

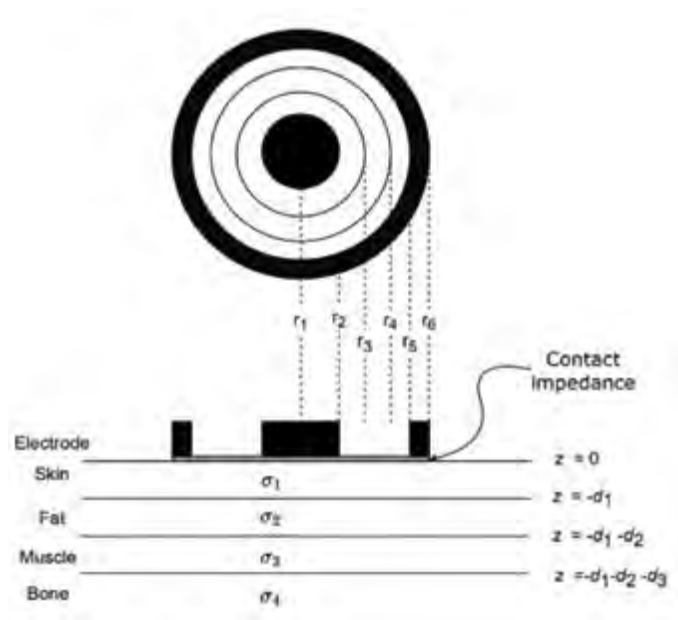


# MATH AT THE ANKLE

A New Route to Bladder Control

Author: Christian Keszthelyi

What if numbers and mathematical equations could do away with invasive bladder control medications by applying electrodes to someone's ankle? **Prof. Cristiana Sebu** tells **THINK** magazine how biology can be translated to applied maths, and how a simple solution could improve the lives of many patients.



An illustration of the electrode configuration

**P**rof. Cristiana Sebu from UM's Department of Mathematics uses applied mathematics to solve a practical problem: how to activate a nerve safely and accurately from the skin's surface. By rethinking electrode placement and shape, her team aims to activate the correct nerve in the ankle with a gentle current. This could eliminate the need for wires inside the body, reducing procedures and complications for people with bladder control issues.

## RETHINKING ELECTRODE DESIGN

The story started years ago in the United Kingdom, where Sebu collaborated with colleagues interested in functional electrical stimulation (FES) – the practice of using small currents to activate nerves and muscles for therapy and training. FES has helped paraplegic athletes row, aided stroke rehabilitation, and offered relief in pain management and epilepsy. But the standard two-electrode

setup – think of two ECG-style pads stuck to the skin, with current flowing between them – has a flaw. As Sebu puts it, people using these electrodes regularly 'get burns on the skin because you need to inject quite a bit of current'.

The problem is not the electricity itself, but how current density builds up at the edges of standard pads. This can create hot spots that damage the skin. Sebu's research team proposed a new electrode shape that could reduce current density peaks while achieving more localised activation of specific nerves.

The suggested new design consists of a central disk electrode and a surrounding annular ring. This setup focuses the activation under the centre of the probe and permits more current to be applied without harming the skin.

First, they used mathematics to work out the physical model and then showed that the electrode design can be optimised for different patient builds. Mary Grace Cassar, a recent doctoral graduate, led the project. She scanned her own ankle

with an MRI, built a 3D model, and ran simulations to determine whether the new probe could activate the posterior tibial nerve near the ankle.

The posterior tibial nerve is well known to urologists. Stimulate it, and you can influence bladder function via connected pathways – a technique that underpins several therapies today. The catch? Much of the current practice relies on implanted electrodes or configurations that are awkward to place around the ankle. In outlining the project's turning point, Sebu notes that her student demonstrated that the posterior tibial nerve can be activated at a specific depth using the newly designed electrodes placed on the skin surface. Crucially, bladder control can be achieved by placing surface electrodes on the ankle, rather than using implanted electrodes.

That shift – from inside to outside – matters. Implanted systems can work very well for the right patients, but they are undeniably invasive, expensive, and not without risk. 'One in three patients who are using implanted electrodes need further



**Dr Mary Grace Cassar (left) alongside Prof. Cristiana Sebu (right), at her Ph.D. graduation**

surgery to remedy a situation,' Sebu says, citing problems like broken or misplaced electrodes. Complications are not rare. 'In 15% of cases, you might have infections, and you might start to have bowel problems in 5% of cases because you don't only activate the nerve which controls the bladder, but also other surrounding nerves,' Sebu says.

The complicated set of trade-offs make justifying the use of implanted systems rather difficult to accept if you do not have to. 'If you can achieve the same results with surface electrodes, why should a patient go through several surgeries to remedy any problems that might occur with implanted electrodes?' Sebu says.

The ankle-friendly probe aims to make surface stimulation practical, precise, and comfortable. 'With the standard geometry of electrodes currently in use, you don't have enough space to place two electrodes on the ankle to activate the tibial nerve. But with our little probe, you have enough space to place it on the ankle and activate the posterior tibial nerve,' she says.

Because the innovation lives in geometry and modelling rather than exotic materials, the setup could be made affordable and straightforward. 'It's very easy to produce, and you can just buy them off the shelf,'

she says. Many applications are connected via two wires to a small power source – the sort of wearable controller that could fit in your pocket. Even in cases requiring continuous therapy, the device must remain wearable at all times.

The goal here is not only bladder control. 'It applies to all the other applications of this technique,' Sebu notes. She mentions a non-exhaustive list: FES for paraplegic training, bladder and bowel control, strengthening of the muscles and physical fitness, seizure prevention in epilepsy, post-stroke rehabilitation, treatment of drop foot, and pain management. In each case, the same core advantage – localised surface activation with less damage to the skin – could help clinicians activate deeper nerves more comfortably.

### **BRIDGING MEDICAL GAPS**

Even though the device is simple, getting it used in clinics is not. In Malta, Sebu's team does not have links with medical practitioners. They have published three papers from Cassar's Ph.D., but Sebu is not sure whether anyone in medicine is aware of the work. What is missing are connections, awareness, and clinical trials. This gap is both a challenge and an opportunity.

This is where mathematics helps build trust between different fields.

'Mathematics is the key to everything,' Sebu says. 'We are in a physical setup, where we inject a current on the surface of the skin, and we want to mathematically determine the distribution of the electrical field within the tissues.' Get that right, with validated models tied to MRI-derived anatomy, and you can tell a clinician not only that a surface FES should work, but precisely where to place the electrodes, their sizes, and other design parameters for a given patient.

She offers a framing that many medical readers will appreciate: 'Have you heard of MRI? Have you heard of X-ray tomography? Have you heard of CT scans? Engineers developed the machines, but the reconstruction algorithms are developed by mathematicians,' she says. Every time an image is reconstructed from measurements made outside the body, 'you want to infer the inner structure of the body from the collected data, and this is an inverse problem.' FES targeting has a similar logic: measurements and models, tuned to a person's anatomy, guiding where and how to stimulate.

Mathematics allows for personalisation in Sebu's approach.



**A Finite Element Method (FEM) mesh of the ankle**

With MRI-based models, clinicians can plan electrode placement for each patient's anatomy. Once these plans are made, they can be turned into simple products like stickers and straps, rather than requiring surgery.

Sebu is clear-eyed about the limits of what a mathematician can achieve alone. 'It's up to the clinicians to apply it practically. The doctors have access to patients who need to use this technique for different applications. They can experiment based on our mathematical results as they should know where to place the electrodes. They should know how to set the electrode configuration to achieve maximum activation,' she says. On her side, she is ready to run all the numerical simulations needed to build some trust within the community and convince the doctors to try this novel configuration.

Sebu feels a sense of urgency. It is hard to start and maintain collaboration between different fields. She feels frustrated that the contributions of mathematicians are often overlooked by other disciplines, perhaps because mathematics is seen as more theoretical. Yet its value becomes clear in practical applications, just as in this study on using surface FES for bladder control.

Without connections between fields of study, good ideas may

never be used in practice. This does not have to happen. The medical community does not need to wait for a special device maker. The key parts are already available: published mathematical models, MRI-based designs, a simple electrode layout that labs can make, and a clear clinical target in the posterior tibial nerve.

### **TURNING MATHS PRACTICAL**

The next steps are straightforward. Although FES technology is already used in areas such as FES rowing, pain management, and post-stroke rehabilitation, adopting FES for bladder control using surface electrodes will still necessitate meeting stringent ethical, regulatory, health and safety, and clinical requirements before any testing on human subjects can begin.

With these obligations in place, researchers and clinicians would first need to identify patient groups for whom bladder control remains a severe quality-of-life burden despite existing treatment options. Based on these cohorts, they could then prototype the ankle-mounted probe within a safe, fully regulated research environment and initiate small, carefully designed studies. These trials should compare

patient comfort, skin integrity, and symptom relief against both the standard two side-by-side disk electrode configurations and, where appropriate, implanted systems. From there, the findings could be shared openly, allowing hospitals and research groups across borders to iterate, validate, and refine the approach together.

Sebu's request is practical. If there is funding and a clinical partner, she can help adapt the models for specific uses. The goal is to turn a mathematical idea into a regular clinical practice, making neuromodulation easier and more comfortable.

Sebu offers a chance to try a more straightforward method: less current where it is not needed, more where it is, for fewer burns and surgeries.

'The know-how is up there for anybody to use,' she says about their findings, provided the community gets 'a bit more aware that there's another electrode configuration that can be customised for special patients' builds and needs.'

Mathematics has tangible results when someone uses a small probe on their ankle, feels a gentle buzz, and regains part of their daily life. The mathematical equations make this possible. Collaboration does the rest. 