Team Results Document

ParisBiotek



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7 August 2026

SensUs

1. Abstract: Summary for the SensUs website

ParisBiotek's 2026 team is glad to work on a complex scientific project that will test and improve our science skills while allowing us to work on a genuine social problem. We are searching for a sustainable solution to Parkinson's disease by creating our own wearable and using a system that has not been used before to our knowledge. We are looking forward to presenting you our solution to a disease that is causing many damages in patients' lives. Furthermore, we are impatient to exchange with the other teams about their approaches, the strategies they developed throughout the year, the challenges they faced and the lessons they learned from this competition. Our motivation, curiosity and willingness to do better are our strong points and are the reasons we want to be part of the SensUs journey this year again.

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

2.1. Molecular recognition

The biosensor uses two complementary molecular recognition strategies to ensure specific detection of dopamine-related signals in physiological fluids.
The first mechanism relies on the enzyme aromatic L-amino acid decarboxylase (DDC), which catalyzes the conversion of levodopa (L-DOPA) into dopamine. This enzymatic reaction generates dopamine that can subsequently be detected by the electrochemical system. To maintain sensor performance in biological fluids, the sensing surface is protected by a chitosan-polyvinyl alcohol (PVA) hydrogel coating, which reduces non-specific protein adsorption and improves biomolecule stability.
The second recognition mechanism uses a dopamine-specific DNA aptamer that selectively binds dopamine through ligand-induced folding (Kaiyum et al.). The aptamer is immobilized on the electrode through its 5' end, and when dopamine binds, the change in conformation induces an electrochemical signal.
The combination of enzymatic and aptamer-based recognition increases specificity and enables signal cross-validation.

2.2. Physical transduction

The developed biosensor is an electrochemical aptamer-based sensor that converts the specific recognition of dopamine into a measurable electrical signal. The sensing element consists of a DNA aptamer that is specifically designed to bind dopamine. The aptamer is immobilized onto a gold electrode through a 5'-terminal disulfide (C6) linker, which forms a stable Au–S bond with the gold surface.
A self-assembled monolayer is used to provide a well-organized sensing interface, reduce nonspecific adsorption and ensure a controlled orientation of the immobilized aptamers.
The 3' end of the aptamer is labelled with methylene blue (MB), a reversible redox-active molecule that serves as the electrochemical reporter. Although MB is attached to the aptamer rather than directly to the electrode, it can exchange electrons with the gold electrode during electrochemical measurements because the aptamer is fixed to the electrode.
In the absence of dopamine, the aptamer adopts its native conformation. When dopamine binds to the aptamer, the recognition event induces a conformational change that folds the aptamer and brings the methylene blue reporter into a more favorable position for electron exchange with the electrode.
This conformational rearrangement results in an increase of the electrochemical signal, which can be monitored by techniques such as cyclovoltammetry.
Because the interaction between dopamine and the aptamer is reversible, dopamine can subsequently dissociate from the aptamer. The aptamer then returns to its initial

conformation, restoring the original position of the methylene blue label and the corresponding electrochemical signal. This reversible recognition mechanism enables the sensor to perform repeated and real-time measurements without requiring replacement of the sensing element.
Overall, the biosensor transduces the molecular recognition of dopamine into a measurable electrical signal through reversible conformational changes of the aptamer that modulate the electron exchange between methylene blue and the electrode.

2.3. Cartridge technology

We designed a microfluidic circuit adapted to the dimensions of the electrode, the latter being the bulkiest component of the system. The circuit consists of a straight channel downstream of the inlet, measuring 0.50 mm in height, 3 mm in width, and 22.30 mm in length. This choice of a straight channel, without bends, limits turbulence and simplifies fabrication while ensuring a stable and predictable flow of interstitial fluid at a flow rate of 1 µL/min.

The channel is lined with our gel, 1 mm thick, which carries out the first stage of enzymatic conversion: the transformation of L-DOPA into dopamine. The fluid then continues its path to the reaction chamber, which constitutes the detection zone, where our aptamers ensure the specific recognition of the generated dopamine.

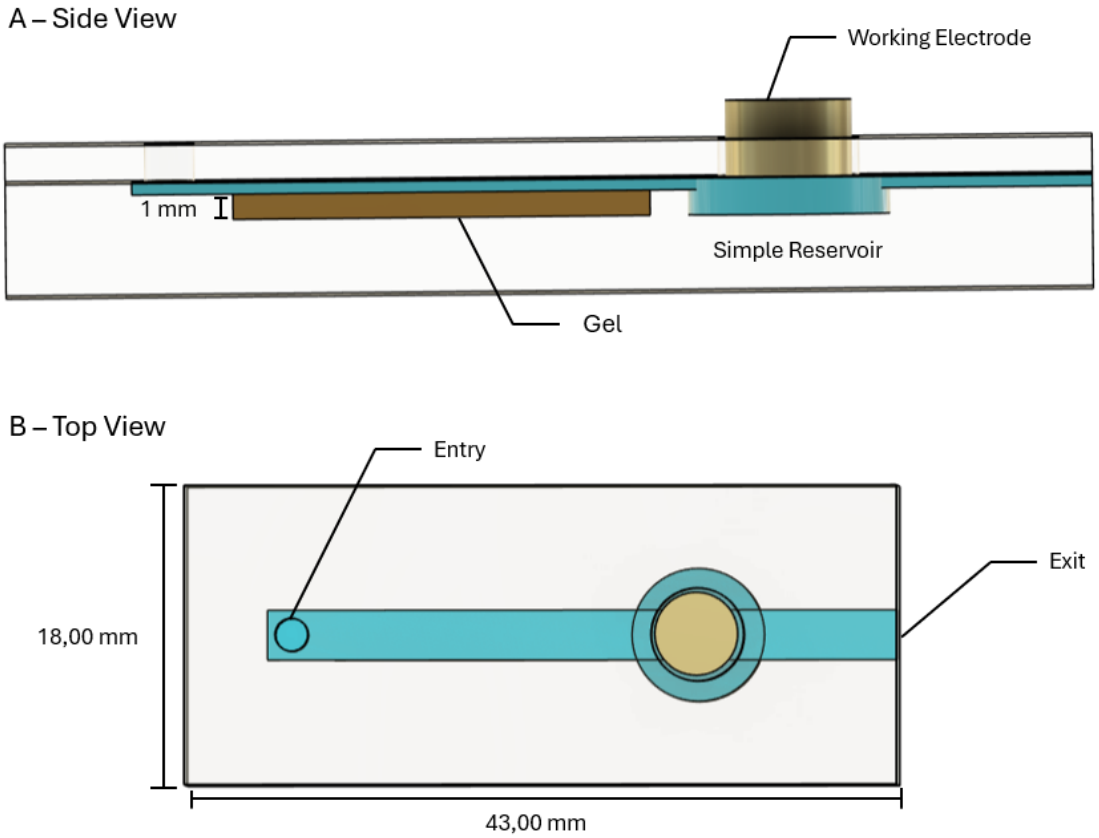


Figure 1. (a) Side view of the microfluidic reaction chamber integrated with the electrode and the gel layer. (b) Top view of the microfluidic reaction chamber integrated with the electrode.

The channel inlet is connected to a microneedle in direct contact with the patient's interstitial fluid, following the same principle as continuous glucose monitoring (CGM) devices used by diabetic patients. Although this approach is relatively invasive, it enables continuous and reliable sampling, which is essential for closely tracking L-DOPA fluctuations in Parkinson's disease patients.

The circuit is fabricated in PDMS (polydimethylsiloxane), a material offering several advantages for our application: it is biocompatible, optically transparent (allowing visual monitoring of channel filling and flow), gas-permeable, and compatible with soft lithography molding, providing high fabrication precision at the micrometer scale.

2.4. Reader instrument and user interaction

To measure the electron flow, the hardware uses a cyclovoltammetry method. To perform an accurate measure, we chose to use a high impedance and accurate ADC and TIA, integrated in a single front end featuring many programmable outputs. The sensor is the AD5940 which is dedicated to chemical measurements. To ensure getting the best accuracy in a small space, we decided to have a whole printed circuit board dedicated to electrochemical measurements and another dedicated to power management, numerical processing, and connectivity.

The analogic board includes the AD5940 and two dedicated LDOs and ferrites. This coupled to the EMI protection of using a separate PCB to ensure minimal readout noise. The ADC/TIA sensor is connected to the electrodes through an FFC/FPC connector. The removing of the cartridge is made by the user by disconnecting the flexible PCB featuring electrodes and the microfluidic system.

The analogic board is controlled and powered by the numerical board by a backplane connector. This PCB includes an nRF52840 chip, Bluetooth and NFC antennas, and a high-performance li-ion battery. The core of this board is the nRF52840. It can be programmed by USB and can communicate with either BLE or Serial. The battery is made by Samsung and has a better energy density than mainstream li-ion batteries. It needs a higher charge voltage that thus needs a special converter and BMS. We wanted the instrument to have a long autonomy with an estimated 7 days on a single charge. To achieve such a goal, we embedded two crystal oscillators, with one dedicated to compute times and another to sleep modes. An efficient switch load is also included to physically disconnect the power supply of the sensor.

The communication protocol was also specifically designed to reduce excessive power consumption and increase privacy of medical data.

The reader instrument fits in a 30mmx10mm cylinder which makes it easy to carry, on an arm as a wearable sensor.

Yet the cartridge is linked through a reliable fpc cable for its robustness and versatility (to be able to get new IOs easily, but soon we expect to have the whole cartridge on a flexible pcb plugged in a dedicated low profile ffc/fpc connector. Thus, it will be easy to change without any dedicated tools.
The user only must remove that cartridge every week or two and recharge the device through pogo pins on the unveiled face of the pch when removing the cartridge.

The reader instrument sends its data to a dedicated smartphone app by bluetooth and nfc (for authentication) with a high-level encryption level to ensure privacy. The user can decide though its phone to authorize some doctors to see and analyze its data. The LDopa levels are displayed continuously on a graph. By specifying the user's meals and medication, we expect to develop a light ai model to predict the right time for Ldopa medication. Reducing the risks of over and under medication.
The app can also send alerts on battery and cartridge recharge levels over time and send such data to specialists to get a cartridge recharge in time.

3. IN award: Biosensor innovation

3.1. Wearable sensor

Our long-term vision is to transform NeuroTrack into a miniaturized wearable device capable of longitudinally monitoring L-DOPA levels in the interstitial fluid, while separating the disposable biological/microfluidic component from a reusable electronic reader. The concept combines carbon microneedles, enzymatic recognition, electrochemical transduction, embedded signal processing, and wireless transmission to a smartphone. This architecture builds on the technological components developed this year while further adapting them toward a format compatible with everyday wear.

Functional architecture

Interstitial fluid → microneedles → DDC → dopamine → dopamine-specific aptamers → electrochemical detection → methylene blue → current → AD5940 → MCU → Bluetooth → application

The microneedles form the interface with the skin and provide access to the interstitial fluid with limited invasiveness. Previous studies have already demonstrated the feasibility of

electrochemical L-DOPA monitoring using microneedles in artificial interstitial fluid and following skin penetration, supporting the relevance of this architecture for NeuroTrack.

In our system, L-DOPA is converted into dopamine by DOPA decarboxylase (DDC), after which dopamine-specific aptamers provide selective molecular recognition. DDC requires pyridoxal-5'-phosphate (PLP) as a cofactor; therefore, its availability and stability will need to be carefully controlled within the cartridge. The resulting sensing process is subsequently coupled to electrochemical detection at low potential using methylene blue, a redox mediator used to facilitate electrochemical signal transduction.

DNA aptamer are specific for dopamine. The aptamer undergoes a conformational fold induced by binding to dopamine. The 5' end is immobilized on the electrode / 3' end is labeled with methylene blue. When dopamine binds, the change in conformation alters the distance between the methylene blue and the electrode, inducing a variation in the electrochemical signal. DNA sequence of the dopamine aptamers: **5'-CGACGTCAGTITGAAGGTTCGTTCGCAGGTGTGGAGTGACGTCG-3'**(1).

The enzymes and biological recognition components are immobilized within a chitosan/PVA gel in order to retain the biological components locally and promote their stability. Previous studies have demonstrated the relevance of chitosan and polymeric matrices for enzyme immobilization in electrochemical biosensors. The chitosan/PVA gel further contributes to the structuring of the sensing interface and controlled transport of analytes.

The biological and microfluidic components will be integrated into a removable cartridge, whereas the reader, battery, and electronic components will remain reusable. This modular separation facilitates the replacement of biological components that are subject to degradation over time and prevents the electronic system from being discarded after each operating cycle.

Continuous monitoring

True continuous monitoring requires the sensor to accurately track both increases and decreases in analyte concentration. Our approach therefore relies on the continuous or periodic renewal of fluid in the vicinity of the reaction zone. The low-volume microfluidic environment limits the accumulation of enzymatic reaction products and enables the signal to re-equilibrate when L-DOPA concentration decreases.

The main long-term limitation is therefore not the electrochemical detection principle itself, but rather the stability of the biological and functional components, including DDC activity, PLP availability, aptamer stability and selectivity, methylene blue stability, and membrane ageing. These parameters will ultimately determine the maximum operating lifetime of each cartridge before replacement is required.

3.1.1. Technological novelty of wearable sensor

The novelty of NeuroTrack does not lie in the isolated use of microneedles or in the ability to electrochemically detect L-DOPA, as these principles have already been described in the literature. Rather, it lies in the integration of these technological building blocks into a complete system specifically designed for the longitudinal therapeutic monitoring of Parkinson's disease.

The analysis of the competitive landscape highlights a technological space that remains insufficiently addressed. Laboratory-based methods can provide accurate biological measurements, but they are inherently intermittent and incompatible with dynamic day-to-day monitoring. Some emerging devices aim to quantify L-DOPA in capillary blood, but they still operate on a discontinuous basis. Conversely, several wearables dedicated to Parkinson's disease enable prolonged monitoring of motor symptoms, but they mainly rely on indirect data such as movement and do not directly measure the patient's exposure to L-DOPA. NeuroTrack specifically targets the intersection between these approaches: direct molecular measurement of L-DOPA, performed repeatedly and ultimately continuously, in interstitial fluid and integrated into a wearable device. This distinctive positioning is clearly reflected in the project's competitive analysis, which places NeuroTrack toward both "continuous and direct" monitoring.

The technological differentiation of the system therefore relies on several levels of integration:

• A DDC–aptamer biochemical recognition strategy. L-DOPA is first converted into dopamine by DOPA decarboxylase (DDC), after which dopamine-specific aptamers provide selective molecular recognition. The target signal is therefore not based solely on the direct electrochemical oxidation of L-DOPA: NeuroTrack uses enzymatic conversion and selective molecular recognition to improve the specificity of the sensing process.

• A multilayer chitosan/PVA–methylene blue electrochemical interface, in which each component performs a distinct function: biological immobilization and structuring, controlled transport and sensing-interface stabilization, and electrochemical transduction. Part of the innovation lies in the functional combination of these materials with the enzymatic and aptamer-based sensing strategy.

• A modular wearable architecture, separating the components in contact with the biological environment—microneedles, enzymes, electrodes, and microfluidic elements—into a replaceable cartridge, while retaining the electronic reader as a reusable component. This separation directly addresses a major challenge in continuous biosensing: biological components have a limited lifetime, whereas the electronic hardware does not need to be replaced after each use.

• An electronic chain specifically designed for low-current measurements, integrating electrochemical acquisition, electrical noise reduction, embedded processing, and Bluetooth communication. The current prototype notably uses a power-supply architecture incorporating LDO regulators, ferrites, and filtering components to reduce noise that could impair signal quality. In the final wearable, merging the two current PCBs into a single board is expected to reduce device size, interconnections, assembly costs, and certain potential sources of noise or failure.

• A digital layer designed to make the measurement biologically and clinically actionable. The concept developed in the project goes beyond simply determining a concentration: the data are intended to be converted into temporal profiles, reference values, individual trends, and alerts, and then made accessible through a patient–clinician interface. This continuity between the biosensor, signal processing, and the application is already central to the functional architecture of NeuroTrack presented in the project.

The main novelty of NeuroTrack can therefore be described as a system-level innovation: integrating, within a single device, molecular recognition of L-DOPA, interstitial sampling through microneedles, enzymatic conversion, electrochemical transduction, low-current acquisition, embedded processing, and longitudinal interpretation of the resulting data.

The transition toward more highly integrated electronics is intended to further reinforce this approach. The proposed use of a low-power SoC combining a microcontroller, Bluetooth Low Energy connectivity, and embedded inference capabilities could, in particular, enable the exploration of an edge AI approach. Rather than systematically

transmitting raw electrochemical data to a remote server, certain filtering, trend-recognition, or personalization processes could be performed directly within the wearable. Ultimately, the objective would be to build an individualized representation of each patient's pharmacokinetic profile and to correlate variations in L-DOPA levels with clinical information collected through the application.

This final dimension is particularly important for positioning NeuroTrack relative to existing solutions. A biological assay answers the question, "What is the concentration right now?"; a motor-monitoring wearable answers, "How is the patient moving?"; NeuroTrack aims to connect "How much L-DOPA is available over time?" with "How is the patient's clinical condition evolving?"

The product would therefore not simply constitute a new L-DOPA sensor, but rather a therapeutic monitoring platform designed to bring clinical decision-making closer to the patient's actual exposure to treatment. This approach is consistent with the value proposition already formulated in the project deck: moving from intermittent or indirect monitoring toward monitoring that is "continuous, direct, and clinically actionable."

Reader instrument: The reader instrument uses a comlpex noise reduction suite made of LDOs and ferrite beads to maximize its accuracy.
User interaction: The whole user experience and interaction is realized through its smartphone. The wearable features a whole control through wireless communications. It also fits in a reduced volume to maximize the user's tolerance to the device. To do so, it features a special high-density battery.

3.1.2. Technical feasibility of wearable sensor

Feasibility was investigated progressively rather than by attempting to develop the final wearable device from the outset.

A first electronic architecture based on an ESP32-C3 combined with a dedicated board integrating the AD5940 was used to validate the principle of electrochemical signal acquisition. The AD5940 is specifically designed for high-precision potentiostatic, amperometric, and voltammetric measurements. It integrates a 16-bit ADC and a low-noise potentiostat, making it well suited for portable electrochemical sensing applications.

Our tests using resistors and capacitors with known values showed an error of approximately ±5%. These experiments do not yet constitute validation of biological L-

DOPA measurements, but they demonstrate that the electronic acquisition chain is capable of generating the required signals and measuring electrical responses within the accuracy range targeted for the prototype stage.

The next-generation architecture is designed toward a more compact product: integration of the two PCBs into a single board, use of low-power components, deactivation of unused loads, and a battery capacity of approximately 1 Wh, together with an appropriate charging circuit and magnetic charging system. However, no precise battery-life claim should be made before a complete experimental power budget has been established.

From a biological perspective, the DDC-based sensing principle combined with dopamine-specific aptamers is scientifically plausible. DDC enables the conversion of L-DOPA, while the downstream electrochemical detection strategy is designed to provide a quantitative signal.

The chitosan + PVA gel is used as a functional membrane at the sensing interface to support the sensing layer and contribute to controlled mass transport and selectivity. Nevertheless, the most critical aspects that still require experimental demonstration include the long-term stability of enzymatic activity, preservation of PLP, aptamer selectivity in a real biological matrix, stability and ageing of the chitosan/PVA functional layer, and the correlation between interstitial L-DOPA concentrations and therapeutically relevant information.

Electronic feasibility is therefore already supported by internal testing and by the use of components specifically suited for portable electrochemistry. In contrast, long-term biological feasibility remains the key aspect that must still be demonstrated before NeuroTrack can claim to operate as a fully functional continuous wearable biosensor.

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For the electronic part, the critical element is the electrochemical sensor that measures currents, voltages, and generates chosen waveforms on a range of frequencies. We performed measures to confirm its accuracy on known resistors and capacitors. It reaches a correct accuracy of +-5% on those. That value is enough for the measurements we perform. The remaining components are already selected and approved for deployment on a real sensor. From the battery, its adapted charger dedicated for the battery voltage

and fast charge with reduced losses, to the high efficiency microcontroller with switch loads to maximize the time span between two recharges of the 1Wh battery.

Before finalizing this architecture, the team iterated through an earlier prototype built around an ESP32-C3 microcontroller, validated on a dedicated AD5940-based sensing front-end board. This progression from a first functional prototype to the current optimized design demonstrates the team's ability to translate a proof-of-concept into a more efficient, production-oriented architecture and a more precise and functional product.

The biological feasibility of the proposed L-DOPA biosensor relies on the compatibility and performance of two key recognition elements: DOPA decarboxylase (DDC) and dopamine-specific aptamers. DDC provides a highly selective enzymatic conversion of L-DOPA into dopamine and requires pyridoxal-5'-phosphate (PLP) as an essential cofactor to maintain optimal catalytic activity. Consequently, preserving enzyme activity, ensuring PLP availability, and maintaining suitable physiological conditions (pH and temperature) are critical for efficient substrate conversion. The second key component is the dopamine-specific aptamer, whose high affinity and selectivity determine the accuracy of dopamine recognition while minimizing interference. Furthermore, the immobilization strategy must preserve both the catalytic function of DDC and the structural integrity of the aptamers to ensure stable and reproducible electrochemical measurements. Since DDC-catalyzed reactions and aptamer-based electrochemical sensing are both well-established and extensively validated technologies, their integration supports the biological feasibility of the proposed wearable L-DOPA biosensor.

In our microfluidic circuit, the channel has a uniform width along its entire length and adopts a straight, non-winding geometry in order to limit turbulence, reduce the risk of cross-contamination between successive samples, and promote continuous, stable flow.

We initially designed a circuit incorporating additional bends, aiming to extend the fluid's residence time and thereby increase the conversion rate. Simulations performed using COMSOL confirmed the viability of this geometry in terms of fluid flow. However, achieving uniform deposition of our gel within such a channel, without generating local turbulence, proved too complex to reliably control. We therefore opted for a simpler geometry, which in practice offers better overall efficiency.

3.2. Reliability of sensor output

To maximize reliability, the sensor performs a calibration of its internal measurement components on a reference resistor. It thus leads to a measurement independent of external parameters. The sensor is also able to perform averages of post treatment of those to increase its reliability. The noise is also suppressed by filters on the power suply and analog filters will be added on the output in the near future.

3.2.1. Technological novelty of reliability conceptThe proposed wearable biosensor improves measurement reliability by integrating several complementary technologies into a single sensing platform. A microfluidic sampling system ensures controlled and reproducible transport of the biological fluid to the sensing area, while the biochemical recognition and electrochemical transduction modules operate sequentially to generate a quantitative signal. This integrated architecture minimizes sample handling, reduces contamination risks, and limits signal variability associated with manual processing. Furthermore, the wearable format enables standardized measurements under real-life conditions, making the device suitable for continuous monitoring. The combination of controlled fluidics, selective molecular recognition, and electrochemical readout constitutes the main technological innovation underlying the reliability of the proposed biosensor.

The proposed strategy relies on a multi-level calibration approach combining biochemical selectivity, electronic self-checks, signal processing, drift compensation, and clinical validation. DDC-mediated enzymatic conversion and aptamer-based recognition, together with low-potential electrochemical detection and a chitosan/PVA membrane, contribute to improving selectivity and reducing interference. Periodic measurement of an internal reference resistor enables verification of the potentiostat–ADC measurement chain, while averaging, filtering, and outlier detection improve signal robustness. A planned enzyme-free reference channel will allow background current and common-mode drift to be monitored and compensated independently of analyte concentration. Finally, periodic comparison with reference HPLC/LC-MS measurements will provide external clinical calibration and validation.

The corrected L-DOPA concentration can therefore be estimated using:

$$C_{L\text{-}DOPA} = (I_{measured} - I_{background} - b) / S$$

Where S represents the sensitivity obtained from the calibration curve and b corresponds to the offset. The use of a reference channel would additionally make it possible to monitor sensor drift independently of changes in analyte concentration.

This architecture makes system reliability observable and controllable, rather than treating calibration as an one-time procedure performed exclusively under laboratory conditions.

3.2.2. Technical Feasibility of the Reliability Concept

The feasibility of the electronic layer has already been partially demonstrated. Tests performed using known resistors and capacitors show that the current architecture is capable of generating and measuring electrical signals with an approximate accuracy of ±5%. The use of the AD5940 is also consistent with this objective, as this component integrates a low-noise potentiostat, a transimpedance amplifier (TIA), a 16-bit ADC, a programmable gain amplifier (PGA), and internal references specifically designed for electrochemical measurements.

Self-calibration using a reference resistor will help distinguish electronic drift from genuine variations originating from the sensor. In parallel, LDO and ferrite-based power-supply filtering reduces fluctuations and electrical noise.

However, these electronic results alone are not sufficient to demonstrate the accuracy of the final L-DOPA concentration measurement. Analytical performance will also depend on enzymatic kinetics, the microfluidic interface, and the biological matrix. The next validation stage must therefore quantitatively determine sensitivity, linearity, repeatability, drift, response time, selectivity, and agreement with HPLC/LC-MS reference measurements.

This distinction between the performance of the electronic reader and the analytical performance of the complete biosensor is essential for presenting a scientifically credible demonstration of feasibility.

The technical feasibility of the reliability concept relies on the successful integration of the biosensor's individual components into a robust wearable platform. Reliable measurements require efficient microfluidic transport, stable biochemical recognition, and sensitive electrochemical signal acquisition while maintaining low power consumption and user comfort. Particular attention must be given to preventing biofouling, ensuring stable fluid flow, and preserving sensor performance during prolonged use. Electrochemical detection offers rapid response times, high sensitivity, and compatibility with miniaturized electronics, making it well suited for wearable applications. Since each component of the device is based on well-established technologies that have previously been integrated into portable biosensing systems, the proposed concept is technically feasible and capable of providing reproducible L-DOPA measurements.

3.3. Original contributions

The innovative concepts of the wearable biosensor and its reliability strategy were developed by the team. The team conceived and selected the overall sensing architecture, combining microfluidics, DDC-based biochemical conversion, aptamer recognition, low-potential electrochemical detection, and a chitosan/PVA interface. The team also developed the multi-level strategy for improving sensor reliability. The team adapted and experimentally tested these concepts throughout the project. The supervisor contributed to the scientific development by helping validate experimental choices and by suggesting adjustments, particularly regarding the experimental work. Coaches outside the team also provided technical guidance, notably for microfluidic simulations and electronic development. These contributions helped the team refine and validate its concepts. The team would like to express its truly thank to the supervisor and the coaches for their valuable scientific and technical support throughout the project, which helped us refine our ideas and carry out the experimental development.

3.4. Bonus criteria Innovation

Beyond its sensing capabilities, the proposed biosensor introduces a new approach to personalized Parkinson's disease management by enabling continuous therapeutic drug monitoring in a wearable format. Unlike conventional monitoring, which relies on intermittent clinical assessments, the device could provide real-time pharmacokinetic profiles of L-DOPA, allowing clinicians to identify fluctuations in drug availability and optimize treatment on an individual basis. In the future, the biosensor could be coupled to a mobile application for remote monitoring, automated data analysis, and secure data sharing with healthcare professionals. Its modular design also facilitates the replacement of the biological recognition elements, enabling adaptation to other neurological biomarkers or therapeutic drugs without redesigning the entire platform. This flexibility extends the impact of the technology beyond Parkinson's disease and highlights its potential as a versatile platform for personalized medicine.

Electronic innovation:

Wireless communication privacy.

Medical records are extremely sensitive data that must not fall into the wrong hands. Wireless connections thus need to ensure the highest privacy level. It works by coupling Bluetooth and NFC protocols. The wearable is paired with the smartphone by an NFC tap. The tap gives encryption keys so that only the patient's smartphone can read the data sent by Bluetooth. Furthermore, that connection uses an AIS128 encryption level, and will soon feature post-quantum encryption to meet the highest standards. Then the wearable itself only gives keys to the patient's smartphone and for the ones used by authorized doctors. It only accepts orders from those phones to ensure no data can be diverted by anyone.

4. TP award: Translation potential

4.1. Customer interviews

4.1.1. Identification of potential stakeholders

This diversity of profiles makes it possible to approach the project along several dimensions: clinical, human, technological, and organizational. It ensures that the identified needs do not rest on a single category of user, but on a comprehensive view of the care pathway.

Stakeholder	Role	Objective of the interviews
Neurologists specialized in Parkinson's disease	Prescription and adjustment of dopaminergic treatments	Understand the limitations of current monitoring tools and identify unmet clinical needs.
Patients with Parkinson's disease	End users of the device	Identify the difficulties encountered in daily treatment management and assess the acceptability of a wearable device.
Caregivers	Daily support of patients	Understand the challenges associated with symptom monitoring and communication with healthcare professionals.

Stakeholder	Role	Objective of the interviews
Researchers and biosensor experts	Development of innovative medical devices	Assess the scientific relevance of the concept and identify key development constraints.

In parallel, our thinking was also informed by a review of the literature on connected medical devices that have already been widely adopted, continuous glucose monitoring (CGM) systems. These technologies represent a relevant example of the successful integration of a wearable sensor into patients' daily lives. Studying them made it possible to identify several determining factors for the acceptability of a device worn continuously, such as comfort, discretion, ease of use, the perceived reliability of the measurements, and the quality of the associated mobile application. These lessons were taken into account from the earliest design phases of NeuroTrack.

4.1.2. Interview approach and execution

The discussions with the various stakeholders were prepared according to a qualitative approach centered on the identification of needs. In accordance with the SensUs recommendations, the objective was not to present NeuroTrack as an already-defined solution, but to understand the difficulties encountered in the current monitoring of patients and to identify the needs that could justify the development of a new device.

To this end, we developed an interview guide structured around several common themes:

- the current care pathway for patients;
- the methods used to adjust treatment;
- the limitations of existing monitoring tools;
- the difficulties encountered in daily practice;
- expectations regarding a future continuous monitoring device.

The questions were primarily open-ended in order to encourage detailed responses and to avoid steering participants toward a particular solution. This approach made it possible to obtain rich qualitative information on current practices and priority needs.

The information collected was then analyzed thematically. Responses raising similar issues were grouped together to identify recurring needs and to prioritize the elements to be considered in the design of the device. This method made it possible to establish a direct link between the needs expressed by users and the development choices for NeuroTrack.

In addition to the discussions with stakeholders, a review of the scientific literature and of published feedback on wearable medical devices was carried out. The aim of this analysis was to anticipate certain issues likely to arise during the prolonged use of a skin biosensor, in particular regarding comfort, adherence, ergonomics, and integration into daily life.

4.1.3. Interview results and conclusions

The interviews conducted with the different stakeholders identified four major challenges that directly shaped the definition and development of NeuroTrack.

1. Therapeutic adjustment remains too subjective

Neurologists emphasized that treatment adjustments still rely largely on symptoms reported by patients during consultations. In the absence of continuous biological measurements, it remains difficult to objectively assess L-DOPA exposure and accurately relate experienced fluctuations to treatment response. This limitation confirmed the need for an objective and longitudinal measurement of L-DOPA levels.

2. Current monitoring is too intermittent and does not adequately capture fluctuations

Between consultations, a patient's condition can vary significantly throughout the day, particularly with the occurrence of ON/OFF periods. Current monitoring approaches do not allow these variations to be documented accurately over time. This finding led us to prioritize continuous or repeated monitoring rather than isolated measurements.

3. A significant monitoring burden is placed on patients

Patients currently have to observe their symptoms, remember when they occurred, and report them retrospectively during consultations. This self-monitoring can be burdensome and may not accurately reflect their real daily experience. NeuroTrack was therefore designed to automate data collection as much as possible, while still allowing patients to easily provide brief information about their condition in order to correlate subjective symptoms with biological measurements.

4. Clinicians need directly actionable data

Healthcare professionals do not need a continuous stream of raw data, but rather clear and summarized information that enables them to quickly identify relevant trends and fluctuations. This directly guided the development of an application integrating statistical data processing, monitoring curves, alert thresholds, and a dedicated healthcare professional interface. The objective is to transform biological measurements into clinically interpretable information that can support patient monitoring and therapeutic decision-making.

4.2. Design of validation study

NeuroTrack was conceived as a wearable for therapeutic monitoring, and not as a mere electrochemical sensor. The objective is to convert a biological measurement that is currently difficult to access into information that can be used on a daily basis by the patient and by their neurologist. The system thus rests on four integrated building blocks: biological detection of L-DOPA, high-precision electronic acquisition, embedded data processing, and a digital patient–clinician interface. This architecture directly reflects the positioning defined in our pitch: objective measurement of L-DOPA, continuous monitoring, miniaturizable and wearable technology, rapid readout, and a digital connection between patient and clinician.

A measurement chain designed to transform L-DOPA into clinical data

The consumable part of the device relies on a removable microfluidic cartridge intended to convey a small sample volume toward the detection zone. There, L-DOPA is selectively

recognized by specific aptamers immobilized on the electrode surface. The binding of L-DOPA induces a change in the electrochemical response of the sensing interface, which is converted into a measurable electrical signal. The sensor architecture is designed to enhance selectivity toward L-DOPA while limiting interference from other electroactive compounds present in the biological environment. The resulting electrochemical signal is then acquired by an integrated potentiostat and converted into digital data for subsequent processing and transmission.

This separation between a replaceable biological/microfluidic part and a reusable electronic module simultaneously addresses concerns of hygiene, maintenance, and economic viability. The patient replaces only the cartridge containing the biological and microfluidic elements, while the electronics, the battery, and the communication module are retained.

From the electronic prototype to the wearable

The electronic architecture of the wearable will remain close to that already used in the current prototype, in order to build on components whose operation has been tested. The electronic tests carried out on the resistors and elementary components, in particular at high frequency, made it possible to verify the architecture's ability to limit electronic noise and to measure with precision the very low currents generated by the electrochemical reaction.

The next iteration, however, aims at strong industrial optimization: the two electronic boards currently used will be merged into a single board. This choice should simultaneously reduce the bulk of the wearable, decrease the number of interconnections and potential points of failure, simplify assembly, and reduce manufacturing cost.

The microcontroller will also be replaced by an nRF54L20B, making it possible to integrate directly into the device an artificial-intelligence model intended for the analysis and prediction of L-DOPA levels. Local processing is a strategic technological choice: it reduces dependence on the cloud, limits latency, and makes it possible to keep a sensitive part of the data processing directly on the wearable.

From measurement to a clinical value proposition

The final functional chain is therefore designed as follows:

L-DOPA → enzymatic detection → electrochemical signal → high-precision acquisition → embedded processing → personalized estimation → patient application → relevant data transmitted to the neurologist.

The current pitch already provides for the statistical processing of measurements, the creation of trend curves, Bluetooth transmission, the definition of reference values and alert thresholds, as well as a differentiated interface for the patient and the healthcare professional. Pitch deck saclay.pdf Ultimately, the embedded algorithm should go further by exploiting the individual history in order to provide the patient with a personalized estimate of the evolution of their L-DOPA level and of the relevant time for their medication intake this functionality naturally having to undergo specific clinical validation before any use in decision-making.

The wireless connection of the prototype has already been tested from a functional and security standpoint. The next step is to further increase the level of security of the

transmission, within the limits of the permissions available on the Android environment. The objective is to build a privacy-by-design architecture, in which only the necessary data are transmitted to authorized professionals.

Finally, daily use has been integrated into the physical design: handling the cartridge will simultaneously allow its replacement and access to magnetic recharging of the battery. The microfluidic and biological part can be removed quickly, without any intervention on the electronic module.

4.2.1. Selection of the problem

Our Customer Discovery brought out a specific problem: between two consultations, the adjustment of L-DOPA still relies mainly on intermittent and self-reported information, whereas the response to treatment fluctuates throughout the day. The current pathway that we identified is discontinuous: the neurologist prescribes a dose, the patient returns to their daily life, experiences ON/OFF periods or dyskinesias, and then tries to reconstruct these episodes from memory during the next consultation.

The discussions with neurologists and the clinical environment confirmed three priority limitations: therapeutic adjustment that is still subjective, intermittent monitoring, and fluctuations that are insufficiently captured. For the patient, this arrangement also generates a mental burden: they must observe their symptoms, remember their timing, and try to relate them to their medication intake. The clinician then has fragmented information and cannot always determine whether a deterioration requires a change in dose, a change in timing, or simply closer monitoring.

The problem selected is therefore deliberately targeted:

How can exposure to L-DOPA between two consultations be objectified, in order to better characterize therapeutic fluctuations without increasing the burden on the patient or the neurologist?

This problem is compatible with a biosensor-based solution because L-DOPA is a biological variable directly linked to the treatment. The reference dosing methods currently rely on intermittent laboratory analyses; they are not suited to frequent, decentralized monitoring. Our project therefore aims to transform information that is currently difficult to access into a longitudinal signal usable within the care pathway.

The objective of NeuroTrack is thus neither to replace clinical assessment nor to automatically decide on a therapeutic change. It is to provide a complementary objective measurement, capable of linking the evolution of L-DOPA to the patient's lived experience and of giving the neurologist additional information to personalize monitoring.

4.2.2. Conceptual design and use case

Describe the proposed conceptual sensor design and its intended use case. Explain how the solution addresses the identified problem and its critical aspects. Clarify how and why the sensor would create value in practice for patients and/or healthcare professionals. The concept should demonstrate both feasibility and innovation, and its alignment with stakeholder needs should be clearly motivated.

NeuroTrack is a modular wearable for monitoring L-DOPA that combines biological detection, microfluidics, precision electronics, and digital processing. It directly addresses the identified needs: a compact, minimally burdensome, and automated device for the patient, and information that can be readily used by the neurologist.

L-DOPA is selectively recognized by specific aptamers immobilized on the electrode surface. The interaction between L-DOPA and the aptamers induces a measurable electrochemical signal, enabling its quantification while limiting interference from other compounds present in the biological environment. The concept relies on carbon microneedles integrated into a wearable reader.

The low current generated is acquired by the electronics and then converted into a concentration. The current prototype made it possible to validate the selection of components and the system's ability to limit noise during measurements of low currents. The next version will merge the two electronic boards into a single one, in order to reduce bulk, assembly cost, and the risk of failure.

The microcontroller will be replaced by an nRF54L20B, with the objective of ultimately integrating an embedded model for the analysis and prediction of L-DOPA trends. Part of the processing can thus be performed locally, reducing data transfers and strengthening their confidentiality.

Functional chain:
L-DOPA → enzymatic detection → electrochemical signal → quantification → embedded processing → Bluetooth → patient application / clinical dashboard.

The application will bring together monitoring curves, statistical indicators, alerts, and information reported by the patient in order to correlate the measurements with their daily state. These functionalities are already integrated into the NeuroTrack logic presented in the pitch.

The biological and microfluidic part will be removable, while the electronics will be reused. The replacement of the cartridge will be combined with magnetic recharging, in order to simplify use and limit handling.

In practice, the patient wears the device on a daily basis and the measurements are recorded automatically. The neurologist then has a longitudinal summary of L-DOPA, set against medication intake and reported symptoms. The value of NeuroTrack therefore lies not only in the measurement of L-DOPA, but in its transformation into clinical information usable to personalize therapeutic monitoring.

4.2.3. Validation study design

The validation will be carried out on two complementary levels: technical performance and relevance of use.

Technical validation. The biosensor will be tested on known concentrations of L-DOPA in order to evaluate its sensitivity, linearity, repeatability, selectivity, response time, and stability. Electronic noise and the reliability of the Bluetooth transmission will also be quantified. The tests will be repeated and analyzed using the mean, standard deviation, and coefficient of variation in order to assess the reproducibility of the system.

User validation. The MVP will be presented to patients and neurologists according to a standardized protocol. The following will be measured on quantitative scales: acceptability of the wearable, understanding of the solution, ease of use, readability of the dashboard, and perceived clinical usefulness. The neurologists will in particular have to determine whether the data presented provide usable information for therapeutic monitoring.

The objective is therefore to simultaneously validate the three critical dimensions of NeuroTrack: reliability of the measurement, acceptability by the patient, and clinical value for the neurologist. The results will determine whether the device can move to an integrated-prototype phase and then to clinical validation.

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4.3. Bonus criteria Translation Potential

Examples may include, but are not limited to, analyses of manufacturability and production costs, cost–benefit evaluations from different stakeholder perspectives, development of a business model, exploration of market entry strategies, or consideration of regulatory and patent pathways. Clearly explain how these additional contributions support the practical deployment and real-world feasibility of the proposed biosensor.

Beyond the user interviews and the validation of the MVP, we worked on the economic viability, the market-entry strategy, the scalability, and the scaling-up of NeuroTrack in order to transform the SensUs prototype into a credible MedTech project.

Market and entry strategy. Our market study identified a significant and growing need: the pitch retains 8.5 million patients worldwide, around 270,000 in France, and 27,000 new cases per year. The global market for digital Parkinson's monitoring was estimated at €1.5 billion per year, with a SAM of about €200 million per year and a SOM target of €2–6 million per year within five years. The first commercial entry point selected is deliberately targeted:

the 26 French Parkinson Expert Centers and around 3,000 neurologists, in order to concentrate the first clinical and commercial evidence in highly specialized institutions.

Business model. We built a B2B2C MedTech model combining three revenue streams: sale of the reader to expert centers/university hospitals, recurring consumables related to the cartridges, and a software subscription for the dashboard and clinical integration. In our beachhead scenario, an equipped center represents about €41k per year in revenue, i.e., a potential of more than €1 million per year across the 26 expert centers, according to the assumptions used in the pitch. This structure makes it possible to combine initial hardware revenue with recurring, more scalable revenue.

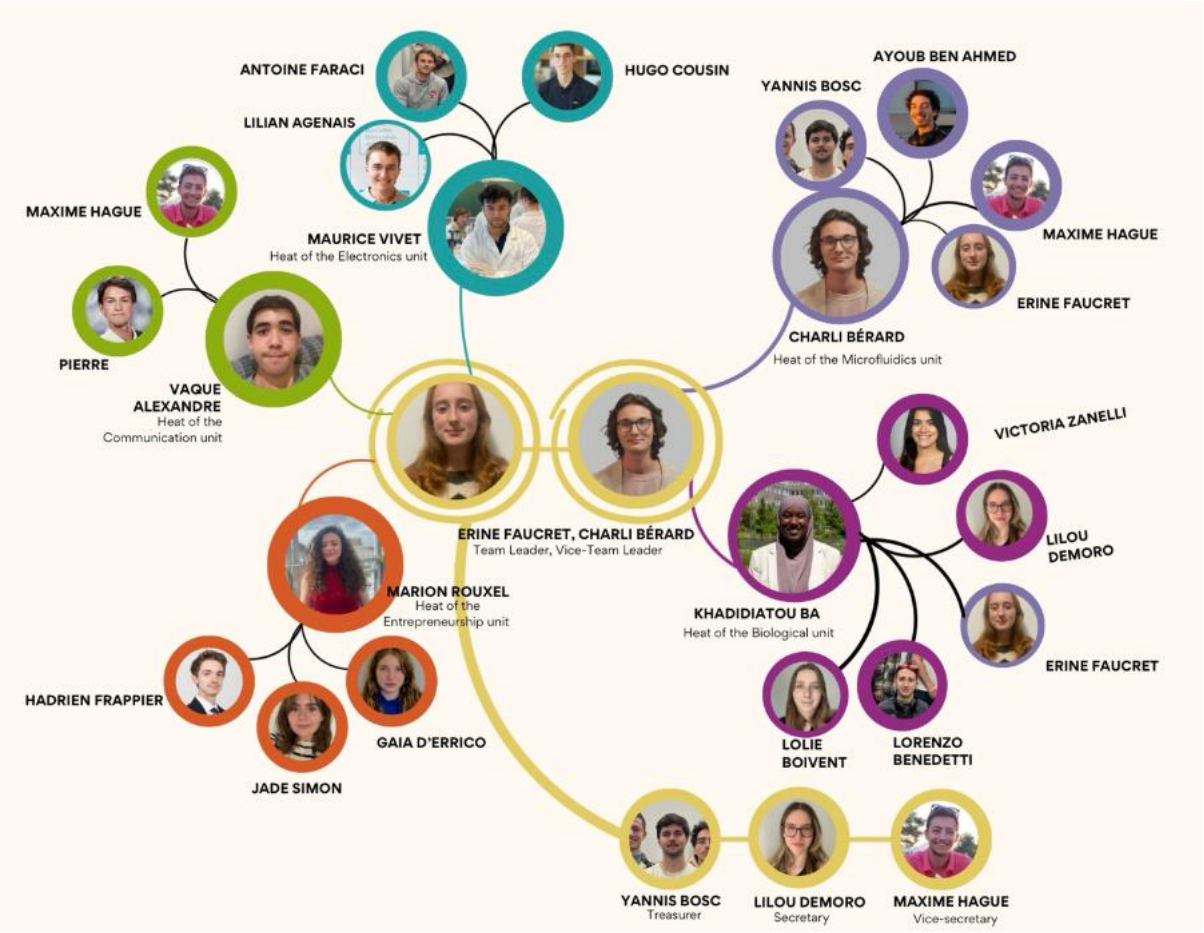
Scalability and manufacturability. The technical design was conceived for scaling up: reusable electronics, a replaceable microfluidic/biological cartridge, miniaturization compatible with a wearable, and an electrochemical architecture that can be industrially integrated. The next version also plans to merge the two electronic boards into a single one, in order to reduce bulk, the number of points of failure, and assembly cost. This decoupling between the reusable reader, the consumable, and the software directly supports the recurring economic model and facilitates industrialization.

Competitive positioning. Our benchmark distinguishes three existing categories: laboratory biological assays, one-off measurements of L-DOPA, and wearables for symptom monitoring. NeuroTrack positions itself at the still poorly covered intersection of these approaches: direct and continuous measurement of L-DOPA in a wearable format, combined with digital exploitation of the data.

Translation roadmap. The strategy follows a logic of progressive risk reduction: proof of clinical usefulness → pilot centers → industrialization → certification → commercialization → scale-up. The detailed roadmap provides for R&D and design (M0–M6), preclinical validation (M6–M12), technology transfer and industrialization (M12–M18), quality system and regulatory preparation (M18–M24), pilot and then pivotal clinical studies, certification and pre-launch up to M42, then commercialization, capacity ramp-up, reimbursement, and geographic expansion.

Finally, this entrepreneurial reflection was extended through the preparation and presentation of a value-creation pitch, the production of a sponsorship dossier, the search for partners able to accelerate the clinical proof and the scaling up, as well as the exploration of incubation support schemes. The objective is not to limit NeuroTrack to the SensUs competition, but to prepare, starting now, the conditions necessary for its scientific, clinical, and entrepreneurial continuity.

5. Team and support



5.1. Contributions of the team members

FAUCRET Erine is the president of the association and part of the experimental unit. Thanks to her expertise in the competition, she leads us and gives advice to the unit to do a better job.

BERARD Charli is the vice president and head chief of the microfluidic unit. He worked hard to create a microfluidic system that will enable our wearable device to work.

DEMORO Lilou is one of the two secretaries and member of the experimental unit. She worked on the chain reaction that will occur in the device to detect Levodopa in blood serum.

BOSC Yannis is the treasurer of the team and member of the microfluidic unit. Between the bills he worked on the wearable device, helping Charli to make everything fit.

HAGUE Maxime is the second secretary and member of the communication unit. He is creating posts to make the association more famous on Instagram and worked on team cohesion.

BA Khadidiatou is the head chief of the experimental unit. She leads her team wisely thanks to her expertise in the laboratory and the competition.

ROUXEL Manon is the head chief of the entrepreneurship unit. Thanks to her contacts and her knowledge of the marketing field, she made the association known in the eyes of the businesses and represented us during events.

COUSIN Hugo is a member of the electronic unit. He worked on the detection system of Levodopa in our product.

VIVET Maurice is the head-chief of the electronic unit. He led his team in the construction of the microchip, managing the team and distributing tasks. He worked on the electronic software to ensure a reliable sensor with minimal errors and reduced noise. He also conducted interviews with medical professionals to better understand the problem and identify the best solution for the sensor.

AGENAIS Lilian is a member of the electronic unit. He worked on the device to make it meet the needs of a wearable device in today's world. He also represented the association with Marion during events.

D'ERRICO Gaia is a member of the entrepreneurship unit. She worked on the different documents needed to exchange with companies and keeping in contact with them.

BOIVENT Lolie is a member of the experimental unit. She works on the chain reaction to obtain the chemical products we need for detection.

ZANELLI Victoria is a member of the experimental unit. She works on the detection of Levodopa in our system through chemical reactions.

AUTRAND Pierre is a member of the communication unit. He works on Instagram posts, making them more pleasant and affecting.

VAQUE Alexandre is the head-chief of the communication unit. He works on the posts, especially on video editing for our pitches and the planning of publication.

5.2. People who have given support

Vincent SAUVEPLANE: Assistant Professor at AgroParisTech and researcher in the UMR Micalis (INRAE). He guided us through the experimental aspects of our project as well as the more entrepreneurship aspects. Thanks to him we also got access to labs.

Jean-Frédéric AUDIBERT : Project engineer at the ENS Paris-Saclay. He helped us a lot with the modelisation of the microfluidic circuit and its printing.

Rasta GHASEMI : Platform engineer at the ENS Paris-Saclay. She designed and printed gold electrodes that were designed according to our needs.

François MAVRE :

Kevin LACHIN : Professor at AgroParisTech and researcher

5.3. Sponsors and partners

Fondation AgroParisTech : Helped us financially thanks to the funding it allocates to innovative projects.

INRAE Micalis : This research institute helped us by giving us materials for our experiments

The Bench: Helped us with our market strategy and financial support too.

6. Final remarks (max 1/2 A4)

Please include any additional information that you think might be important for the Jury and the general public to know. You may also thank people in this section and describe your future plans for after the Competition relating to your biosensor. Do not give a summary of your Team Results Document here (This should be done in the summary section).

7. References (no page limitation)

(1). Ligand-Induced Folding in a Dopamine-Binding DNA Aptamer (Kaiyum et al.)
(2). Satoh Y , Tajima K, Munekata M, Keasling JD, Lee TS. Engineering of L-tyrosine oxidation in Escherichia coli and microbial production of hydroxytyrosol. Metab Eng. 2012;14(6):603–610. doi:10.1016/j.ymben.2012.08.002.

8. (Optional) Appendix (no page limitation)

Appendix A. Composition of our team

For this international student competition, we have made the strategic choice to bring together students from Four French “grandes écoles”, located in close proximity to each other on the Paris-Saclay plateau. The aim is to capitalize on the complementary nature of our educational backgrounds to take a multi-disciplinary approach to the project and reinforce its scientific and technical excellence.

AgroParisTech: specializing in life sciences, the environment and sustainable living, AgroParisTech provides expertise in biology, experimentation and life engineering. Students acquire a solid grounding in applied research, particularly valuable for the development of our project's experimental pole.

École normale supérieure Paris-Saclay (ENS Paris-Saclay): renowned for the excellence of its training in the basic sciences, ENS Paris-Saclay contributes to our project in particular in the areas of physics and microfluidics. Students at this school are trained for top-level research and scientific innovation.

CentraleSupélec: an engineering school specializing in advanced technologies, CentraleSupélec brings to the project skills in electronics, embedded computing and systems design. It is an essential pillar in the technological development of our solution.
École polytechnique: internationally renowned for its excellence in science and engineering, students from École polytechnique brings expertise in entrepreneurship, electronics and embedded systems. Its rigorous scientific training and engineering approach contribute to the design, integration and optimization of the electronic components of our project.
All three institutions are highly selective, nationally and internationally recognized, and award engineering or master's degrees on completion. This collaboration enables us to strengthen our skills, enrich our approaches, and lead an ambitious project with high innovation potential.

Appendix B. Expression and purification of recombinant DDC

B.1 Production of recombinant DDC

As commercial L-DOPA decarboxylase (DDC) is expensive and not easily available, the enzyme was produced in Escherichia coli.
The porcine DDC coding sequence (1460 bp) was amplified from the pBbE1k-DDC plasmid (Addgene plasmid #71723) using PCR. The amplified fragment was inserted into the laboratory expression vector pSMG-390 by Gibson Assembly. The resulting recombinant plasmid, designated pSMG-390-DDC, places the ddc gene under the control of a T7 promoter and introduces a C-terminal 7×His tag to facilitate purification by methods of chromatography. The construct carries a kanamycin resistance cassette.
Schematic representation of the plasmids are show in **Figure 2A** and 2**B**.
The recombinant plasmid was transformed into E. coli Mach1-T1 for cloning and sequence verification before being introduced into the expression strain E. coli NiCo21(DE3) (**Figure 2C**).

A **B**

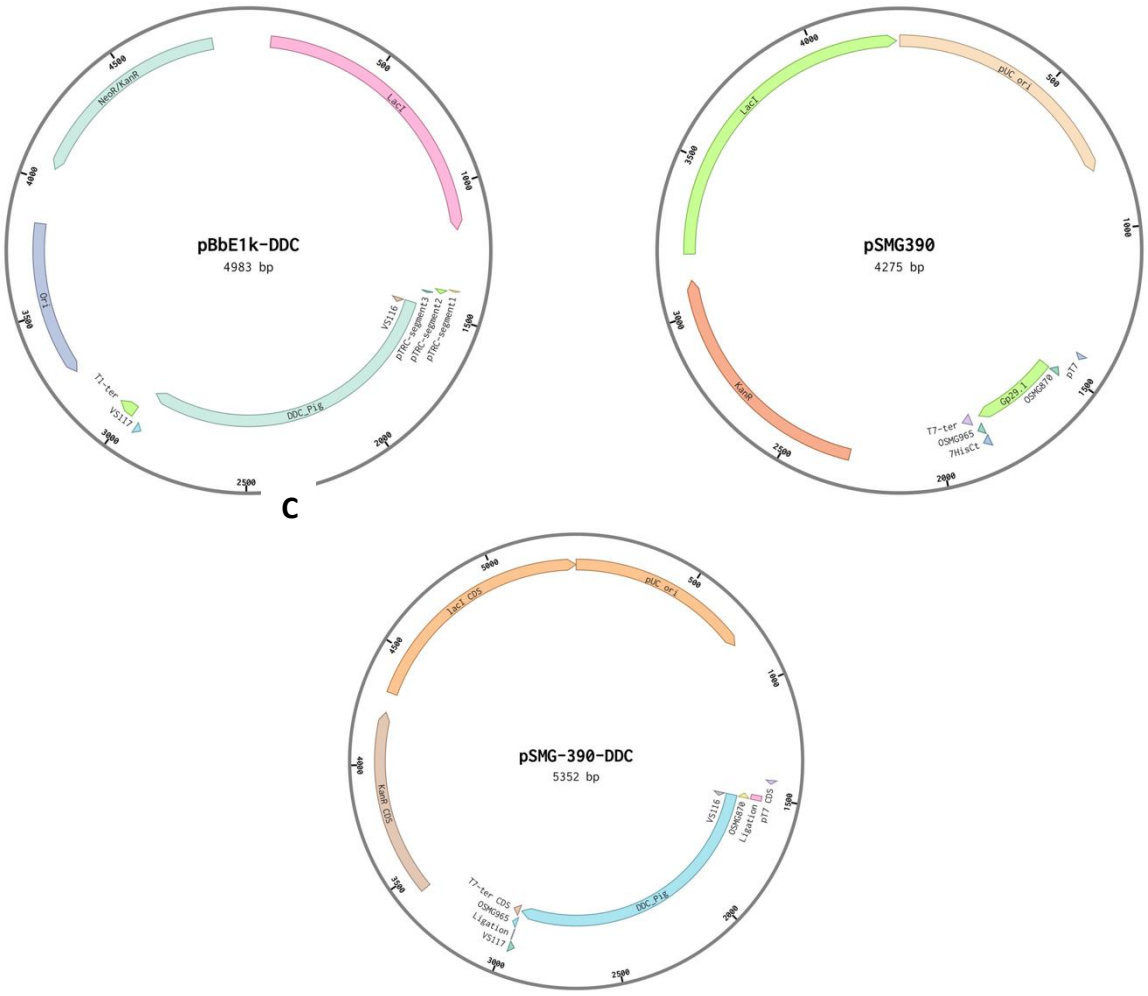


Figure 2. Schematic of the construction of the recombinant expression vector pSMG-390-DDC by Gibson assembly. (A) Donor plasmid containing the DDC gene, serving as a template for PCR amplification of the insert. (B) Plasmid expression vector pSMG-390 amplified and linearized by PCR to remove the gp29.1 sequence and allow insertion of the gene of interest. (C) Recombinant plasmid pSMG-390-DDC obtained after Gibson assembly between the DDC insert and the linearized vector.

B.2 Recombinant DDC expression

Successful plasmid construction was confirmed by restriction analysis using EcoRV and by Sanger sequencing, demonstrating the correct insertion of the ddc gene without mutations (**Figure 3**). The validated plasmid was transformed into E. coliNiCo21(DE3), and glycerol stocks were prepared for protein production.
Protein expression was evaluated under two different conditions to maximize soluble DDC production. In the first strategy, cultures were grown in LB medium at 37°C until an OD600 of 0.6–0.8, at 19°C, induced with 0.1 mM IPTG, and incubated overnight. In parallel, an auto-induction medium incubated overnight at 30°C was also tested. After cultivation, cells were harvested by centrifugation and lysed by sonication. The lysates were separated into soluble and insoluble fractions for purification.

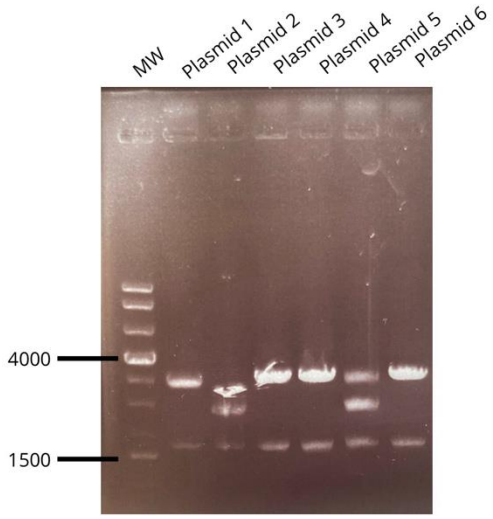


Figure 3. Analysis by electrophoresis gel for the verification of recombinant plasmid construction by EcoRV restriction analysis. Colonies 1, 3, 4 and 6 show the expected restriction profile of pSMG-390-DDC.

B.3 Purification of recombinant DDC

Following cell lysis, soluble proteins were purified by immobilized in an affinity chromatography using the C-terminal His-tag. The soluble extract was loaded onto a nickel affinity column, washed with low-imidazole buffers to remove non-specifically bound proteins, and eluted using 200 mM imidazole. Fractions with the highest absorbance at 280 nm were pooled and dialysed against storage buffer before further purification by size exclusion chromatography.
Because SDS-PAGE analysis revealed that a significant proportion of DDC accumulated in the insoluble fraction as inclusion bodies, this fraction was also processed. Proteins were solubilized under denaturing conditions using 8 M urea, purified on the nickel affinity column, and subsequently refolded through successive dialysis steps with decreasing urea concentrations (6 M, 4 M, 2 M and finally 0 M urea). This protocol enabled the recovery of additional recombinant DDC while limiting precipitation during refolding.
Protein purity throughout the purification procedure was monitored by SDS-PAGE.

Successful recombinant expression was confirmed by SDS-PAGE analysis, which revealed a protein band of approximately 50 kDa, consistent with the expected molecular weight of recombinant porcine DDC (**Figure 4)**. Expression was observed in both soluble and insoluble fractions, although a substantial proportion of the protein accumulated as inclusion bodies, indicating incomplete folding under the tested expression conditions (**Figure 5**).
Nickel affinity chromatography successfully enriched recombinant DDC from both fractions. While the soluble fraction purified protein after affinity purification, residual contaminant proteins remained detectable. Recovery of DDC from the insoluble fraction through solubilization in urea and controlled refolding provided an additional source of recombinant enzyme.

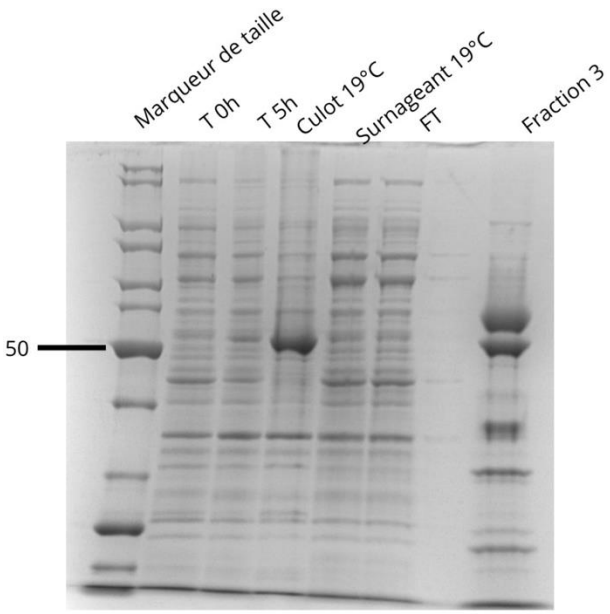


Figure 4. SDS-PAGE analysis of the expression and purification of DDC from the soluble fractions obtained in a culture induced by IPTG at 19 °C.

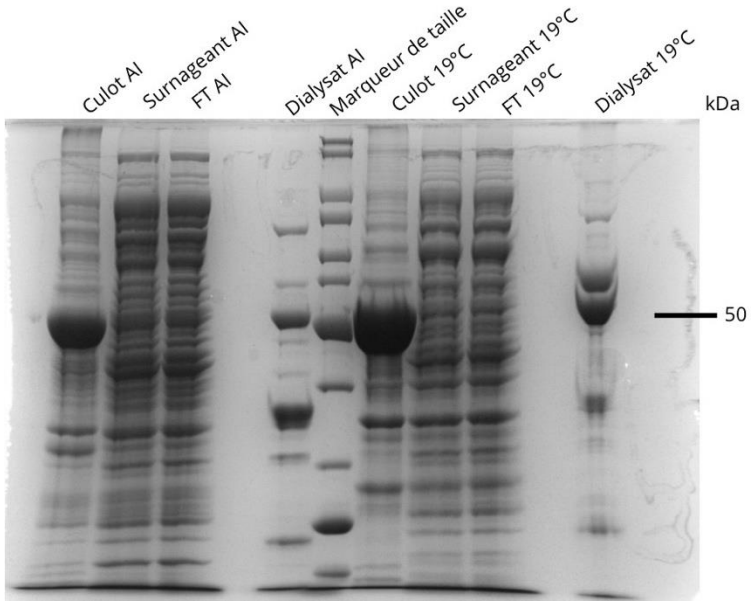


Figure 5. SDS-PAGE analysis of the purification of DDC from the soluble fractions obtained in an auto-induced medium at 30 °C and in a culture induced by IPTG at 19 °C.

To improve purity, dialysed soluble fractions were further purified by size exclusion chromatography. Calibration of the chromatography column with protein standards enabled accurate identification of the elution volume corresponding to recombinant DDC (**Figure 6&8**).

The chromatogram obtained after injection of purified DDC showed one major peak together with a limited number of minor contaminant peaks. SDS-PAGE analysis of the collected fractions demonstrated that fractions A12–A14 contained predominantly recombinant DDC with high purity (**Figure 7**). The elution volume corresponded to an apparent molecular weight of approximately 100 kDa, consistent with the expected dimeric form of the enzyme (**Figure 8**).

These results are similar to those reported in the literature (2).

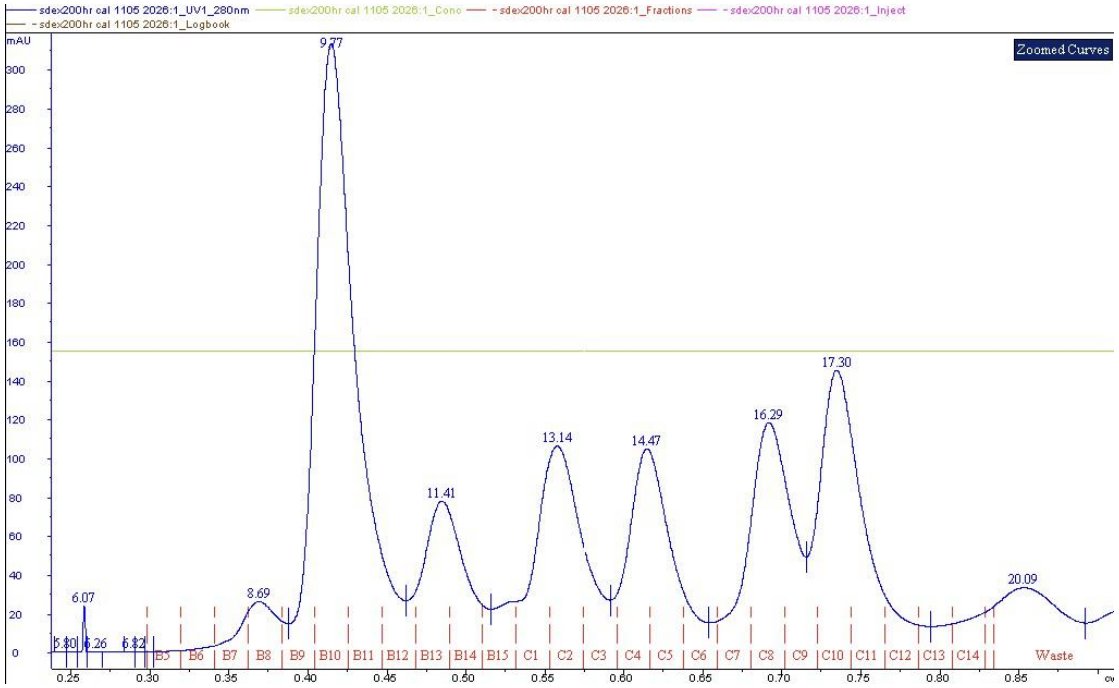


Figure 6. Calibration chromatogram of the molecular screening column using a mixture of standard proteins.

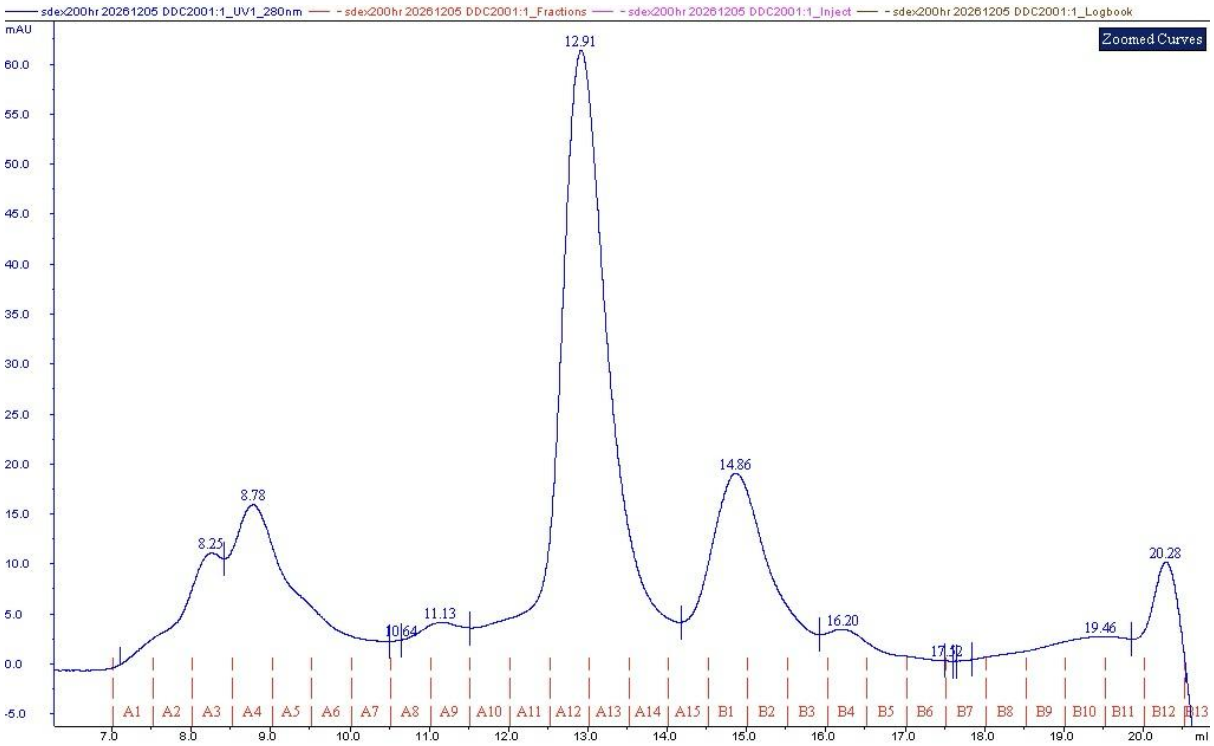


Figure 7. Chromatogram of size-exclusion chromatography of recombinant DDC after purification on nickel resin and dialysis.

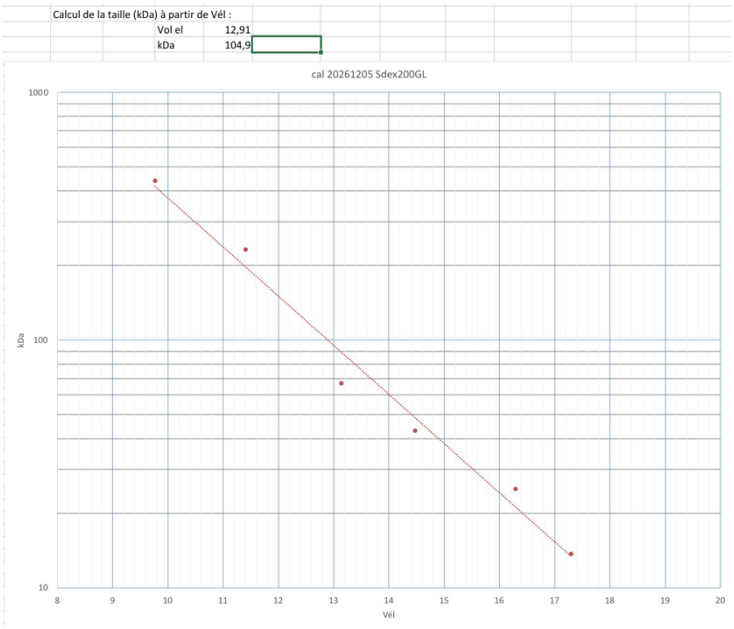


Figure 8. Calibration curve for calculating the weight of the DDC protein from the elution volume obtained by molecular screening.

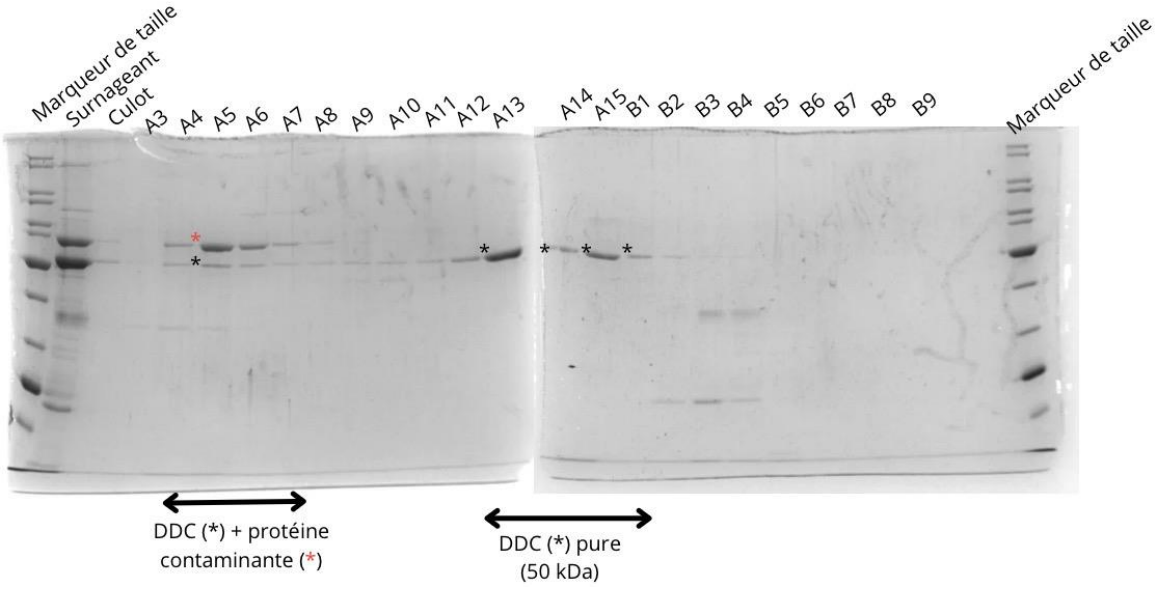


Figure 9. SDS-PAGE gel electrophoresis of the fractions collected during molecular screening of DDC.