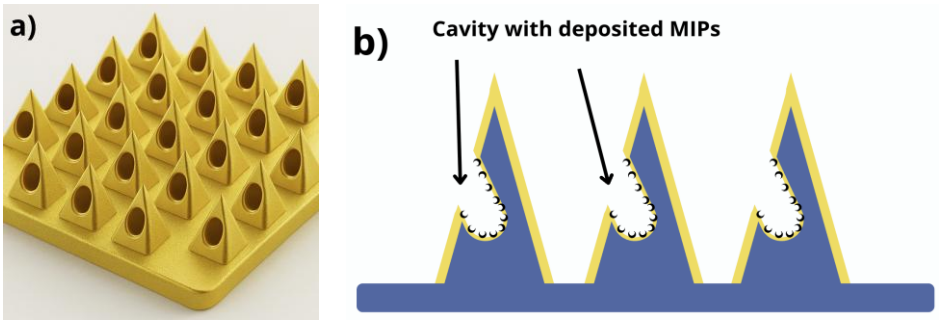

Figure 7: (a) 3D-Model of Microneedle-Array with a protective cavity at the tip that shields the MIP layer from mechanical stress and a pyramidal body for enhanced strength compared to straight pillar geometries (Lin, 2019) (b) correctional view of microneedles demonstrating the layers of gold and MIP in the cavity; AI-generated.

3.2.2. Technical feasibility of reliability concept

To ensure that the microneedle design described in section 3.2.1 is mechanically stable, we conducted preliminary mechanical tests and outlined a robust test plan for validating needle integrity and measurement consistency.

Mechanical Stability – Parafilm Testing

To mimic the mechanical resistance of skin, we used a 10-layer parafilm (PM-996) model (as proposed by (Larrañeta et al., 2014) an accepted method for simulating skin penetration with microneedles. Each layer is approximately 127 µm thick, and successful penetration of multiple layers is considered a good approximation for insertion depth into the epidermis (~300–900 µm). We conducted a pilot experiment using a basic microneedle prototype. The microneedle array was pressed against the layered parafilm using varying forces (light to maximum) as demonstrated in Figure 8a. Forces were estimated using water weight in a beaker, based on gravitational force, simulating 10–50 N, the estimated range for microneedle insertion (Larrañeta et al., 2014). The forces we want to test will range well above and below this range to test the limit of the design. For maximal force, preliminary results show penetration of 2 layers (Figure 8b), demonstrating basic proof of concept. Visual inspection of microneedle tips before and after insertion showed some deformation but not complete destruction, this could indicate early feasibility considering maximal force was used.

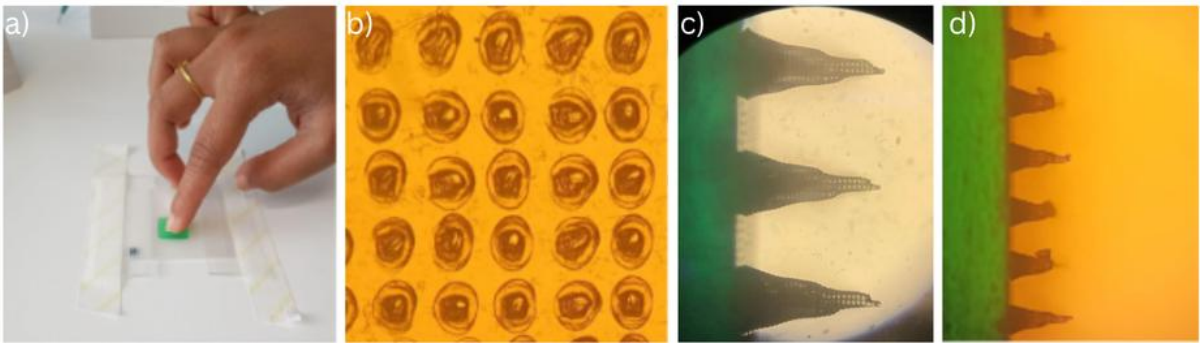

Figure 8: (a) experimental set-up for parafilm perpetration. The microneedle array was pressed using our finger on to the parafilm stack (b) one layer of penetrated parafilm (c) before parafilm penetration (d) after parafilm penetration

We plan further testing of optimized needle shapes (e.g., those with inward cavities) under the same conditions to confirm that the final design offers similar or better mechanical resilience.

Signal Consistency – NFC Powering Stability

The integrated circuit will ensure consistent powering for each measurement, avoiding under- or overpowered cycles. It will fit patient expectations of 1-2 daily readings, not absolute continuous tracking therefore, reliability is measured over repeated, discrete uses. We are currently validating the repeatability of current output in repeated NFC-activated cycles to confirm signal stability across sessions.

3.3. Original contributions

The biosensor concept was developed by our team, combining promising and feasible ideas into a single, original design. While we consulted professors, experts, and the TP team for feedback, the core idea originated within the team.

- **Conceived by:** The team, proposing microneedles with MIPs and a gold-coated cavity.
- **Selected by:** The team, choosing this approach for its originality and practicality.
- **Adjusted by:** The team with external feedback, improving needle shape, resin choice, and gold-coating concept.
- **Tested by:** The team, through microneedle printing, material testing

Statement from supervisor

The Glomero team has shown outstanding independence and originality in developing a wearable biosensor for continuous creatinine monitoring. Importantly, the core concept and design choices were developed entirely by the students themselves, without being suggested or directed by their supervisors or coaches. From the outset, they approached the project with curiosity and determination, investigating different sensing strategies before independently selecting an electrochemical approach using molecularly imprinted polymers (MIPs) for recognition.

Their design integrates methylene blue into the MIPs to enable conductivity and introduces copper to enhance sensitivity, an innovative combination inspired by literature but uniquely brought together by the team. They also devised a wearable format using microneedles for fluid extraction, optimizing the needle shape to ensure reliable skin penetration and stability with the MIPs.

While they received technical feedback from a postdoc, a PhD student, and other researchers at DTU, the project's direction and ideas were entirely their own. The team consistently demonstrated initiative, creativity, and scientific insight, resulting in a promising and novel biosensor that highlights their ability to work independently and contribute meaningfully to the field.

Supervisor
Prof. Winnie Edith Svendsen

Team captains
Miriam Roller & Guilherme Caseiro

4. TP award: Translation potential

For our biosensor technology to achieve real-world impact and commercial viability, it must address a clearly defined clinical need; this requires identifying a patient group where the product can deliver the greatest value.

4.1. Customer interviews

Our strategy for meeting the product-market fit followed a two-phase approach. In Phase 1, we aimed to define our users by exploring which kidney disease (KD) patient group would benefit the most from continuous creatinine monitoring. In Phase 2, we conducted a deep dive into the selected group's needs through targeted stakeholder interviews.

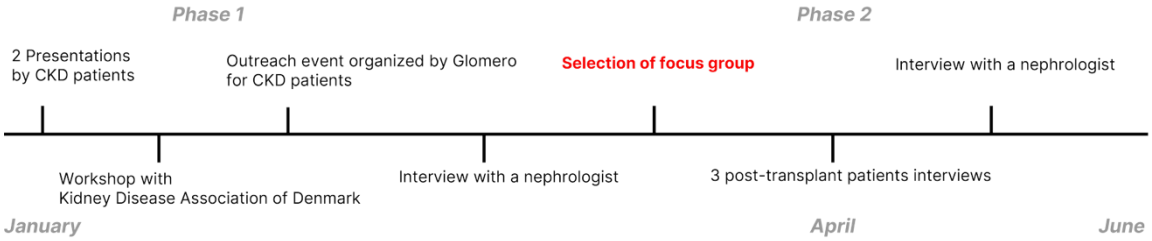

Figure 9: *Timeline of conducted translational potential activities.*

In Phase 1, we undertook a broad exploration, to understand the diversity of needs and contexts. Activities summed up in Figure 9. enabled us to identify and compare three primary patient segments.

Pre-failure patients (CKD stages 1–3a), representing roughly 10% of the adult population (Kovesdy, 2022). These patients are often undiagnosed or only occasionally tested (~every 6 months), with creatinine levels frequently in the normal range. Their risk factors typically include diabetes, obesity, cardiovascular disease, and hypertension.

Kidney failure or dialysis patients (CKD stages 3b–5), making up around 8% of the adult population (Kovesdy, 2022). This group is often diagnosed and experiences rapidly declining kidney function, often alongside comorbidities. Creatinine monitoring in this group is mainly useful for long-term trend tracking (~every 6 months), while potassium and hydration levels are more critical for day-to-day management.

Post-transplant patients, estimated at around 18,000 individuals annually in the EU (Conor Stewart, 2024), primarily aged 50–70. This group is not on dialysis but undergoes frequent (daily or weekly) check-ups, especially in the period immediately following transplantation when the risk of organ rejection is highest. They are on immunosuppressants, and creatinine is a key biomarker for detecting early rejection.

Post-transplant patients emerged as the group where continuous creatinine monitoring offers the greatest impact. Unlike pre-failure patients, who don't require frequent testing,

or dialysis patients, where creatinine is not critical for daily management, transplant recipients rely on frequent measurements to detect early signs of organ rejection, with creatinine being the key biomarker. Enabling at-home monitoring for this group could replace many hospital visits, reduce the risk of complications and hospital-acquired infections, and provide patients with reassurance about their health status.

Interview methodology

All interviews were semi-structured, allowing flexibility to follow the flow of conversation. Patient interviews were conducted in person, with audio recordings made under signed consent. Patient interviews explored personal experiences with KD and transplantation, daily health management, current monitoring practices and awareness, pain points and emotional impacts, and feedback on a proposed continuous monitoring prototype (see Appendix for interview guide and summaries). Nephrologist interviews took place both in person and online, covering similar themes, but from the clinician's perspective.

Key findings from the interviews - Post kidney-transplant patient group

Medical reasoning

Standard post-transplant monitoring:

- Hospitalization: 5–14 days with 1–2 daily creatinine tests.
- Follow-up: 2 times per week (1 month), then once per week (3 months).

- Our sensor is viable for the patient up to **6 months after transplantation**, then a single use device is more appropriate.

Customer interviews take-aways

- Transplant patients must go frequently to the hospital as defined by the standard care procedure. This is both mentally and physically draining for a patient that is fragile. In unanimity, the patients agreed that in the after-transplant period they wanted more peace of mind and less hospital visits that made them feel even sicker.
- There is space for our biosensor in the patient's life after transplant, where it could reassure their recovery is in the right parameters, and warning any complications.

The sensor follows the 'point of care' trend:

- Patients, doctors and hospitals would benefit, by allowing the patient to go home faster.
- The patient recovers better with mental stability and familiar environment. The biosensor offers a tool of comfort for anxiety without compromising the doctor-patient clinical relationship. Reduces unnecessary hospital time and visits.

Financial aspect:

- Cost saving up to 7780 € per patient. Assuming 300 transplant per year in Denmark, it could save up to 2.3 M €. With the same data, the equation changes to roughly 140 M € per year for the EU (18 000 kidney transplants annually). (see in Appendix)

4.2. Design of validation study

Problem statement from the patient's perspective

The key problem identified from our interviews is the physical and mental burden caused by frequent post-transplant monitoring, especially during the 6-month recovery phase. Our solution addresses this by enabling at-home, non-invasive, easy-to-use creatinine monitoring.

A. Conceptual Prototype and Use Case

Our conceptual prototype is a wearable biosensor designed for kidney transplant patients during their 6-month recovery period. The sensor adheres directly to the skin and is designed to be non-invasive, comfortable, and minimally disruptive to daily life. It integrates microneedles for painless sampling and uses an NFC chip for passive communication. The patient retrieves data by tapping their phone on the device, triggering results to appear in a simple, readable app interface. This aligns with patients' preferences for clarity, independence, and stress-free monitoring.

Use Case (Storyboard):

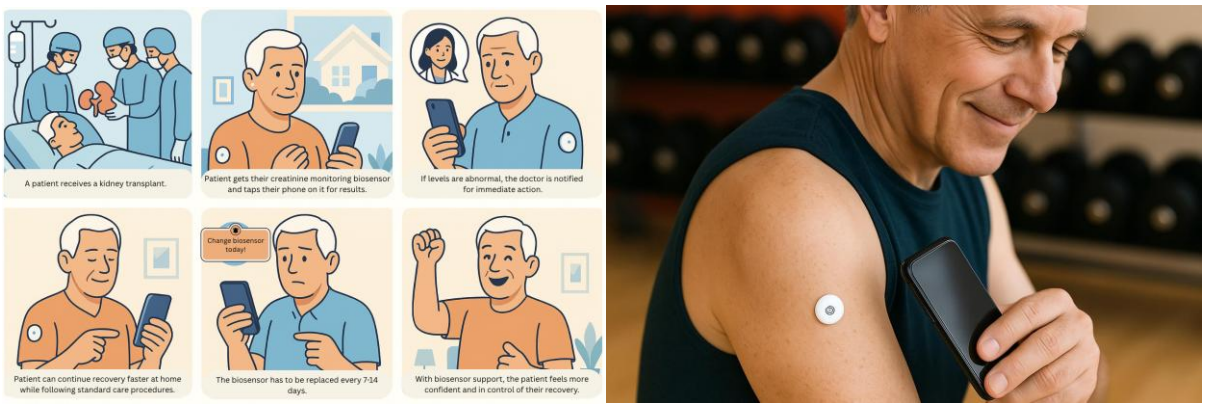

Figure 10: Use-case storyboard (left). Prototype mock-up (right). Generated by AI

B. Critical Aspects of the Proposed Solution

The critical aspects to be validated focus on usability, comfort, and system trustworthiness:

- Sensor wearability: How well does it stick, is it comfortable is it over time?
- Sensor placement: What body placement are optimal for comfort and functionality?
- Self-application: Can the patient apply the sensor independently and confidently?
- Interaction with phone/app: Can the patient successfully read results using NFC?
- App usability: Is the data clear, simple, and easy to interpret?
- Perceived trust: Do patients feel safe replacing physical check-ups with the system?

C. Validation Study Design (8–10 patients, recovery phase)

The aim of the study is to evaluate whether the proposed biosensor system delivers added value to kidney transplant patients during recovery. We hypothesize that it improves

mental comfort, reduces hospital dependency, and enables more independent, stress-free monitoring compared to current practices.

Methodology

A. Mock-Up Interaction Test

Patients receive a physical mock-up of the sensor (e.g. silicone patch with NFC tag) and a clickable app prototype, to simulate real use without requiring functional sensor hardware. They are asked to: apply the sensor to their predetermined body location, then tap a phone to simulate reading results and navigate through the app interface.

Metrics collected:

- Self-reported comfort level (0–10 scale)
- Observed ability to apply and use the device without help
- Task success rate and time (e.g. applying sensor, opening results)
- Feedback on preferred placement and interaction clarity

B. Questionnaire on Perceived Added Value

After the mock-up test, participants complete a brief questionnaire using a 5-point Likert scale to rate: mental comfort and stress reduction, trust in the system, preference over traditional hospital visits, and optional tools: System Usability Scale (SUS) or NASA-TLX may be used to quantify usability and workload.

Outcomes and Evaluation Plan

The following types of data will be collected and analysed:

Quantitative scores: Average ratings for well-being, trust, independence, and usability. These will indicate the **strength of the perceived added value**.

Usability challenges: Observations and questionnaire results will reveal any problems in using the sensor or app (e.g. confusion, discomfort, difficulty with interaction).

Qualitative feedback: Open-ended responses will provide insight into what participants liked most, what felt unnecessary, and what they would improve.

Design refinement input: All findings will be used to guide improvements in both the sensor design (e.g. shape, placement, wearability) and app interface (e.g. clarity, user flow).

Conclusion

This validation study aims to assess whether our conceptual biosensor provides real added value to post-transplant patients by improving comfort, independence, and usability. Through mock-up testing and patient feedback, we will evaluate key aspects of the design and identify areas for improvement. The results will guide further development and ensure the solution fits real-world patient needs while reducing the burden on healthcare systems.

5. Team and support

5.1. Contributions of the team members

TEAM MEMBER	ROLE
GUI	Co-Team lead, innovation team: concept development
MIRIAM	Co-Team lead, analytical team: cartridge technology
MIREIA RICO	Analytical team lead, and has contributed greatly to other teams
CONNOR	Analytical team lead: molecular recognition and physical transduction
LUCAS	Analytical team: cartridge technology
THEA	Analytical team: molecular recognition
ZITA	Analytical team: molecular recognition and physical transduction
RUO	Analytical team: Software
NIKA	Innovation team lead: research and concept development
RASMUS	Innovation team: research and concept development
YAMINI	Innovation team: research and concept development
MARTIN	Translational team lead: event organization, branding, customer validation
DENISA	Translational team: Workshop organization, social media responsible
LUCIE	Translational team: Event organization, core ideas definition; Innovation team: research and idea definition
LUCA	Translational team: Medical expert interview, event organisation

5.2. People who have given support

NAME	ROLE
WINNIE SVENDSEN	Supervisor
CHRISTIAN BERTELSEN	Coach, helped with any questions or problems we faced, administrative tasks
DANIEL CRISTEA	Coach, helped with any questions, especially about electrochemical sensing
ANNETTE HOLEK	Administrative tasks
MARIA DIMAKI	Administrative tasks
PULKIT SALUJA	Input on sensor design
MARIA ANTONSEN	Teambuilding workshops and pitching support
AABHA BAJAJ	Support during DTE
NEETI KALYANI	Support during DTE
NIELS ERIK OLESEN	Advice on microneedles

5.3. Sponsors and partners

NAME	ROLE
DANISH KIDNEY ASSOCIATION	Speakers at events, interviews
DITTE HANSEN	Medical expert, professor in Nephrology

6. Final remarks

During the development of our biosensor, we identified additional biomarkers beyond creatinine that could help monitor kidney function in transplant patients. While creatinine remains a key indicator of glomerular filtration rate (GFR), incorporating other biomarkers like Cystatin C could offer a more comprehensive assessment (Santos, 2015). We believe this dual-biomarker approach can enhance patient monitoring and improve transplant outcomes and longevity.

Another potential improvement is the integration of machine learning or AI into the sensor system to further enhance its accuracy, adaptability, and predictive capabilities. Studies show that early acute rejection within the first year after kidney transplant significantly increases the risk of graft failure (Yoo et al., 2017). Machine learning methods offer flexible and effective tools for predicting graft survival from creatinine measurements and incorporating such approaches could add substantial value to our sensor in the future.

We would like to close this report by honouring an incredible person, Henning Sondergaard. We were truly fortunate that he decided to spend his last time on Earth helping us develop our sensor. His dedication and unwavering support inspired us on improving care for those with chronic kidney disease.

7. Bibliography

BelBruno, J. J. (2019). Molecularly Imprinted Polymers. *Chemical Reviews*, *119*(1), 94–119. https://doi.org/10.1021/acs.chemrev.8b00171

Conor Stewart. (2024, 22. November). *Organ transplantation activity in the EU 2023| Statista*. Statista. https://www.statista.com/statistics/1204326/organ-transplantation-activity-in-the-eu/

Duente, T., Schrapel, M., Schulte, J., Janssen, N., Al-Azzawi, I. & Rohs, M. (2024, September 21). A Touch of Gold — Spraying and Electroplating 3D Prints to Create Biocompatible On-Skin Wearables. *MobileHCI 2024 Adjunct Proceedings - Publication of the 26th International Conference on Mobile Human-Computer Interaction*. https://doi.org/10.1145/3640471.3680227

Kim, K. B., Lee, W. C., Cho, C. H., Park, D. S., Cho, S. J. & Shim, Y. B. (2019). Continuous glucose monitoring using a microneedle array sensor coupled with a wireless signal transmitter. *Sensors and Actuators, B: Chemical*, *281*, 14–21. https://doi.org/10.1016/j.snb.2018.10.081

Kovesdy, C. P. (2022). Epidemiology of chronic kidney disease: an update 2022. *Kidney International Supplements*, *12*(1), 7. https://doi.org/10.1016/J.KISU.2021.11.003

Krorakai, K., Klangphukhiew, S., Kulchat, S. & Patramanon, R. (2021). Smartphone-based nfc potentiostat for wireless electrochemical sensing. *Applied Sciences (Switzerland)*, *11*(1), 1–13. https://doi.org/10.3390/app11010392

Larrañeta, E., Moore, J., Vicente-Pérez, E. M., González-Vázquez, P., Lutton, R., Woolfson, A. D. & Donnelly, R. F. (2014). A proposed model membrane and test method for microneedle insertion studies. *International Journal of Pharmaceutics*, *472*(1–2), 65–73. https://doi.org/10.1016/j.ijpharm.2014.05.042

Lazaro, A., Villarino, R., Lazaro, M., Canellas, N., Prieto-Simon, B. & Girbau, D. (2023). Recent Advances in Batteryless NFC Sensors for Chemical Sensing and Biosensing. In *Biosensors* (Vol. 13, Issue 8). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/bios13080775

Lee, D. H., Lee, W.-Y. & Kim, J. (2023). Introducing Nanoscale Electrochemistry in Small-Molecule Detection for Tackling Existing Limitations of Affinity-Based Label-Free Biosensing Applications. *Journal of the American Chemical Society*, *145*(32), 17767–17778. https://doi.org/10.1021/jacs.3c04458

Pereira, A. C., Oliveira, A. E. F. & Bettio, G. B. (2019). β-Cyclodextrin electropolymerization: mechanism, electrochemical behavior, and optimization. *Chemical Papers*, *73*(7), 1795–1804. https://doi.org/10.1007/s11696-019-00732-x

Santos, J. (2015). Estimating glomerular filtration rate in kidney transplantation: Still searching for the best marker. *World Journal of Nephrology*, *4*(3), 345. https://doi.org/10.5527/wjn.v4.i3.345

Tehrani, F., Teymourian, H., Wuerstle, B., Kavner, J., Patel, R., Furmidge, A., Aghavali, R., Hosseini-Toudeshki, H., Brown, C., Zhang, F., Mahato, K., Li, Z., Barfidokht, A., Yin, L., Warren, P., Huang, N., Patel, Z., Mercier, P. P. & Wang, J. (2022). An integrated wearable microneedle array for the continuous monitoring of multiple biomarkers in interstitial fluid. *Nature Biomedical Engineering*, *6*(11), 1214–1224. https://doi.org/10.1038/s41551-022-00887-1

Tsai, H.-A. & Syu, M.-J. (2005). Synthesis of creatinine-imprinted poly(β-cyclodextrin) for the specific binding of creatinine. *Biomaterials*, *26*(15), 2759–2766. https://doi.org/10.1016/j.biomaterials.2004.07.037

Yoo, K. D., Noh, J., Lee, H., Kim, D. K., Lim, C. S., Kim, Y. H., Lee, J. P., Kim, G. & Kim, Y. S. (2017). A Machine Learning Approach Using Survival Statistics to Predict Graft Survival in Kidney Transplant Recipients: A Multicenter Cohort Study. *Scientific Reports*, *7*(1). https://doi.org/10.1038/s41598-017-08008-8

Younespour, S., Rahimi Foroushani, A., Maraghi, E., Rostami, Z., Einollahi, B., Eshraghian, M. R. & Mohammad, K. (2016). Longitudinal Serum Creatinine Levels in Relation to Graft Loss Following Renal Transplantation: Robust Joint Modeling of Longitudinal Measurements and Survival Time Data. *Nephro-Urology Monthly*, *8*(5). https://doi.org/10.5812/numonthly.39292

8. Appendix

Translational potential team:

Calculations of hospital care:

A day in hospital (in Denmark) with a standard care costs 270€. By calculating that the patient spends 5-14 days in the hospital, the price for hospitalization is 1350€ - 3780€ per transplanted patient.

After the transplant the patient undergoes roughly 20 regular checkups in the 6 months period after. A price per check-up is 200€, which leads us to 4000€ in total. When we sum up hospitalization and checkups, we get to the number of 5350€ - 7780€ per patient.

Annual kidney transplants in Denmark ~300. Annual kidney transplants in the EU ~18 000.

7780€ * 300 = €2 334 000.00

7780€ * 18000 = €140 040 000.00

Interview guide with summary:

Patient Interview Guide

Goal: Explore the life burdens of kindey disease patients after transplantation

Introduction (2 min)

- Monitor kidney functiom, Continuous sensor, measuring creatinine

Tell about glomero. Target transplant patients.

1. Warm-up & Context (5 min)

- Can you tell us a bit about your experience with kidney disease or transplantation?
- Can you walk me through the process of receiving the news that you were getting a transplant, going through the operation and following recovery
- What does your typical week look like in terms of managing your health?
- Who else is usually involved in helping you with that (e.g., family, healthcare providers)?

2. Current Monitoring & Awareness (10–15 min)

- When was the last time you had your kidney function tested?
- Can you walk us through how that test happened?
- What kinds of things do you know are being measured in those tests? *(If they don't mention creatinine:) Have you ever heard of creatinine? Does that term mean anything to you?*
- How often do you usually get tested?
- How do you receive the results — app, call, clinic visit?

- What usually makes you decide to go to the doctor outside of regular check-ups?
- Is there anything you wish you could know about your kidney health between appointments?
- How much time are they spending in the hospital? Do they like the location or not
- Why do they feel safe at hospital vs not? What could we do to support this

Focus on fears and hopes

3. Pain Points & Emotional Layer (10–15 min)

- Have you ever had a time where you felt something was off but couldn't be sure?
- What's the most frustrating or annoying part of managing your condition?
- What's the hardest part about managing your condition?
- Do you try to track or monitor anything yourself between visits?
- Who do you talk to if something doesn't feel right?
- How much do you rely on your doctor vs. managing or interpreting things yourself?
- Are there any fears you live with around your condition?
- Are there any symptoms you pay close attention to or worry about?

4. Feedback on Concept & Early Prototype (10–15 min)

- **Say:** *We're exploring a tool that could help people like you monitor kidney function more continuously at home. It's still in a very early stage, and we'd love your honest thoughts.*

Storyboard:

- What's your first reaction to this idea?
- How do you imagine something like this could help you?
- When would it feel useful? When wouldn't it?
- What might make you **not** want to use something like this?
- What would you expect to see or understand from a tool like this?

Prototype:

- What do you think this is or does? What is your first reaction when you see this?
- Anything about the form or design that worries you or interests you?

- Could you imagine using or carrying something like this? When or how?

Big vs small

Rigid vs flexible

Bring a glucose sensor from lucie. How would you feel about this invasive solution.

Would you willing to wear this everyday. What should it be able to do for you, make you feel make you look and what needs should be covered.

5. Wrap-up & Closing (5 min)

- Is there anything we didn't ask that you think is important to share?
- Would you be open to us checking in again later as we develop this?
- Do you know anyone else who might be open to a conversation like this?

Summary from each interview

P1

- Gets tested every 4-5 months, with one test at the hospital and one over the phone
- The tests measure kidney function, creatinine, blood sugar, electrolytes like sodium and potassium
- Has had issues with infections and fluctuating kidney function, requiring more frequent monitoring at times
- Tries to avoid going to the hospital if possible
- Very knowledgeable about their condition and proactively manages it
- Believes it's important for patients to understand their lab results
- Discusses pros and cons of having more frequent at-home testing options:
    - Could be helpful in certain situations, like when feeling unwell before a trip, to check if everything is okay

- But also worries it could cause more stress and obsession for some patients, especially early on

P2

- Has had a kidney transplant for around 10 years
- Sleeps a lot, around 8-9 hours at night and 1-2 hours in the evening
- Feels very tired all the time and has trouble with balance and mobility
- Does light activities like reading, volunteering, and playing cards
- Stopped working 2 years ago to focus on their health and enjoy life
- Expresses a need for a biosensor to monitor specific markers like CRP (C-reactive protein) to detect infections early, without having to go to the hospital

- **Shared Perspectives**

- Recognize kidney patients can have very different needs and approaches when it comes to monitoring their health
- Believe it's important for patients to be proactive and knowledgeable about their condition
- Discuss the balance between having more data/control and avoiding unnecessary stress or obsession
- Acknowledge the potential value of a biosensor, especially for detecting issues like infections early, but also the need to be cautious about over-monitoring

P3

The patient received a kidney transplant in 2008 after having issues with her kidneys for many years. In the beginning after the transplant, she had some challenges where the new kidney was not functioning optimally, and she had to be hospitalized several times due to infections and fluid buildup.

During that period, the first 6 months after the transplant, a wearable biosensor could have been helpful for her. She had to go in for frequent check-ups and hospitalizations, and a sensor that could measure relevant values like creatinine and kidney function could have given her more peace of mind and fewer hospital visits. She says herself that it was a very turbulent period where a sensor could have helped.

Today, 13-14 years after the transplant, her kidney generally functions well and she leads an active life. However, she still has some challenges with blood pressure and heart arrhythmia that she needs to monitor. Here, a sensor that could measure blood pressure and heart rate could also be useful for her, so she doesn't have to make as many trips to the doctor.

Overall, the interview shows that a wearable biosensor could have been helpful for the woman, especially in the initial period after the transplant when she had many hospitalizations and check-ups. A sensor could have given her more reassurance and fewer hospital visits.