Impedance Spectroscopy Method to Detect Pelvic Floor Muscle Damage—A Feasibility Study

Marcel Młyńczak, Katarzyna Borycka-Kiciak, Małgorzata Uchman-Musielak, and Adam Dziki

Abstract

Impairment of the pelvic floor muscles and fecal incontinence affect 5–10% of the adult populations of European states. The most common cause is perinatal obstetrical anal sphincter injury (OASI) resulting from vaginal delivery. There is no method for screening in the period immediately after delivery. Diagnosis is limited to physical examination. The gold standard, transanal ultrasonography and manometry, can be performed after a few weeks, whereas clinical practice requires that injury be detected as early as possible for optimal treatment. Therefore, we would like to validate an alternative technique, impedance spectroscopy. The aim of the study is to analyze the accuracy of problem detection within the 3–1000 kHz frequency range in 3 radial positions. 22 females (10 issued and 12 included in a control group) were engaged. Impedance moduli and phase shifts were estimated using a bipolar impedance spectrometer along with a specific anal probe. We calculated parameters assessing different subranges of analyzed frequencies and treated them as input vectors for detection. Accuracies were estimated for Naïve Bayes, Random Forest, Support Vector Machine and Quinlay's C5.0 models. We performed recursive feature elimination to find the most significant subranges of frequencies. An accuracy of 86.4% was observed for the Random Forest technique and entire set of considered parameters. It appears that impedance spectroscopy allows assessment of problems with pelvic floor muscle (particularly OASI), directly after vaginal delivery and faster and easier than gold standard methods.

Keywords

Pelvic floor muscle damage • Obstetrical anal sphincter injury • Impedance spectroscopy • Classification Diagnostics

1 Introduction

Fecal incontinence is a clinical symptom of insufficiency of the closing mechanism of the anus [1, 2]. The problem of anal sphincter insufficiency affects about 5–10% of the adult population of European states [1, 3, 4]. The most frequent cause is perinatal damage to the pelvic floor muscles. Symptoms of sphincter damage (with different degrees) are observed in 13–25% subjects after vaginal delivery. Resulting fecal incontinence signs may appear immediately, but they can also develop gradually with age and exacerbate after menopause [5, 6].

The most common type of perinatal damage is partial injury of the external anal sphincter, usually undetected during labor and often asymptomatic. In endosonographic examinations, lesions of one or both anal sphincters are detected following 35% of first deliveries and 44% of later ones.

The basic prevention technique is the controlled episiotomy. The decision is based mainly on the intuition and experience of a doctor, or results from the rules adopted in a given region. However, after the intervention, further damage may occur—the incision line may expand. Therefore, the value of such procedure is controversial. No associated reduction in the risk of gas and stool incontinence has been

M. Młyńczak (✉)
Faculty of Mechatronics, Institute of Metrology and Biomedical Engineering, Warsaw University of Technology, Warsaw, Poland
e-mail: mlynczak@mchtr.pw.edu.pl

K. Borycka-Kiciak
Department of General, Oncological and Gastrointestinal Surgery, Orlowski Hospital, Centre of Postgraduate Medical Education, Warsaw, Poland

M. Uchman-Musielak
Department of Obstetrics and Gynecology, Solec Hospital, Warsaw, Poland

A. Dziki
Department of General and Colorectal Surgery, Medical University of Łódź, Łódź, Poland

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demonstrated [7]. A study on pelvic floor muscle dysfunction observed four years after delivery also confirmed that routine episiotomy does not protect against symptoms of fecal incontinence [8].

Available diagnostics (imaging—transrectal ultrasonography, MRI or defecography—or functional examination—manometry) are limited, in terms of both time (they cannot be performed until a few weeks after delivery) and availability (they require specialized equipment and, especially, highly qualified staff to interpret results). Sometimes both types of diagnostics should be performed.

Therefore, new diagnostic methods are sought. One proposal is to register electrical impedance, particularly its module and phase shift, in a specific part of the pelvic floor muscles, using a special probe—impedance spectroscopy.

The aim of the study is to analyze the accuracy of problem detection within the chosen frequency range (3–1000 kHz) in 3 radial positions.

2 Materials and Methods

A group of 22 females (10 issued, with detected sphincter damage, aged 30.9 ± 3.7; 12 healthy, included in a control group, aged 40.8 ± 11.0; 36.3 ± 9.8 overall, all ages expressed as mean ± standard deviation) was engaged. All were informed about the aim of the study and signed forms indicating informed consent. The study was accepted by the Bioethics Commission of the Medical Chamber in Warsaw (KB/977/15).

All participants were first examined and assigned to a group (issued or control). Then, the main registrations were carried out by placing a special anal probe (Periprobe RU/AAnalis, manufactured by BeacMed, Italy, commonly used for electrostimulation and biofeedback applications) in the anal canal. 2 gold electrodes were positioned on opposite sides. We tested 3 radial positions:

- along the main axis (front-to-back),
- with a 60-degree shift to the right in relation to the main axis, and
- with a 60-degree shift to the left in relation to the main axis.

Bioimpedance was measured using an Impedimed SFB7 spectrometer (developed by Impedimed, Australia QLD), which enables measurement of resistance and reactance in the frequency range of 3–1000 kHz (256 points, unevenly distributed) using the current method (injecting current to the tissue and measuring the modulated voltage signal).

From resistance and reactance, one can calculate impedance moduli and phase shifts, which were used during the analysis. The SFB7 is designed to operate with a tetrapolar electrode configuration, but the anal probe had only 2 electrode contacts. We therefore used the bipolar technique, connecting two pairs of electrodes (with single application and receiving channel in each pair). Finally, from each participant, we acquired 3 impedance modulus curves for the 3 radial positions, and the corresponding 3 phase-shift curves.

We calculated the set of input parameters by averaging the values of impedance moduli and phase shifts (for all radial positions) within 8 frequency subranges (equal in terms of logarithmic transformation of frequency range):

- 3.0–6.2 kHz (31 points)
- 6.2–12.8 kHz (32 points)
- 12.8–25.6 kHz (31 points)
- 25.6–54.8 kHz (34 points)
- 54.8–113.2 kHz (31 points)
- 113.2–234.0 kHz (33 points)
- 234.0–483.8 kHz (32 points)
- 483.8–1000.0 kHz (32 points)

Therefore, for each subject, we had 48 parameters, and treated them as input vectors for problem detection. Several classification methods were taken into account (tuning parameters determined experimentally):

- Naïve Bayes algorithm (NB),
- Support Vector Machines (SVM; with linear kernel),
- Random Forests (RF; with 300 trees), and
- Classification tree model using Quinlan's C5.0 algorithm (C5.0; 10 trials).

For each case, we divided the data into 2 subsets, training (50%) and testing (50%). 10-fold cross-validation was assumed. Accuracy, sensitivity and specificity were calculated; we estimated them for 2 conditions, considering:

- the entire set of 48 parameters, and
- the "optimal" set, the set obtained with the objective recursive feature elimination (RFE) method.

All calculations and analyses were performed in R.

3 Results

The curves of impedance moduli and phase shifts, obtained for all participants, are presented in Fig. 1 (left and right), for the main radial position, and Fig. 2 (left and right), with a 60-degree shift to the right in relation to the main axis. Groups were distinguished by marker color and shape.

Visual inspection of the data showed that the main differences can be seen in the whole frequency range for

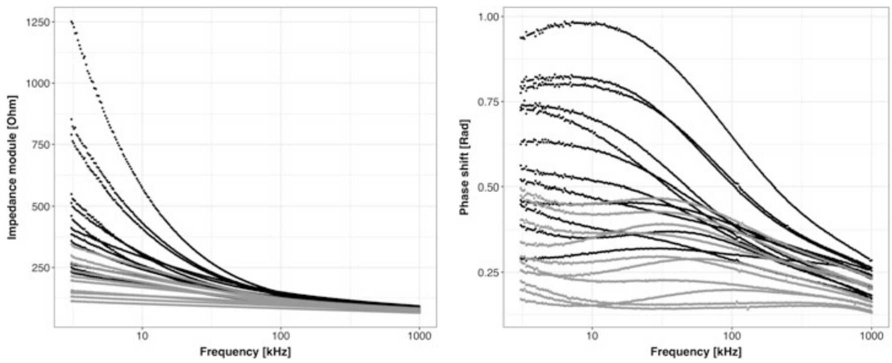

Fig. 1 Left—the graph of impedance moduli across the considered frequencies. Right—the corresponding graph of phase shifts. Both were calculated for the main radial position. Black circles correspond to control group, grey triangles to issued one

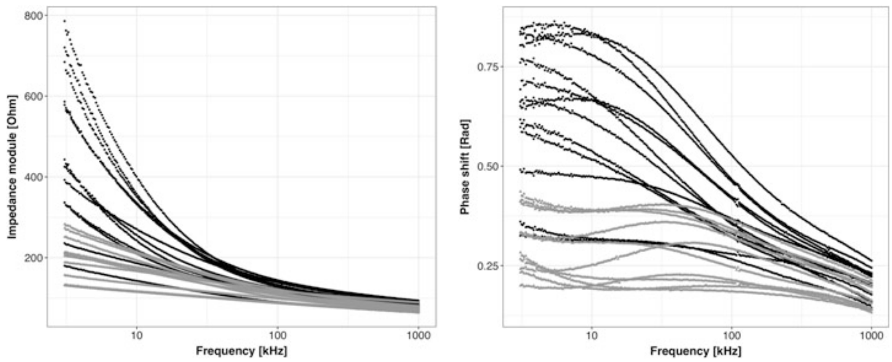

Fig. 2 Left—the graph of impedance moduli across the considered frequencies. Right—the graph of the corresponding phase shifts. Both were calculated for the position with a 60-degree shift to the right in relation to the main axis. Black circles correspond to control group, and grey triangles to issued one

impedance moduli and for smaller frequencies for phase shifts. This was confirmed with objective testing using the RFE method. Therefore, as a reduced set of parameters, we chose the 3–234 kHz range for impedance moduli and 3–54.8 kHz for phase shifts.

Table 1 summarizes the accuracies obtained for all the considered classification techniques and for the full and reduced (RFE-selected) sets of impedance parameters. The results are presented for comparison. The full set seems better in terms of all analyzed features. Overall, random forests provided the best accuracy. However, it is worth noting that the C5.0 algorithm had the highest sensitivity (about 83%).

4 Discussion and Conclusions

Clinicians face a lack of screening methods that can be used to detect pelvic floor muscles just after delivery. Transanal ultrasonography and manometry may be performed after a few weeks and manual examination seems limited in terms of quantitative and reproducible inference. On the other

Table 1 The summary of the accuracies obtained for all considered classification methods for the full and reduced sets of impedance parameters; abbreviations: Acc.—accuracy, Sens.—sensitivity, Spec.—specificity

Classification technique	Full			Reduced		
	Acc. (%)	Sens. (%)	Spec. (%)	Acc. (%)	Sens. (%)	Spec. (%)
NB	85.5	80.0	92.0	**82.7**	75.0	**92.0**
RF	**86.4**	80.0	**94.0**	80.9	73.3	90.0
SVM	77.3	66.7	90.0	74.5	68.3	82.0
C5.0	85.5	**83.3**	88.0	**82.7**	**80.0**	86.0

hand, diagnostic and therapeutic algorithms are constantly modified [1, 3, 4, 7].

The treatment depends particularly on the speed with which damage is detected. Simple surgical sphincter stapling is possible only up to 24 h from the injury (later reconstruction is done after a few months and using the loop stoma). Moreover, even if the damage consists only of the sphincter and/or neurogenic injury, rehabilitation should be started in the first days after delivery.

The main problem is that few of these injuries (only about 20%) are detected in the early post-delivery period. That is why few patients are referred for further, more specialized diagnostics. Our aim is to deliver a method that allows not only increased clinical symptoms, but also simple, non-invasive examination that almost anyone can perform. From that, we assumed that both anatomical and physiological (functional) information, can be revealed in electrical bioimpedance when considering a wide frequency range. Impedance spectroscopy has been used in many similar applications, e.g., the detection of interstitial cancers of the cervix, colon cancer, bladder pathology, or neuromuscular diseases [9–12].

An impedance spectroscopy method with a specific anal probe was used to preliminarily evaluate the possibility of using impedance-related information and to check the reliability with which participants exhibiting the condition could be distinguished from the healthy control group. Relatively high accuracy (above 85% for 3 different methods, cross-validated) was observed, despite the use of bipolar impedance measurement and a simple set of parameters. This allows us to state that the proposed method seems to enable assessment of problems with pelvic floor muscle (particularly OASI) directly after vaginal delivery and faster and easier than gold standard methods.

There are several limitations. Only 22 participants were tested, each only once and only with a very simple probe, which forced the use of the bipolar technique. The "issued" group represents a range of conditions rather than a specific problem.

We will continue analyses in this field, with tetrapolar electrode configuration provided by a target anal probe (compatible with patent application WO 216/190763 A1), more sophisticated impedance-related parameters, more states and diseases to recognize, and reproducibility and progress analyses. Moreover, we plan to determine what affects the level of impedance modulus and phase shift in the presented application and to what extent.

Conflict of Interest The authors declare that they have no conflict of interest.

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