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Difference in Electrical Bioimpedance of Belly of Healthy Subjects with Full and Empty Bladder: A Pilot Study

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Abstract. This research introduces an assessment of bladder function using bioimpedance spectroscopy, noted for being not invasive. Eight healthy volunteers were selected to measure impedance spectra of belly under full and empty bladder conditions. The study demonstrates a significant relationship between belly impedance and bladder state, suggesting that this technique could be useful for monitoring it without resorting to invasive or more complicated procedures like echography and tomography. The findings indicate a promising approach that could facilitate the clinical management of patients with incontinence, improving their quality of life.

Keywords. Bioimpedance, belly impedance, bladder state, impedance spectroscopy measurements.

1. Introduction

The evaluation of bladder function in patients with sphincter control disorders, such as urinary incontinence and several bladder dysfunctions, has traditionally depended on urodynamic tests. Although these tests are effective in diagnosing problems such as lower urinary tract obstruction, they are invasive: They can be uncomfortable for patients, limiting their applicability in certain demographic groups, particularly those with medical vulnerabilities [1]. The need for less invasive and more comfortable diagnostic methods is evident, especially in sensitive populations such as elderly subjects, who often suffer from chronic conditions that complicate standard procedures.

In response to this need, the bladder impedance measurement has emerged as a promising alternative. This technique uses variations in the electrical properties of bladder tissues to assess the filling status of the bladder, thus providing a potentially less invasive and more informative method [2, 3]. Electrical Impedance Spectroscopy (EIS) is a very powerful electrical characterization tool for any type of system. Particularly, it is a very important tool in the area of biomedical engineering, where it is called biomedical impedance spectroscopy. This consists of applying a signal with a small voltage (commonly with an amplitude of less than 50 mV) of a certain frequency and monitoring the current response, or vice versa. The response is shifted in time regarding the applied signal, which can be seen as an angular difference (the phase θ). On the other hand, the ratio of the signal amplitudes (voltage/current) results in the impedance amplitude, |Z|. The set of |Z| and θ characterizes the system measured at that frequency. If the system is measured at different frequencies, then what is obtained is the impedance spectrum.

The anatomy of the urinary bladder is essential to understand electrode placement in bioimpedance studies. The bladder expands and contracts during the filling and emptying phases, controlled by the autonomic nervous system. Normal bladder capacity varies between 400 and 600 ml, although this can vary significantly between individuals and with pathological conditions [4]. During filling, the detrusor muscle remains relaxed while the internal and external urinary sphincters contract to retain urine. In the voiding phase, the detrusor contracts to expel urine, and the sphincters relax [5].

Electrode placement must consider these dynamics, as well as variability in the distribution of blood and surrounding tissues, which can influence the bioimpedance measurements [6]. Anatomical and physiological characteristics of the bladder may present limitations in impedance measurement, especially in patients with pathological changes such as detrusor overactivity or obstructions [5]. In [7], the impedance of 8 healthy subjects was measured by applying a current of 1 mAp-p, at 10 kHz, and 4 electrodes were used. According to the results, a negative correlation was observed between the measured voltages and the urinary volume of the bladder during bladder activity. It was also observed that the leftmost and rightmost points of the abdomen were the best places to place the electrodes in which the current was injected and the other two were placed 3 cm from the center of the abdomen.

In [8], bioimpedance was measured in a healthy subject, after injecting a current of 100 uA, at 50 kHz and using 4 electrodes. In this study, a clear trend of change in impedance was observed during the bladder-filling process.

In other investigations, bladder bioimpedance was also measured to observe changes depending on its filled level. A healthy subject was measured at 50 kHz in [9] and it was observed that the impedance gradually decreased as the filling time passed. In [10], a healthy subject was also measured, using 4 electrodes, and inducing a current of 500 µA at 50 kHz. It was observed that there was a difference in the rate of change between bioimpedance and phase in the urinary volume of the bladder.

The present study sought to explore how variations in bladder electrical impedance could correlate with full and empty states. To do this, 8 healthy subjects were measured, excluding those with active urinary infections or a history of surgeries that affected the structure or function of the bladder.

Unlike previous studies, a voltage of the order of mV was injected, and not only at one frequency but a sweep was made from 10 Hz to 10 kHz.

As a result, bladder impedance data were obtained to estimate the variation during its activity. The central hypothesis of the study is that variations in the electrical impedance of the bladder are directly correlated with its degree of filling. This approach could not only improve the clinical management of patients with urinary disorders but also increase quality of life by reducing the frequency and impact of invasive diagnostic tests.

The objective of this work is to analyze impedance variations in the bladder under filling and emptying conditions to identify distinctive patterns based on frequency and other relevant parameters. This study aims to establish an effective biomarker that allows accurate detection of the bladder filling condition in patients with sphincter control problems.

2. Materials and Methods

2.1 Subjects

A sample of 8 participants was measured (4 men, denoted as S1-S4; and 4 women, denoted as S5-S8) who met the following inclusion criteria: Being between 20 and 29 years old, being healthy, not currently studying any disease or infection in the urinary tract.

The study was constraint to subjects under 30 years old, to reduce the probability of having bladder problems.

Men have a height between 1.75 and 1.80 m (1.77 m +0.02) and a weight between 60 and 85 kg (74.7 kg +10.04). Women have a height between 1.5 and 1.6 m (1.52 m +0.03) and a weight between 45 and 60 kg (51.7 kg +3.5). All individuals who did not meet these requirements

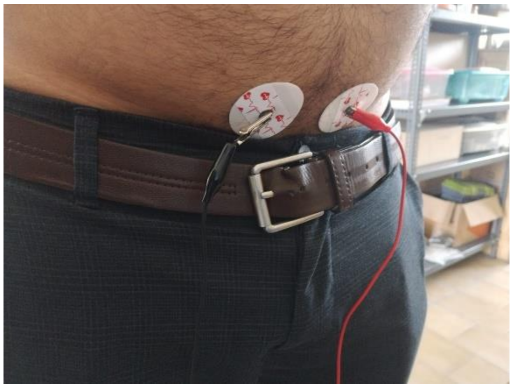

Fig. 1. Representative photo of the electrode connection

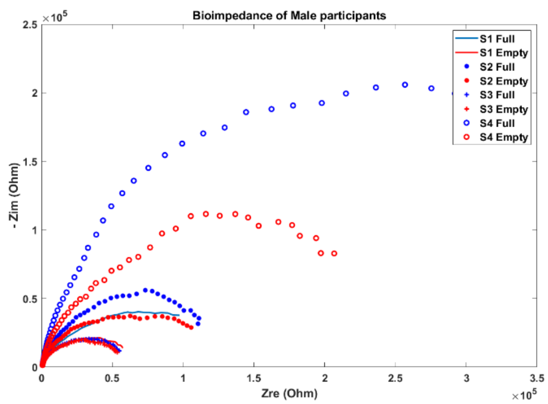

Fig. 2. Nyquist plot of impedance of the men group. In blue, the full bladder results are depicted; in red, the empty bladder results are shown

were excluded. This information is shown in Table 1.

The bioethical and biosecurity fundaments presented in this work were adopted and aligned with Helsinki Declaration and with the local and international normative about research with human beings.

2.2 Equipment

To carry out the impedance measurements from the bladder, the equipment BCS-Com Biologic BCS-815 was used, along with skin electrodes, and wires for the correct connection.

Moreover, glasses and pH strips were used for collecting urine and then observed the

Table 1. Participant's information

Subject	Gender	Age (years)	Height (m)	Weight (kg)	IMC
S1	M	23	1.75	77	25.14
S2	M	25	1.75	60	19.59
S3	M	25	1.78	80	25.24
S4	M	25	1.80	82	25.30
S5	F	24	1.56	56	23.01
S6	F	22	1.5	48	21.33
S7	F	26	1.55	53	22.06
S8	F	25	1.5	50	21.4

Table 2. Configuration of BCS-Com Biologic BCS-815 for impedance measurement

Parameter	Value
DC voltage	0 V vs Eoc
f_i	10.000 Hz
f_f	10,000.00 Hz
Sinus amplitude Va	100.0 mV (Vrms 70.71 mV)

corresponding pH value. The equipment was configured as shown in Table 2.

2.3 Procedure

2.3.1. Phase 1: Prior measurements

The participants were asked to sign an informed consent letter, in which the objectives, procedure, and possible risks were explained.

Moreover, it was specified to all subjects that the provided data were anonymous, confidential and only for research purposes. Each one read the bladder´s impedance signal acquisition protocol ("Protocolo de adquisición de señal de impedancia de la vejiga (INAOE-BUAP)") and completed a Google form with basic and clinical information.

After that, the equipment BCS-COM Biologic BCS-815 was configured as shown in Table 2. The participants were asked to drink water before the measurements so that the bladder would be full while measuring the impedance (for about 6 to 10 min). If someone was not drunk enough water, he/she was asked to do it. They were also asked to stay calm and avoid movements to assure reliable measurements.

2.3.2 Phase 2: Full-bladder measurements

The participants were standing in front of the equipment, staying still and in a relaxed position. Two skin (disc) electrodes were placed in the pelvic region, with a distance between them of 6 cm (see Figure 1). They were located near the bladder. The wires were connected from the equipment to the electrodes in order to induce a Voltage of 100 mV and hence measure the impedance from 10 Hz to 10 kHz.

It had a duration of 6 min. Once the measurement was finished, the wires were disconnected and the participant was asked to go the bathroom to pee and collect a small quantity of urine in the glass. Then, in the lab, with the aid of pH strips, the pH value was recorded.

This was to discard volunteers that were undergoing any bladder infection. It is clear that the technique is not 100% effective to identify subjects with infection, but it is an important first simple step.

2.3.2 Phase 3: Empty-bladder measurements

The same process, described before, for the impedance measurements of the full-bladder were repeated for the empty-bladder. Again, after 6 min approximately, the wires were disconnected and thanked the participant for being part of the study.

2.4 Processing

Once both measurements were done (full- and empty-bladder), the processing was performed by means of MATLAB. It consisted of plotting the obtained impedance and phase results, for both, full-bladder and empty-bladder, and for male and then female participants.

Moreover, the ratio between full and empty bladder were computed, not only for the impedance, but also for the phase, along all frequencies. This was done in order to compare and observe if there is a change between full and empty levels.

3. Results

3.1 Male Participants

For this male group, it can be observed in all cases that the bioimpedance values when the bladder is full are higher than when the bladder is empty, as can be shown in Figure 2.

Subjects S1 and S4 showed higher bioimpedance values when the bladder is full, as compared when it is empty. This variation may indicate a significative response to the change of level. Subjects S2 and S3 had a smaller variability between levels, as compared with S1 and S4. In Figure 3, the phase results are shown, for both full and empty bladder. As can be observed, the phase is smaller when the bladder is full than when it is empty, especially for low frequencies (below 250 Hz). All subjects had a similar behavior. S3 showed a small variation between both levels, while S4 a high difference can be observed.

The bioimpedance ratio between full and empty bladder changed with frequency per each subject, and is useful to prove that there is a difference between bioimpedances. The values greater than one indicate that the full-bladder bioimpedance is higher than empty-bladder bioimpedance. For this group, it was observed a higher ratio in the low frequencies, as shown in Table 3, where only 7 frequencies are presented for each subject.

For subject S1, while the frequency increased, the ratio decreased. As observed in the table, at 10 Hz, the ratio is 1.77, and when the frequency is 10 kHz, the ratio is 1.07. The same occurs in all male participants: the ratio decreased when increasing the frequency.

In blue, the full bladder results are depicted; in red, the empty bladder results are shown

3.2 Women Participants

The results show that bioimpedance is in two cases higher when the bladder is full than when it is empty. This can be observed in Fig. 4 in S6 and S8, while in S5 and S7 the impedance is smaller when the bladder is full than when it is empty.

In Fig. 5, the phase results are shown. It can be seen that the phases are higher for low frequencies, than for high frequencies. Moreover, it can be observed that in S5, the phase is higher

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for full-bladder than for empty-bladder, especially in frequencies below 1000 Hz. Above 1 kHz, the opposite occurs. For S6, the phase is smaller for full-bladder than for empty bladder. This occurs for frequencies below 50 Hz. Then, the phases for both levels are very similar for the rest of the frequencies. In the case of S7, the phase is slightly higher for full-bladder than for empty-bladder in all frequencies. For S8, from 20 Hz to 20 kHz, the phase is smaller for full-bladder than for empty bladder. Above 20 kHz, both phases are very similar.

Taking a look to the Impedance spectra of men subjects (see Fig. 2), one could observe that their overall intensity is larger when the bladder is full, for all the subjects. On the other hand, the plots of phase versus frequency (Fig. 3) show that there is a gradual change in the phase of bioimpedance with increasing frequency for both full and empty bladder. As frequency increases, the difference in phase between full and empty bladder appears to decrease.

These results are not replicated by female subjects, where no clear tendency is observed. This may happen due to other factors not present in men, like menstruation. Subjects S5 and S8 have a more pronounced decrease in phase with frequency in the full bladder compared to when empty, which is typical when conductivity increases due to fluid. Whereas in subjects S6 and S7 the differences in phase between the full and empty states are less pronounced, which may indicate less variability in tissue response to the filled state.

In our study, the general reduction in bioimpedance in the filled state observed in women may be explained mainly by the increased water content in the bladder, an excellent electrical conductor. This phenomenon is in agreement with the study by Smith and Carter (2021), which highlights how water content influences tissue conductivity [11]. However, it is crucial to consider additional variables such as an elevated body mass index in some subjects, which could alter the expected conductivity, as demonstrated by Lee and Thompson (2022) in suggesting that tissue composition significantly affects impedance measurements [12].

Despite contradictory results in certain subjects, this could be due to the presence of fluids in the tissues, thus increasing their conductivity, in line with what has been observed in the current literature [13]. It is necessary to consider the possibility of infections, which, according to Wang and Zhao (2023), could modify bioimpedance in

Table 3. Ratio between full and empty bladder impedance per each male participant and for certain frequencies

Frequency (Hz)	S1	S2	S3	S4
10	1.77	1.05	1.03	1.64
50	1.39	1.25	1.06	1.41
102	1.31	1.21	0.99	1.29
501	1.17	1.10	1.00	1.10
1002	1.13	1.09	0.99	1.07
5013	1.07	1.03	1.00	1.04
10001	1.07	1.02	1.00	1.03

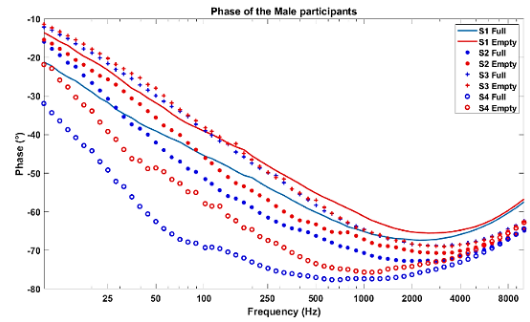

Fig. 3. Phase in the men group. In blue, the full bladder results are shown; in red, the empty bladder results are presented

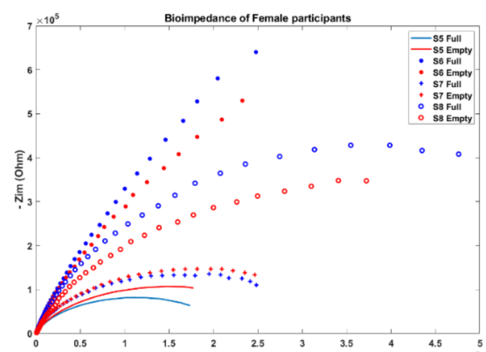

Fig. 4. Nyquist plot of impedance of the women group

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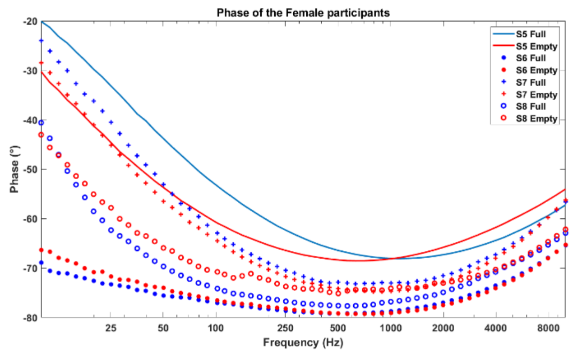

Fig. 5. Phase in the women group. In blue, the full bladder results are shown; in red, the empty bladder results are presented

Table 4. Ratio between full and empty bladder impedance per each female participant and for certain frequencies

Frequency (Hz)	S5	S6	S7	S8
10	0.90	1.19	0.97	1.23
50	1.19	1.10	1.07	1.26
102	1.29	1.08	1.09	1.21
501	1.39	1.06	1.08	1.16
1002	1.40	1.06	1.07	1.14
5013	1.33	1.06	1.07	1.08
10001	1.29	1.07	1.06	1.07

unanticipated ways [14]. In the present study, the subjects did not present infections, however, for future work it is worth considering this.

Changes in bioimpedance facilitate detection of bladder filling status and provide valuable information about tissue health and potential abnormalities [15].

The bioimpedance phase, affected by the capacitive properties of the tissue, shows significant variations with the amount of fluid present, especially at high frequencies where the intrinsic properties of the tissue become more dominant, which is in agreement with that reported in [16].

The correlation between full and empty bladder in women highlights a clear variability in bioimpedance responses, suggesting underlying physiological differences such as bladder tissue composition, bladder size, or the amount of fluid retained, as reported in [17].

For men, bioimpedance reduction with a full bladder may be influenced by constitution and content conduction, showing similar patterns in some cases to the female group, but also clear differences in how states affect bioimpedance measurements [18].

Women might show higher impedance values due to a higher proportion of adipose tissue, which has different electrical properties compared to the more prevalent muscle tissue in men.

This difference in tissue composition between genders could explain why impedance curves in women present a wider distribution, suggesting variations in conductivity due to water and fat tissue content, whereas in men, the curves tend to be narrower and less dispersed [19].

These results underscore the importance of considering bioimpedance spectroscopy not only as a diagnostic tool for assessing bladder filling, but also as a potential indicator of tissue health, adaptability, and physiological response in different states and conditions. Future research should further explore how individual differences and tissue composition affect bioimpedance, with the potential to improve diagnostic and treatment techniques based on clinical bioimpedance spectroscopy [20].

4 Conclusion

With this work it was found a clear difference in the bioimpedance of bladder when measured in its full or in its empty state, independently on the gender. However, just in the case of men a clear tendency was observed. This can be attributed to the presence of additional factors in the case of women. This means that for the case of women, additional measurements or considerations should be taken into account, to be able to use bioimpedance spectroscopy as a tool to determine the state of the bladder.

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References

1. **Smith, P.P., DeAngelis, A., Kuchel, G.A. (2018).** The bladder-Brain connection: putative role of uremic toxins. J Am Geriatr Soc., Vol. 66, No. 2, pp. 424–428.
2. **Jones, J.S., Patel, A.S., Sullivan, M.J., et al (2019).** Bladder impedance tomography: Potential implications for urinary tract health. Urology, Vol. 131, pp. 24–30.
3. **Noyori, O., Kato, K., Miyazato, M., et al (2022).** Impedance characteristics of the bladder: Towards new diagnostic tools. Urol Int., Vol. 108, No. 1, pp. 59–66.
4. **Abrams, P., Cardozo, L., Wagg, A., Wein, A. (2017).** Incontinence 6th Edition. ICI-ICS. International Continence Society, Bristol, pp. 295–300.
5. **Andersson, K.E., Arner, A. (2004).** Urinary bladder contraction and relaxation: physiology and pathophysiology. Physiol Rev., Vol. 84, No. 3, pp. 935–986.
6. **Tyagi, P., Tyagi, V. (2021).** Impedance spectroscopy of the bladder: a new diagnostic modality for evaluation of bladder sensation. Neurourol Urodyn, Vol. 40, No. 2, pp. 458–465.
7. **Li, Y., Peng, Y., Yang, X., Lu, S., Gao, J., Lin, C., Li, R. (2019).** Analysis of measurement electrode location in bladder urine monitoring using electrical impedance. Biomed. Eng. Online, Vol. 18, No. 34.
8. **Palla, A., Rossi, S., Fanucci, L. (2015).** Bioimpedance based monitoring system for people with neurogenic dysfunction of the urinary bladder. Assistive Technology, IOS Press: Amsterdam, The Netherlands, pp. 892–896.
9. **Sakai, R., Nakatake, S. (2019)**. An impedance measurement of intravesical urine volume appropriate to seated posture. Proceedings of the IEEE Asia Pacific Conference on Circuits and Systems (APCCAS), pp. 385–388.
10. **Noguchi, T., Fukai, S., Ishikawa, Y., Shimizu, A., Kimoto, A., Toyoda, I. (2018).** A urinary bladder volume measurement circuit using a simplified very small phase difference measurement circuit. Electr. Eng. Jpn., Vol. 203, pp. 28–36.
11. **Smith, J., Carter, B. (2021).** Impact of water content on tissue electrical conductivity. Journal Clin. Bioelectromagnetics, Vol. 34, No. 2, pp. 112– 119.
12. **Lee, P., Thompson, A. (2022).** Body composition and its effect on electrical impedance measures. Biophys J., Vol. 48, No. 1, pp. 33–45.
13. **Taylor, S., Kumar, V. (2020).** Hydration dynamics and electrical properties in biological tissues. J Bioelectromagnetics, Vol. 41, No. 2, pp. 130–145.
14. **Wang, Y., Zhao, X. (2023).** Cellular structural impacts on bioimpedance. Adv Clin Bioeng., Vol. 39, No. 3, pp. 154–162. DOI:10.1021/acsnano.2c 10896.
15. **Patel, R., Singh, S. (2022).** Variability in bioimpedance: Implications for clinical assessment. J Med Physiol., Vol. 37, No. 4, pp. 210–222. DOI:10.1002/ncp.10230.
16. **Hernandez, E., Martin, G. (2024).** Frequency dependence of tissue impedance properties. J Electromagn Biol Med., Vol. 46, No. 1, pp. 77–85.
17. **Johnson, K., El-Hussein, M. (2022).** Analyzing tissue impedance at high frequencies for medical diagnostics. Bioimpedance and Bioelectricity Basics., Vol. 53, No. 1, pp. 24–37.
18. **Chang, Y., Kumar, V. (2022).** Sex-specific variations in bioimpedance: A comparative study. Urol Sci Res., Vol. 43, No. 3, pp. 98–106. DOI:10.3389/fgene.2023.1038529.
19. **Green, M., Turner, S. (2023).** Bioimpedance as a diagnostic tool for bladder cancer detection. Clin Biochem Rev., Vol. 44, No. 2, pp. 85–94.
20. **Nguyen, D., Patel, R. (2023).** The clinical utility of bioimpedance in bladder state

assessment. Med Meas Appl., Vol. 45, No. 1, pp. 58–68.

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