

Bioelectrical Impedance Analysis for Historical Evaluation in People with Spinal Cord Injury: A Systematic Review [†]

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Abstract: The objective of this study was to investigate the empirical evidence to support the use of bioimpedance analysis in persons with spinal cord injury (SCI). The Methods: A systematic review of “PubMed/Medline, EMBASE, CINAHL, Web of Science, PSYCHINFO, CINAHL, CENTRAL, and the library Cochrane for systematic review databases” were conducted to determine all possible trials that address “Bioelectrical Impedance Analysis” (BIA) in SCI before September 2020 in English. This systematic review was introduced as stated in the PRISMA Chosen Reporting Article strategies. The study was combined Using Boolean operators “OR” and “AND.” “Bioelectrical Impedance Analysis”, OR “body composition”, OR “fat-free mass”, OR “fat mass”, “Total body water obesity”, OR “weight gain”, OR “body mass index”, AND “Spinal Cord Injury.” The Results: In total, 3354 articles were identified, but 3303 were excluded. Among the 51 eligible studies, 21 were excluded since they did not fulfill the inclusion criteria. Finally, thirty studies fulfilled the inclusion criteria. The bioimpedance analysis method is used to estimate the body composition of SCI society during follow-up, rehabilitation therapy, monitoring obesity management, and nutrition; the study observed that BIA is beneficial and predictable for evaluating the patient’s status of body composition. The Conclusion: BIA is a non-invasive, portable, fast, and inexpensive technique. This systematic review recommends further study on BIA to improve medicinal benefits in prediction.

Keywords: bioelectrical impedance analysis; body composition; spinal cord injury; rehabilitation



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1. Introduction

Bioelectric impedance analysis (BIA) is a widely used technique for evaluating body composition (BC) and assessing clinical diagnostic tests [1–3]. Thus, BIA allows calculating or measuring necessary body compartments, such as: “Body Cell Mass (BCM), Body Mass Index (BMI), Fat Mass (FM), Fat-Free Mass (FFM), Total Body Water (TBW), Extracellular Water (ECW), Intracellular Water (ICW), Basal Metabolic Rate (BMR), Phase Angle (PhA), Resistance (R), Reactance (Xc), Body Capacitance (C)” [4–7]. There is a full range of physical training in clinical and healthcare tools, such as disease diagnosis and vital body condition detection. Accordingly, along with this comprehensive practice, we feel this necessitates a survey of essential features for bioimpedance analysis’s clinical assessment and health care purposes [3,8]. Hence, articles on BIA since 1962 have been published. Thomasset examined the use of bioimpedance in the overall assessment of TBW using needle electrodes. Nyboer presented quadruple surface electrodes for bioimpedance measurements to determine an individual’s FFM [9,10]. Hoffer discussed the relationship between tritium dilution techniques and TBW concentration. Natural resistance is defined as the capacity

of biological tissues to obstruct electrical flow [11]. Bio-impedance analysis methods have been used because of their non-invasive approach, low cost, simplicity, and mobility. Therefore, numerous researchers have published BIA analysis experiments, demonstrating their use for calculating BC and measuring clinical fitness [12]. An examination of BIA criteria for assessing BC and monitoring chronic diseases using an inclusive collection of standards, widely used formulae, and novel techniques was developed [13]. H. Lukaski examined the conceptual requirements for evaluating bioimpedance to quantify physiological activity and predict illness. Scientists found that the multiple regression techniques used in the critical analysis of bioimpedance have limited utility in assessing an individual's capability. Accordingly, BIA may be classified as a measurement technique incorporating single or multiple MF [14]. Bioimpedance measurements were performed throughout the body using frame segments and other approaches. Various studies have examined BIA in SCI and shown its validity; for example, in an article published in 1995, Allison and his coworkers discovered that muscle potential in patients with spinal cord injuries is less influenced by cables linked to the lower limbs [15].

Similarly, in 1997, Kacina Paula has studied the BIA estimates of the BC of SCI adults. He found that FFM and total body fat measures are obtained [15]. Hence, skinfold and bio-impedance equations may be developed to estimate the BC of SCI accurately. In 2000, J. C. Desport et al. demonstrated that BIA's validity estimates the TBW and FFM in BC. The authors reasoned that utilizing BIA is better when comparing results with other methods [16].

Consequently, in 2007, C. Liu S. et al. considered BIA a simple, non-traumatic, and dependable process to analyze BC [17]. Azevedo and colleagues demonstrated that BIA is an effective, sensible, and practical technique for diagnosing obesity in SCI individuals [18]. Moreover, obesity or high-fat percentage and FM increase the risk of SCI patients. Additionally, in 2017, M. G. Panisset et al. established that BIA is feasible to implement for the classification of obesity in acute SCI [19]. This review aimed to emphasize the historical evolution role of bioimpedance analysis and validation of BIA for patients with SCI. In conclusion, the exercises improve the rehabilitation of SCI patients. We indicated that BIA effectively predicted the FFM, FM, MM, and TBW.

2. Materials and Methods

The "PubMed/Medline, EMBASE, CINAHL, Web of Science, PSYCHINFO, CENTRAL, and the library Cochrane of systematic review databases" were screened to find all possible trials published before September 2020 in English. This systematic review was initiated with the PRISMA Preferred Reporting Article strategies (Figure 1) [20] to study published trials that have reported using Boolean operators "OR" and "AND" of the following keywords: "BIA", 'or,' "Bioimpedance", 'or,' "Body Composition", 'or,' "fat-free mass", 'or,' "fat mass", 'or,' "Total body water", 'or,' "obesity", 'or,' "Body mass index", 'And,' "spinal cord injury." The title and abstracts of publications were updated throughout the screening step, and duplicate research was eliminated. Following that, copies of the entire text were screened to determine their suitability for a systematic review. The inclusion criteria were broad and included any observational reviews with BIA and SCI regardless of the study, age, gender, or clinical environment. The research was completed in combination with medical history and information about other global locations. Reviews that did not include BIA or SCI parameters were omitted because they did not meet the requirements for a systematic review. The authors included this review due to their efforts to validate BIA in evaluating people with SCI.

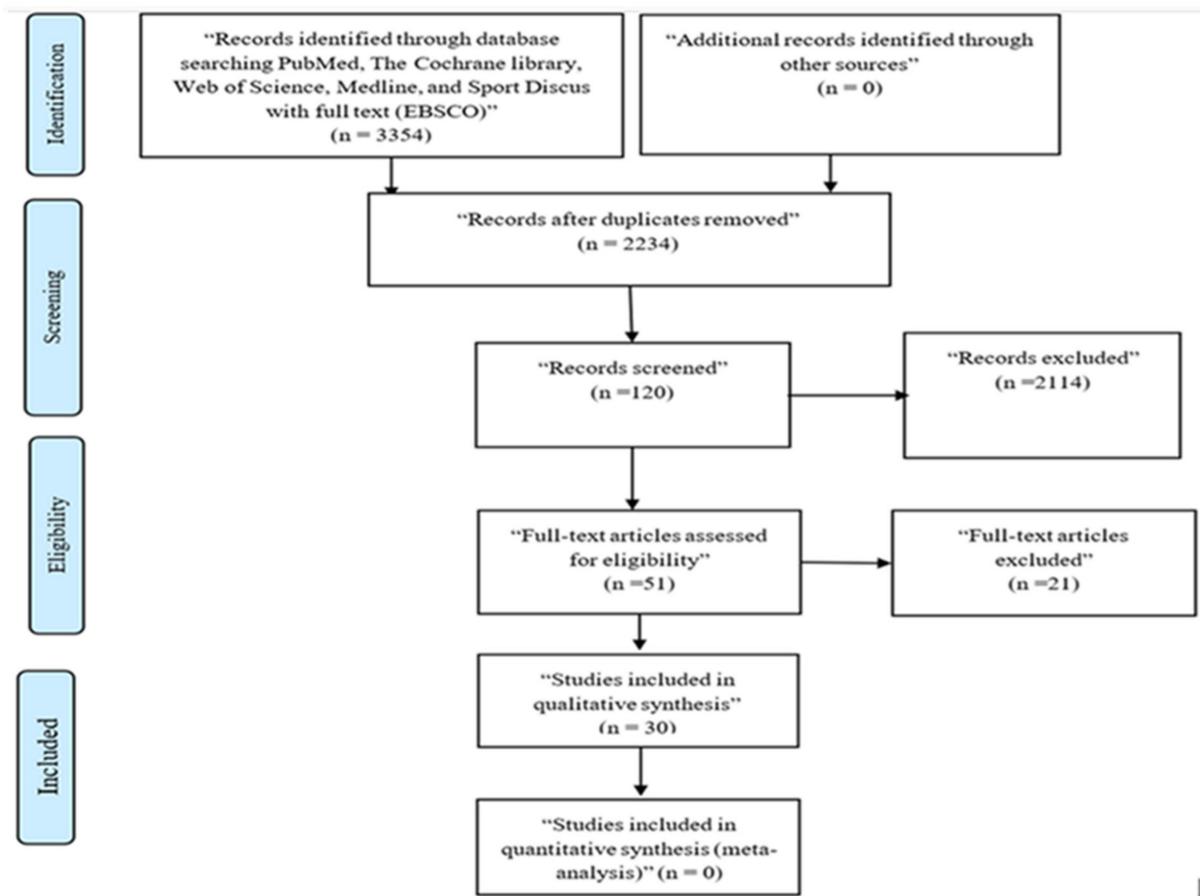


Figure 1. The flowchart above is based on PRISMA Reprinted/adapted with permission from Ref. [20].

3. Results and Discussion

Overall, 3354 reviews and the exclusion of 3303 references were identified. Twenty-one articles were excluded from the fifty-one qualifying studies since the revisions did not follow the inclusion criteria. As seen in Figure 1, PRISMA, thirty studies were finally reached and were incorporated into this study. In Table 1, we will briefly explain historical evidence of the role of bioimpedance analysis of BC in chronic SCI.

Table 1. Characteristics of the included studies.

SN	Authors and Year	Remarks	BIA
1	Thomasset et al., 1962 [21]	The study was the first successful bioimpedance experiment using needles of low frequency.	Experiment.
2	E.C. Hoffer et al., 1969 [9,10]	Conducted experiments to prove the relationship between TBW and “biological impedance.” Impedance estimation can be applied to conclude TBW. Hoffer proved the equation of the impedance index used in BIA.	Experiment.

Table 1. Cont.

SN	Authors and Year	Remarks	BIA
3	H.C. Lukaski et al., 1986. [22]	BIA uses a “single frequency” (SF) (50 kHz), assuming the human body is a single-cylinder. However, the technological constraints of BIA emerged. Another practical example of the same theory is utilizing empirical data to develop an equation for predicting BC (“gender, age, and race”).	BIA, SF,
4	Nyboer et al., 1981. [23]	The method of whole-body electrical impedance has been tested and shown to be accurate in determining body composition. Nyboer incorporated four poles, positioned at each side or opposed to the palms and soles. About the metacarpal.	“Experiment”
5	R.F.Kushner et al., 1986 [24]	Empirical formulae based on the impedance index, body weight, and gender have been established.	Experiment
6	“R.F. Kushner et al., 1992” [25]	The human body comprises five cylinders (“right arm, left arm, torso, right leg, left leg”) instead of one. Hence, all body parts were measured independently at various frequencies, distinguishing between ECW and ICW.	TBW, ECW, ICW
7	Dr. Kichul Cha, 1996, [26]	The world’s first eight-point tactile electrolytic technique has developed with a direct sectional analysis that calculates the five various body impedance pieces at multiple frequencies (MF).	BIA-MF
8	Allison, G T. et al., 1995 [14]	The body posture affects a person’s bioelectrical resistance. Thus, passive resistance can be expected from assessments in a wheelchair.	BIA, BC.
9	Kacina.Paula. 1997 [27]	The BIA estimated the BC of SCI Adults; reference FFM and total body fat (TBF) were obtained. Hence, skinfold and bio-impedance equations may be developed to estimate SCI’s BC accurately.	BIA, FFM, TBF
10	EllisandWong, 1998 [28]	BIA characterized the impedance of body cells mass BCM, tissues, and a radiofrequency alternating electrical current flow.	BIA, BCM
11	Mikes et al., 1999 [29]	BIA is predicated on how voltage alters when current flows through new surfaces. These progressions determined the attendant properties of these materials.	Experiment.
12	J. C. Desport. et al., 2000 [16]	Considering and demonstrating the validity of BIA estimate the TBW and FFM in BC, the authors reasoned that BIA utilizing BIA is better for result contrasted and other methods.	TBW, FFM, BC.
13	A.C. Buchholz et al., 2003 [30]	BMI is particular but has low sensitivities to discriminate between obese and non-obese people with paraplegia. Additionally, single-frequency BIA TBW, FFM, FM, and ECW can be sensibly well-predicted.	BIA-SF TBW, FFM,.
14	A.C. Buchholz et al., 2005 [31]	They suggested that a BMI class particular to SCI be established. Additionally, BMI is often addressed in the spinal cord study.	BMI, FM.
15	C. Liu, S. et al., 2007 [17]	BIA is a safe and reliable way to assess body composition.	TBW, FM, FP
16	“T.Y. Chiu. et al., 2007” [32]	Individuals with SCI have been found to have different body compositions from healthy people. The BIA technique appeared to be a feasible method for determining the BC of SCI.	TBW, BMI,

Table 1. Cont.

SN	Authors and Year	Remarks	BIA
17	S. De Groot et al., 2010 [33]	SCI patients' BMI progressively rises throughout and after inpatient therapy, increasing in the first year.	BMI, BW
18	C. H. Y. Ling et al., 2011 [34]	The DSM-BIA is a valuable tool for evaluating total and segmental BC in middle-aged people, especially LBM.	BIA, LBM
19	C. Yararfisher et al., 2013 [35]	They showed that BMI is a limitation for estimating body fat in women with SCI. In contrast, spinal cord injury patients had a much higher BMI than the average population. As a result, it necessitates further research in SCI across various injuries and validates BMI.	BIA, BMI
20	F. R. Neto et al., 2013 [36]	BMI showed an excellent correlation to the sum of skinfold.	BIA, BC
21	D. Kim et al., 2014 [37]	Training with a motor FES exercise bike reduced BFP. This means that training helps individuals with SCI enhance their BC.	BIA, BMI,
22	P. M. Galea et al., 2015 [38]	FFM estimated via bioimpedance has a practical use since it may be performed on inpatients in the pediatric ward. This is a better metric than body weight to assess dietary sufficiency in SCI.	BW, FFM,
23	Sang Hoon Han et al., 2015 [39]	This study indicated that the FMP might assess overweight in people with SCI. FMP reveals a clear positive association with the duration of clinical features of SCI. BC can be evaluated by measuring body fat by taking a variance in the electrical conduction of different tissues.	BMI, FMP, FM.
24	D. Kim et al., 2015 [40]	Exercising using an indoor hand bike is beneficial in increasing BC, fasting insulin, and overall health in SCI.	BMI, fitness
25	K. H. Cho et al., 2015 [41]	They demonstrated that the body's mass does not directly impact the pressure at the seat contact. As a result, decreased SMM and body fluids may impact the development of pressure sores. Furthermore, it is critical to decreasing seat interface pressure by using a method appropriate for the individual rather than a uniform technique.	BMI, SMM, and
26	E. Azevedo et al., 2016 [18]	BIA has developed a reliable, acceptable, and practicable method for evaluating obesity in people with SCI. Higher BMI, PBF, and FM increase the risk of SCI patients.	BMI, BF,
27	C.N. Matias et al., 2016 [42]	The new validation demonstrates TBW, ECW, and ICW evaluation values. In this way, the new measures will provide appropriate hydration monitoring with applications and benefits for athletes and physicians in sports medicine.	TBW, ECW, ICW
28	N.I. Khramtsova, S.A. Plaksin. 2016 [43]	An accurate, simple-to-perform method for determining body mass, fat, and water content, the BIA is a valuable tool for teaching and learning about the human body. Fat tissue ratio and body water content were also linked to infused fluid.	BIA, BF, TBW.
29	M.G. Panisset et al., 2017 [19]	BIA technique is well-tolerated and validates obesity categorization in acute SCI. It is also achievable.	BFP, FFM, BMI
30	S.L. Silveira et al., 2017 [44]	Obesity in individuals with SCI was quantified and classified using BIA metrics such as BMI, body fat percentage (BFP), and body weight. As a result, experiments have discovered that BMI estimation is more often used in SCI literature.	BMI, BFP.

Many scientists have investigated various techniques for evaluating body composition and the gap between them. There is a growing interest in indirect ways of estimating BC utilizing BIA measurements in epidemiological and clinical research [45]. These investigations demonstrated that researchers created novel equations and the role of BIA in enhancing

performance. Seven studies were addressed in the first section of Table 1, addressing the development of new experimental prediction equations for use with the SF-BIA device. At 50 kHz, these equations were used in SF or MF to calculate parameters such as TBW, ICW, ECW, BCM, BMI, percent FM, FFM, PhA, resistance, and reactance. Thus, the majority of variables in the equations were created. The second section of Table 1 summarizes three experiments using the MF method to create new equations that included gender and age [9,46]. A direct sectional analysis created the world's first eight-point tactile electrode device. Recently developed by Dr. Kichul Cha's five separate body parts, impedance is measured using MF [40]. Consequently, scholars measured and validated the BC's BIA-derived TBW and FFM values. The researchers contend that using BIA produces good performance compared to other techniques. In the third part of Table 1, thirteen studies have demonstrated that BIA's use in SCI has been confirmed to be extremely specific but barely susceptible to the disparity between obese and non-obese people with paraplegia. It is feasible to predict TBW, FFM, FM, and ECW quite well using a specific frequency computed by Bugaresti et al. to categorize SCI-specific BMI. As observed in the findings, BMI is often documented in the spinal cord literature. Years later, S. De Groot et al. discovered that when individuals who might have SCI undergo inpatient therapy, their BMI increases, with higher increases appearing within the year after release [47]. C. Yazar-fisher et al. have verified that the adiposity of BMI in women with SCI is reduced. Additionally, the BMI of the SCI population is substantially higher than the average population. Hence, it requires more studies on SCI across various injuries and validates BMI. Likewise, TY. Chiu et al. have emphasized that the BC of subjects with SCI differed from other non-SCI due to their injury. Consequently, the BIA way shows a suitable technique to evaluate SCI for BC calculation. Additionally, BIA has established that assessing obesity in individuals with SCI was a valid, feasible, and effective practice. In addition, high-fat percentage and FM increase the risk of SCI patients [48]. BIA has recognized validation for the classification of obesity in acute SCI [19]. In a recent study, the evaluation and classification of overweight persons with SCI were performed using BIA parameters such as BMI, BF%, and body weight. Henceforth, studies have exposed that SCI literature uses BMI as the most commonly used indicator of obesity [44]. Studies have shown a considerably lower body fat percentage in training with an FES rowing machine powered by a motor, as in the fourth part of Table 1. Exercise helped the patients improve BC in persons with SCI [49]. D. Kim et al. have verified that exercising with an indoor hand bike is an operative modality to enhance BC, fasting insulin, and healthiness in individuals with SCI [37]. Additionally, K. H. Cho et al. have proved that mass BC has no direct consequence on seat interface pressure under other conditions. Accordingly, reduced SMM and body water may affect the development of pressure sores [50].

Hereafter, C. Matthias et al. have provided new valid and unbiased standards for TBW, ECW, and ICW assessment in national athletes from different athletic. Hence, the new measures would ensure careful hydration control with applicability and benefits for athletes and medical experimenters since TBW and its sections are significant in health and athletic efficiency. Here, the exercises helped improve individuals with SCI rehabilitation [40]. Additionally, the level of injuries in the spinal showed a difference in the measurement using the BIA instrument. Hence, this difference should be considered when measuring persons with SCI. BIA is non-invasive and considered a simple, non-traumatic, low-cost, and reliable method to examine BC.

4. Limitations of the Study

There are certain limitations in this study that must be addressed. One instrument technique was included in this research. Many methods may be added in future research. Increased knowledge of these changes may be achieved by conducting biomedical and clinical investigations. We omitted non-English publications to avoid publication bias.

Additionally, we found locked sources for some parameters in our study. Hence, these were not included in the study. We did not find more studies on BCM and BMR parameters.

Despite these limitations, the research showed significant changes in body composition of individuals with spinal cord injuries, especially BMI, BFP, FM, TBW, and FFM. Thus, bio-impedance is a unique technique for determining BC and a patient's health status.

5. Conclusions

Bioimpedance analysis is a method used to estimate the body composition of individuals with SCI. Numerous academics and physicians have verified BIA diagnostic and therapeutic relevance. BIA has been used during the rehabilitation of SCI, and it has helped measure body composition. Accordingly, the level of injuries in the spinal has shown a difference in the measurement using the BIA tool. So, this difference should be considered when measuring SCI patients. Thus, the study revealed that BIA is beneficial and predictable for evaluating patients' status and clinical treatment. Therefore, BIA is an inexpensive technique but still not common practice. Furthermore, this systematic review recommends further research on BIA to enhance medical benefits in SCI body composition compartments equation. It suggests the BIA method because of its non-invasive, perfect results, portable, quickness, ease, and low-cost qualities.

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