**Regular Article**

# Effect of lying duration on body composition assessments using multi-frequency bioelectrical impedance analysis in para-athletes

Haruhiko Goto[1]*, Reiko Momma[1], Keiko Namma-Motonaga[1], Noriko Hakamada[1], Takeo Matsubayashi[1]*

1) Department of Sports Sciences, Japan Institute of Sports Sciences, Tokyo, Japan
*Correspondence: Takeo Matsubayashi ✉takeo.matsubayashi@jpnsport.go.jp
*Correspondence: Haruhiko Goto ✉haruhiko.goto@jpnsport.go.jp

**Abstract:** Background: The assessment of body composition, including measurements of fat-free mass (FFM) and body fat percentage (%BF), is essential for para-athletes. Multi-frequency bioelectrical impedance analysis (MF-BIA) in the supine position is typically performed after lying for 15 minutes; however, it would be preferable if reliable values could be obtained in a shorter time. This study aimed to investigate the effect of shorter lying durations on body composition values obtained using MF-BIA. Methods: Nineteen para-athletes in the sitting category participated in this study. MF-BIA in the lying posture was conducted at 5, 10, and 15 minutes after lying down. Systematic errors for whole-body and segmental FFM and %BF were evaluated using Bland–Altman analysis. Values obtained at 15 minutes were used as reference. Total body water and segmental body impedance at each time point were also examined using repeated-measures analysis of variance (ANOVA). Results: There were slight but significant fixed errors in whole-body and segmental FFM and %BF when the lying duration was shorter than 15 minutes. Repeated-measures ANOVA also revealed that total body water and segmental body impedance measured with shorter lying duration significantly differed from those measured with 15 minutes of lying. These results imply that a shortened lying duration for MF-BIA can substantially affect body composition values. Conclusions: When the lying duration is shorter than the recommended period, slight fixed errors were observed. If these differences are acceptable in clinical practice, body composition could be assessed with shorter lying durations.

**Keywords:** body fat percentage, para-athletics, segmental fat-free mass, fat-free mass

## Introduction

The assessment of body composition, including the measurement of fat-free mass (FFM) and body fat percentage (%BF), is essential for athletes to monitor their adaptation to athletic training. Most FFM consists of muscle tissue and is associated with maximal force and power production. Appendicular FFM is related to movement ability, such as sprinting,[1] making it important for athletes to maintain adequate FFM. For para-athletes in the sitting category, upper-limb strength is related to wheelchair propulsion ability.[2-3] Therefore, they should be highly interested in their upper-limb FFM. On the other hand, %BF should be minimized to enhance athletic performance, as body fat does not produce force or power and is rarely used as an energy source.[4] This is also true for para-athletes: previous studies indicated that wheelchair middle- and long-distance racing performance is associated with maximal oxygen uptake per body weight.[5-6]

Various methods are available for measuring and

assessing body composition, including multi-frequency bioelectrical impedance analysis (MF-BIA), air displacement plethysmography (ADP), and dual-energy X-ray absorptiometry (DXA). MF-BIA applies weak electric current to the body, and measures its impedance and body water content. FFM is then estimated based on the assumption that 73.2% of body water is distributed in FFM. After estimating FFM, body fat mass and %BF can be calculated by subtracting FFM from body weight.[7-8] Recently, many MF-BIA devices have been released as consumer products. MF-BIA devices are now widely used in training fields and clinical practice because they are noninvasive, unlike DXA, and more cost- and time-efficient compared to DXA and ADP. Most previous MF-BIA devices required participants to maintain an upright standing posture for several minutes. However, newer devices that allow measurement in the lying posture have recently been developed and are expected to be useful for para-athletes who have difficulty in maintaining standing posture.

When the body shifts from a standing to a lying posture, gravity causes body water to move from the lower to the upper body, changing total body impedance and affecting body composition estimates.[9-11] Because the redistribution of body water and corresponding changes of body impedance continue for 10–20 minutes,[11] it is recommended to maintain the lying posture for at least 15 minutes before measurement using MF-BIA devices.[12] However, due to reduced fat and/or muscle thickness in their buttocks, some para-athletes who use wheelchairs may find it difficult to remain in a supine position, even for relatively short periods. Additionally, some cannot fully extend their hip or knee joints due to long-term wheelchair use, or cannot maintain a stable posture due to involuntary leg movements.

When assessing athletes' body composition, interpreting changes requires contextual understanding. In clinical practice using MF-BIA, within-day variability has been observed with very minor differences. For instance, within-day variability in total body water has been reported to fluctuate between 0.0 and 0.2 L.[13] Furthermore, an increase of more than 1.6% in fat-free mass (FFM) is likely to be considered a meaningful change reflecting training adaptation.[14-16] Nonetheless, such thresholds may differ depending on the athlete's characteristics or the specific sport.

These considerations highlight the importance of selecting appropriate protocols for assessing athletes' body composition, including para-athletes. In the training field, assessing body composition in para-athletes requires obtaining reliable values within the shortest possible duration. However, to our knowledge, limited research exists on the effects of lying duration and body water redistribution on body composition assessments. Therefore, the present study aimed to examine the effect of shorter lying durations on MF-BIA-derived body composition values in para-athletes.

## Methods

### *Participants*

A total of 19 para-athletes who use wheelchairs in daily life participated in the present study (Table 1). Their specific sports included para-athletics (wheelchair racing), wheelchair tennis, wheelchair fencing, and sit-ski.

**Table 1.** Participant demographics, specific sports, and types of disabilities.

| | Demographics | | | | Specific Sports [N] | | | Type of disability [N] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | Age [years] | Height / Arm span [cm] | Body weight [kg] | Para-Athletics | Wheelchair Tennis | Wheelchair Fencing | Sit-ski | SCI | SB | CP |
| **Male** | 11 | 32.91 ± 8.67 | 175.48 ± 5.17 | 64.45 ± 10.17 | 6 | 1 | 2 | 2 | 10 | 0 | 1 |
| **Female** | 8 | 30.88 ± 9.42 | 155.16 ± 4.84 | 47.14 ± 6.54 | 2 | 3 | 0 | 3 | 4 | 3 | 1 |
| **Total** | 19 | 32.05 ± 8.79 | 166.93 ± 11.41 | 57.16 ± 12.30 | 8 | 4 | 2 | 5 | 14 | 3 | 2 |

CP, cerebral palsy; SB, spina bifida; SCI, spinal cord injury

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The types of disability were spinal cord injury, spina bifida, and cerebral palsy. No participant had upper- and/or lower-limb amputations, although three participants had titanium implants in the spine or hip joint.

The study was approved by the Ethics Committee of the authors' affiliation (#2022-053) and adhered to the principles of the Declaration of Helsinki. All participants provided written informed consent prior to participation.

***Data collection***

Body composition was measured using an MF-BIA device (InBodyBWA, InBody Co., Ltd., Korea). Participants' height and body weight were measured before the MF-BIA measurements, and were manually entered into the device. Data collection was conducted as part of a physical fitness assessment program for para-athletes. All measurements were performed during the morning hours following breakfast, with participants typically refraining from eating and drinking for approximately 1–2 hours prior to the measurement. Although some participants were regularly taking diuretic or urine-retention medications, medication use prior to the measurement was not controlled. The room temperature was maintained between 20 and 25 °C throughout the measurement period. If participants were unable to maintain a standing posture, their arm span was used as a substitute for height because arm span is nearly identical to height in able-bodied individuals.[17] The arm span was defined as the distance between the left and right fingertips when the arms were outstretched with the shoulder joints abducted at 90 degrees.

The MF-BIA measurements of %BF and whole-body and segmental FFM were performed using eight points adhesive electrodes attached on the wrist and ankle joints at eight frequencies ranging from 1–3,000 kHz. Prior to electrode placement, participants' wrists and ankles were wiped with electrolyte tissues. Participants lay on a bed for 15 minutes, and measurements were conducted at 5, 10, and 15 minutes. During the measurements, participants kept their upper and lower-limbs fully extended and maintained slight abduction at the shoulder and hip joints to avoid contact between the upper arms and trunk or between the inner thighs. If participants were unable to maintain the aforementioned stable lying posture for the measurement due to contracture or

spasticity, towels or cushions were used to stabilize their posture or prevent unintended lower-limb movement (Figure 1).

**Figure 1.** Towels placed under the legs to maintain stable posture.

If participants were unable to maintain the aforementioned stable lying posture for the measurement due to contracture or spasticity, towels or cushions were used to stabilize their posture or prevent unintended lower-limb movement.

All values were automatically calculated by the device. Segmental FFM was obtained for the right upper-limb, left upper-limb, trunk, right lower-limb, and left lower-limb. Whole-body and segmental FFM, %BF, total body water, and segmental impedance at 50 kHz were exported using the operating software for the device (LookinBody120, InBody Co., Ltd., Korea). Although body impedance data were available for all eight electric current frequencies, only that for 50 kHz was used in the analysis to align with a previous study.[11]

### *Data analyses*

Measurements of whole-body and segmental FFM and %BF taken after 15 minutes of lying were used as the reference. Bland–Altman analyses were performed to examine systematic errors, including fixed and proportional errors, for each FFM and %BF value between the reference and those obtained at 5 or 10 minutes.[18] The difference for each measurement was calculated by subtracting the reference from the value at 5 or 10 minutes and plotted against their mean. The mean and standard deviation (SD) of the differences were calculated, and the fixed error was evaluated using a 95% confidence interval (CI). The limits of agreement (LoA), defined as the mean difference ± 1.96 × SD, were calculated to assess the agreement between measurements.[18] Additionally, 95% CI for the upper and lower LoA were computed to assess the precision of the estimated agreement limits. Bivariate correlation analysis was also performed to assess the association of the difference with the size of those values. When a significant correlation was identified, the proportional error was considered present. Additionally, differences in total body water and segmental body impedance at 50 kHz for each time point were examined using repeated-measures analysis of variance (ANOVA) and post hoc multiple comparison t-tests with Bonferroni adjustment.

For upper- and lower-limbs, data from each side were used independently (N = 38). All statistical analyses were conducted using SPSS ver. 29 (IBM Corp., Armonk, NY, USA), and statistical significance was set at $P < 0.05$.

## Results

The measured values—whole-body and segmental FFM, and %BF—at each time point are presented as mean ± SD in Table 2. Specifically, whole-body FFM decreased slightly over time, from 38.99 ± 8.20 kg at 5 minutes to 38.83 ± 8.22 kg at 15 minutes, and segmental FFM showed similar trends across all

regions. By contrast, whole-body %BF was gradually increased with longer lying durations, rising from 27.34 ± 8.59 % at 5 minutes to 27.64 ± 8.57 % at 15 minutes. The mean differences and the LoA with 95% CIs between the reference and measured values at 5-minutes and 10-minutes time point are summarized in Table 3.

**Table 2.** Whole-body and segmental fat-free mass and body fat percentage at each time point.

| | | 5-min value | 10-min value | 15-min value |
|---|---|---|---|---|
| **Whole body** | %BF [%] | 27.34 ± 8.59 | 27.56 ± 8.63 | 27.64 ± 8.57 |
| | FFM [kg] | 38.99 ± 8.20 | 38.88 ± 8.20 | 38.83 ± 8.22 |
| **Segmental FFM** | Upper-limb [kg] | 2.86 ± 0.84 | 2.84 ± 0.84 | 2.83 ± 0.84 |
| | Trunk [kg] | 22.80 ± 5.07 | 22.73 ± 5.07 | 22.67 ± 5.06 |
| | Lower-limb [kg] | 5.83 ± 1.74 | 5.81 ± 1.74 | 5.81 ± 1.74 |

%BF, body fat percentage; FFM, fat-free mass.

**Table 3.** Mean differences and limit of agreement with 95% confidence intervals between reference and measured values at each time point.

| | | 5-min value − reference | | | 10-min value − reference | | |
|---|---|---|---|---|---|---|---|
| | | **Mean difference [95% CI]** | **LoA upper [95% CI]** | **LoA lower [95% CI]** | **Mean difference [95% CI]** | **LoA upper [95% CI]** | **LoA lower [95% CI]** |
| **Whole-body** | %BF [pp] | −0.300 * [−0.460, −0.140] | 0.350 [−0.011, 0.711] | −0.950 [−1.311, −0.589] | −0.084 [−0.217,0.049] | 0.456 [0.156, 0.756] | −0.624 [−0.924, −0.324] |
| | FFM [kg] | 0.163 * [0.076, 0.250] | 0.516 [0.320, 0.713] | −0.190 [−0.386, 0.006] | 0.052 [−0.034,0.140] | 0.407 [0.210, 0.603] | −0.301 [−0.498, −0.105] |
| **Segmental FFM** | Upper-limb [kg] | 0.028 * [0.021, 0.036] | 0.073 [0.055, 0.090] | −0.016 [−0.034, 0.001] | 0.012 * [0.007, 0.017] | 0.043 [0.031, 0.055] | −0.019 [−0.031, −0.007] |
| | Trunk [kg] | 0.126 * [0.068, 0.184] | 0.361 [0.230, 0.491] | −0.109 [−0.239, 0.021] | 0.058 * [0.013, 0.103] | 0.243 [0.140, 0.345] | −0.127 [−0.230, −0.024] |
| | Lower-limb [kg] | 0.017 * [0.002, 0.032] | 0.106 [0.071, 0.141] | −0.072 [−0.107, −0.038] | 0.004 [−0.006, 0.014] | 0.062 [0.039, 0.085] | −0.055 [−0.078, −0.032] |

%BF, body fat percentage; CI, confidence interval; FFM, fat-free mass; LoA, limit of agreement; pp, percentage point; *, significant fixed error.

### *Whole-Body Fat-Free Mass*

For whole-body FFM, a fixed error was observed between the reference and the 5-minute value, without any proportional error (Figure 2A). The 5-minute value was significantly higher than the reference value, with a mean difference of 0.163 [0.076, 0.250] kg. The LoA ranged from −0.190 [−0.386, 0.006] to 0.516 [0.320, 0.713] kg. No fixed or proportional errors were observed between the reference and the 10-minute value (Figure 2B, Table 3).

### *Segmental Fat-Free Mass*

For upper-limb FFM, fixed errors were found between the reference and both the 5- and 10-minute values. The 5-minute value was significantly higher than the reference value, with a mean difference of 0.028 [0.021, 0.036] kg (Table 3). The LoA ranged from −0.016 [−0.034, 0.001] to 0.073 [0.055, 0.090] kg. The 10-minute value was also significantly higher than the reference value, with a mean difference of 0.012 [0.007, 0.017] kg. The LoA ranged from −0.019 [−0.031, −0.007] to 0.043 [0.031, 0.055] kg. No proportional error was observed at any time point.

For trunk FFM, fixed errors were observed between the reference and both the 5- and 10-minute value. The 5-minute value was significantly higher than the reference value, with a mean difference of 0.126 [0.068, 0.184] kg (Table 3). The LoA ranged from −0.109 [−0.239, 0.021] to 0.361 [0.230, 0.491] kg. The 10-minute value was also significantly higher than the reference value, with a mean difference of 0.058 [0.013, 0.103] kg. The LoA ranged from −0.127 [−0.230, −0.024] to 0.243 [0.140, 0.345] kg. No proportional error was observed at any time point.

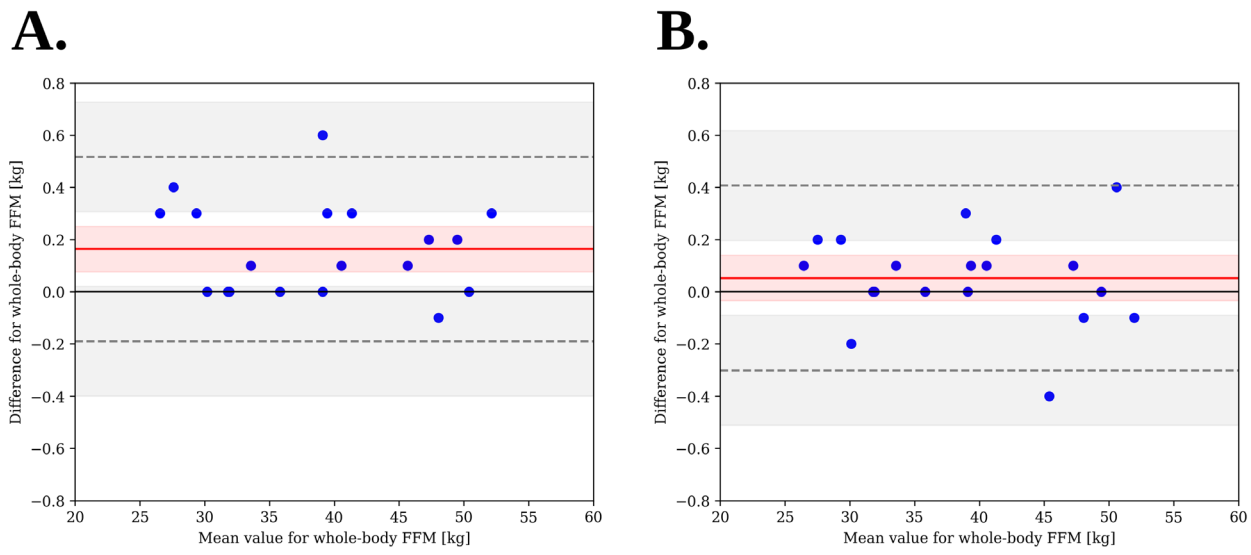


**Figure 2.** Bland–Altman plots for whole-body fat-free mass.

A: Comparison between the reference and 5-minute values. B: Comparison between the reference and 10-minute values. The red line indicates the mean difference, with the red-shaded area representing its 95% confidence interval (CI). The dashed gray lines show the limits of agreement (LoA), and the gray-shaded areas indicate the 95% CI for the upper and lower LoA. FFM, fat-free mass.

For lower-limb FFM, a fixed error was observed only between the reference and the 5-minute value, without any proportional error. The 5-minute value was significantly higher than the reference value, with a mean difference of 0.017 [0.002, 0.032] kg (Table 3). The LoA ranged from −0.072 [−0.107, −0.038] to 0.106 [0.071, 0.141] kg. No fixed or proportional errors were observed between the reference and the 10-minute value.

### *Body Fat Percentages*

For %BF, a fixed error was observed only between the reference and the 5-minute value, without any proportional error (Figure 3A). The 5-minute value was significantly lower than the reference value, with a mean difference of −0.300 [−0.460, −0.140] percentage points (pp) (Table 3). The LoA ranged from −0.950 [−1.311, −0.589] to 0.350 [−0.011, 0.711] pp. No fixed or proportional errors were observed between the reference and the 10-minute value (Figure 3B).

### *Segmental Body Impedance and Total Body Water*

Segmental body impedance at 50 kHz and total body water values at each time point are presented in Table 4. The impedance measured at 15 minutes was significantly higher than that obtained at 10 or 5 minutes in all segments. The impedance values at 10 minutes were also significantly higher than those at 5 minutes in the upper- and lower-limbs.

The total body water measured at 5 minutes was significantly higher than that obtained at 10 and 15 minutes. However, the total body water at 10 minutes was not significantly different from that at 15 minutes.

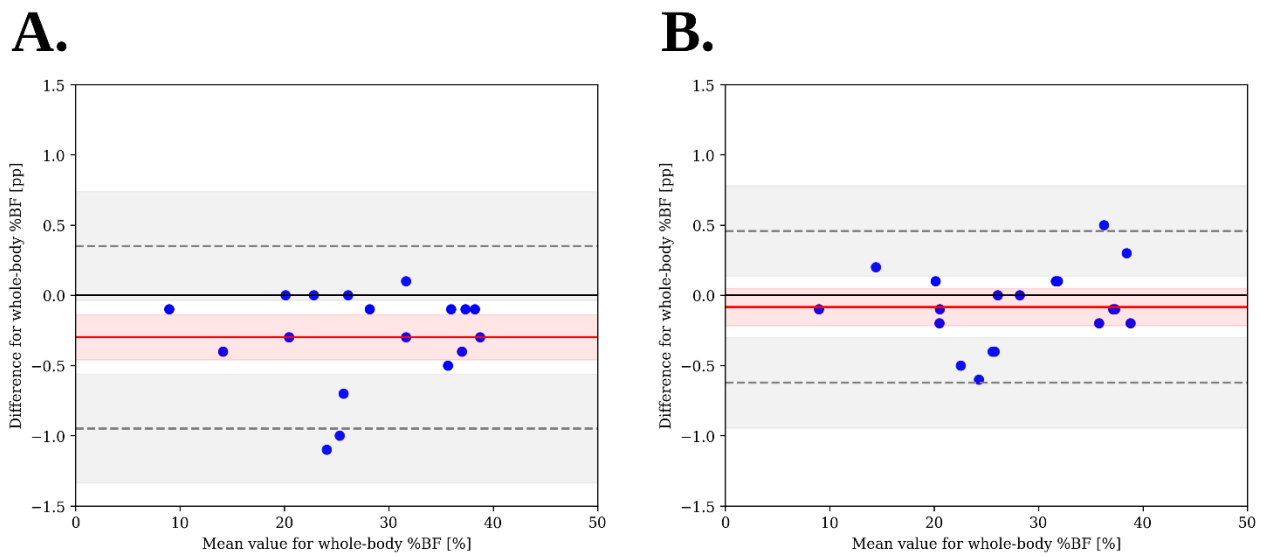


**Figure 3.** Bland–Altman plots for body fat percentage.

A: Comparison between the reference and 5-minute values. B: Comparison between the reference and 10-minute values. The red line indicates the mean difference, with the red-shaded area representing its 95% confidence interval (CI). The dashed gray lines show the limits of agreement (LoA), and the gray-shaded areas indicate the 95% CI for the upper and lower LoA. %BF, body fat percentage; pp, percentage point.

**Table 4.** Segmental body impedance and total body water at each time point.

| | 5 min | 10 min | 15 min |
|---|---|---|---|
| **Impedance for Upper-limb [Ω]** | 210.87 ± 44.70 * | 211.80 ± 44.70 *, ‡ | 213.10 ± 44.93 |
| **Impedance for Trunk [Ω]** | 26.91 ± 2.99 * | 27.04 ± 3.00 * | 27.13 ± 3.03 |
| **Impedance for Lower-limb [Ω]** | 309.93 ± 71.77 * | 310.70 ± 71.53 *, ‡ | 311.97 ± 71.56 |
| **Total body water [L]** | 30.62 ± 6.40 *, † | 30.53 ± 6.39 | 30.50 ± 6.40 |

*, $P<0.05$ vs 15 min; †, $P<0.05$ vs 10 min; ‡, $P<0.05$ vs 5 min.

## Discussion

The present study examined the effect of lying duration on body composition values obtained using the MF-BIA device in para-athletes. Bland–Altman analysis revealed fixed errors in some of the measured values when the lying duration was shorter than the recommended 15 minutes. Repeated-measures ANOVA also showed that segmental body impedance and total body water values at shorter lying durations significantly differed from those measured after lying for 15 minutes. These results imply that a shortened lying duration can substantially affect body composition measurements using the MF-BIA device. The key question is whether these fixed errors are acceptable for clinical application.

The MF-BIA device used in the present study (InBodyBWA) measures segmental body impedance and total body water by applying weak electric current to the body. Higher body impedance indicates lower body water content, and FFM is estimated based on the concept that most body water is contained in fat-free tissue. Subsequently, fat mass and %BF are calculated by subtracting FFM from body weight.[7-8] Although the detailed prediction equation and its references have not been published, body impedance and body water content play important roles in estimating body composition.

In the present study, segmental body impedance in para-athletes, who typically use wheelchairs, showed significant differences between 15 and 10 minutes for both upper and lower limbs, as well as between 15 and 5 minutes for all segments. In able-bodied individuals, body impedance increased when shifting from a standing to a lying posture and continued changing for at least 10 minutes.[11,19] Such changes are thought to be influenced by posture-induced redistributions of body water, which may in turn affect body composition estimates.[9-10] Although time-dependent changes during the transition from a seated to a lying posture have not been systematically examined in able-bodied individuals, the upper limbs and trunk remain in an upright posture even when sitting in a wheelchair; therefore, the body water distribution in those segments may not differ from that observed in able-bodied individuals standing upright. Therefore, shifting to a lying posture in para-athletes may also induce a redistribution of body water that continues for 10 or 15 minutes, resulting in impedance changes similar to those observed in able-bodied individuals.

In addition to the time-dependent changes observed in segmental body impedance, the estimated total body water also showed significant

decrease of 0.12 L throughout the measurement period. However, such a rapid reduction in body water content is unlikely to occur within only 15 minutes of rest, even in para-athletes. Therefore, this apparent decrease may instead be attributed to factors specific to para-athletes rather than a true reduction in body water content. Previous studies have shown that, in individuals with SCI, not only FFM but also body impedance characteristics differ from those in able-bodied individuals.[20-21] Moreover, alterations in body impedance characteristics have also been reported in conditions of disuse atrophy.[22] These suggest that inactivity- or disability-related conditions can influence MF-BIA measurements, particularly employing the prediction equations generally developed using data from able-bodied individuals. Accordingly, in wheelchair para-athletes included in the present study, lower-limb FFM and the associated body water content may be reduced due to disability-related atrophy and possibly altered peripheral circulation. Such differences may contribute to increased error or variability in MF-BIA measurement, potentially explaining the apparent decrease in body water content observed during the 15-minute lying period.

Although there were fixed errors for FFM, the mean difference of 0.052 kg in whole-body FFM and 0.012 kg in upper-limb FFM at 10 minutes both represented less than 1.4% of each measured value. This discrepancy may fall within the range of short-term variability of MF-BIA measurement observed in previous studies,[13] suggesting that such minor fluctuations may reflect inherent measurement precision rather than actual physiological adaptation. When assessing athletes' body composition with MF-BIA devices in training environments, an increase of more than 1.6–4.2% in FFM is considered significant and likely attributable to athletic training.[14-16] In contrast, a 2.3% decrease in FFM is not regarded as meaningful during a detraining period.[23] Throughout the annual training cycle, athletes' body composition often changes dynamically.[16,24] Therefore, a fixed error of 1.4% in FFM may not represent a meaningful difference and could be within the range of measurement accuracy.

For %BF, there was only a fixed error between the reference and the value at 5 minutes, with a mean difference of −0.300 pp. There was no systematic error between the reference and the value at 10 minutes, with a mean difference of −0.084 pp. During the measurement process, %BF is calculated by subtracting FFM from body weight.[7-8] Therefore, it is reasonable that the fixed error for %BF showed a negative value, while that for FFM showed a positive value. The test-retest reliability of %BF measured by the InBody device in a standing posture has been reported with a mean difference of 0.10 pp and an intraclass correlation coefficient (ICC) ranging from 0.996 to 1.000.[25-26] Hence, the present study suggests that lying for 10 minutes enables para-athletes to measure %BF within the error range applicable to able-bodied individuals.

Of course, it is preferable to precisely measure and assess upper-limb FFM in para-athletes who use their upper-limb for wheelchair propulsion and athletic movements. However, whether the systematic error is considered meaningful or negligible depends on the clinical situation.[27] If these differences can be tolerated in the training field, it may be possible to assess body composition using MF-BIA devices in shorter lying durations, such as 10 or 5 minutes. Regarding the practical application for para-athletes,

cross-sectional comparisons can be challenging due to limited reference and target values.[8,28] Moreover, some Paralympic sports, like para-athletics, are held in subdivided competition categories depending on the type and severity of disability. This results in body composition values that may not be directly comparable, even among wheelchair para-athletes. Therefore, para-athletes may instead focus on assessing longitudinal changes in their body composition.

The present study had some limitations. As the data collection was conducted as part of a physical fitness assessment program specifically designed for para-athletes, able-bodied controls were not included, and participants were required to undergo multiple measurements. Therefore, the interval between the last food or drink intake and the body composition assessment could not be strictly controlled. Additionally, factors such as training performed on the previous day, or alcohol and caffeine consumption were not fully standardized. Nevertheless, previous study suggests that food and/or drink consumption has minimal impact on MF-BIA measurements after 2 hours and remains within its precision limits.[29] Moreover, the limited sample size also precluded subgroup analyses by demographics such a sex, specific sports, or type of disability. Whole-body and segmental FFM may depend on the type or severity of disability, such as the level of spinal cord injury.[25,28] This may affect total body water and body composition values. Further studies are needed to examine the effect of lying duration in relation to the variety of disabilities for practical application, given the diversity of para-athletes.

## Conclusions

The present study is the first to investigate the effect of lying duration on body composition values using an MF-BIA device in para-athletes. When the lying duration is shorter than the recommended period, there are slight but significant fixed errors. The %BF may be slightly lower and FFM may be slightly higher than the referenced values. If these differences can be tolerated in clinical practice for each athlete's assessment, it may be possible to assess body composition with shorter lying durations.

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## Author contributions

Study Design: HG, Methodology: HG, RM, KM, NH, and TM, Data Collection: HG, RM, KM, NH, Formal Analysis and Investigation: HG, RM, KM, NH, and TM, Writing Original Draft: HG, Writing-review and editing: HG, RM, KM, NH and TM.

## Declarations

### *Funding and Competing interests*

There are no conflicts of interest to declare.

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