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Review Article

Others Section

Applications of Bioelectrical Impedance Analysis in Diagnosis of Diseases: A Systematic Review

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ABSTRACT

Introduction: Bioelectrical Impedance Analysis (BIA) is a safe, non-invasive, painless, portable, and inexpensive technology that has the prospect to provide information related to the dynamic performance of the human body. Body Composition (BC) assessment is widely accepted as a clinical method to diagnose and evaluate disease status.

Aim: To predict and validate the applicability of BIA in diagnosis of diseases such as Chronic Kidney Disease (CKD), Chronic Obstructive Pulmonary Disease (COPD), Heart Failure (HF), Pregnancy and Spinal Cord Injury (SCI).

Materials and Methods: A systematic clinical review was conducted following the PRISMA guidelines {PubMed, The Cochrane Archive, Web of Research, Medline, and SPORTDiscus with complete text (EBSCO)}. A literature review was carried out randomly, from 2000 to 2018, published in English; the keyword combinations were evaluated using Boolean operators "OR" and "AND" for BIA, CKD, COPD, HF, Pregnancy, SCI.

Results: A total of 1156 search terms, 1139 citations were excluded, and 17 potentially qualifying articles were shortlisted. Hence, as per the inclusion criteria, three articles on COPD, three articles on CKD, three articles on pregnancy, four articles on HF, and four SCI articles were shortlisted.

Conclusion: The calculated BIA parameters showed that the patient's actual health could be analysed quickly to monitor the disease progression and provide significant advances in developing therapies for the diseases. However, this paper recommends further study on BIA to improve a clinical assessment of BC.

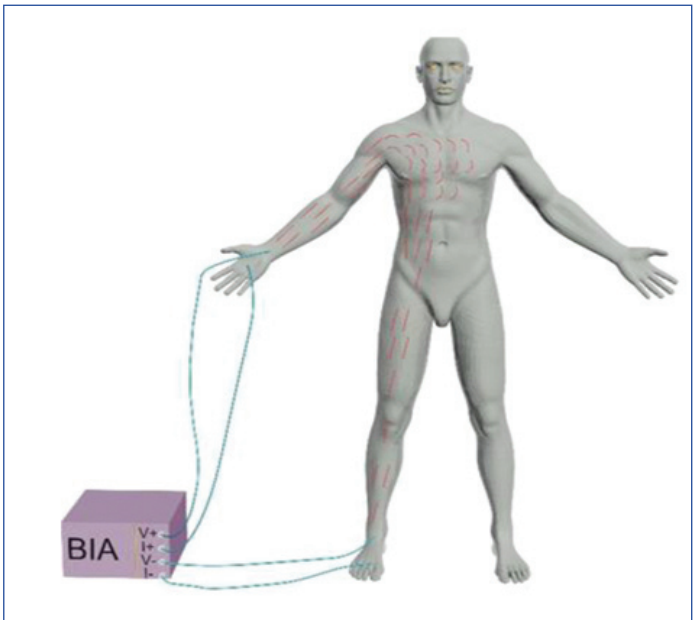
Keywords: Chronic kidney disease, Chronic obstructive pulmonary disease, Heart failure, Pregnancy, Spinal cord injury

INTRODUCTION

The BIA was first applied in 1962. BIA remained an experiment until the first device was in use in the mid-1980s [1-4]. In 1871, the tissue's electrical characteristics were described only as depicting specific properties to a broad range of frequencies on the highest tissue concentration [5]. The primary practice of BIA is in accordance with Ohm's law [6]. Regarding the impedance measurement, a safe range of constant current is applied at a defined frequency to a particular region of the body, and the potential is specified [7,8]. BIA is a technique that is to used to estimate BC concerning a biological predicate. Therefore, BIA measures the bioimpedance of tissue in the natural segment if alternating current flows through it [2,9-11]. The resistive component explains the disruption of a current ionic solution and Intracellular Water Interaction (ICW) and Extracellular Water Interaction (ECW). The capacitive reactance element (Xc) is the added obstruction because of the capacitive reactance concerning tissues' cells. BIA signifies a more considerable measure of the lean mass and the body cell mass [12,13].

BIA is an approach in which the BC of biological tissues is studied from their bioelectrical impedance. BIA is used to calculate and estimate BC to predict various clinical diseases, such as CKD, COPD, HF, etc. The BIA system can be conducted using a couple or four electrodes method to measure module resistance (R) and Xc; both manners of measurement are the same, as shown in [Table/Fig-1] [8]. The surface electrodes implanted into the human body uses two frequencies, single or multi-frequency, to change the properties of a portion of tissue [2,8,14-16]. BIA can designate as a highly impending technique for medical predictions related to BC analysis because of its non-invasiveness, low cost, portable, and easy use [15-19].

Furthermore, the BIA considers the human body as a cylinder, similar to a conductor in some studies [2,20]. Model based approaches



[Table/Fig-1]: Shows BIA configuration with the human body attached with four electrodes [8].

are also reported in the literature for the implementation of BIA. Many researchers have studied BIA for examination and medication in many diseases [21-23]. The purpose of this review was to emphasise the significance of the applicability of BIA to clinical and significant diseases.

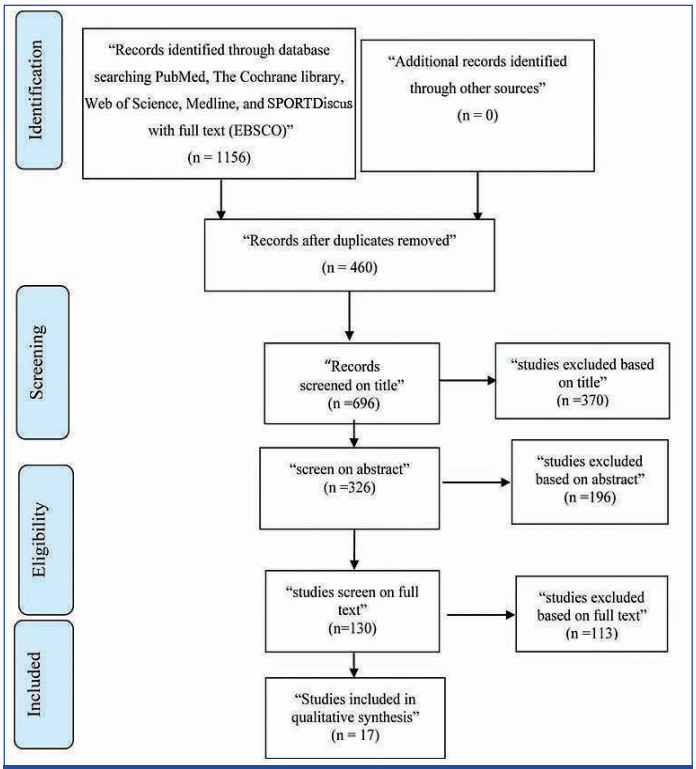
MATERIALS AND METHODS

The present study was a systematic review in which systematic literature analysis was randomly carried out: {PubMed, The Cochrane Library, Web of Science, Medline, and SPORTDiscus with complete

text (EBSCO)"}. The following phrases with Boolean operators "OR" and "AND" were used: BIA, CKD, COPD, HF, Pregnancy; SCI. Of the 1156 records, 460 were duplicates. Based on title, abstract, and full text, 370, 196, and 113 were excluded excluded respectively. After the qualitative synthesis, 17 papers were shortlisted. There were three articles on COPD, three articles on CKD, three articles on pregnancy, four articles on HF, and four articles on SCI.

RESULTS AND DISCUSSION

A total of 17 were included in the present review as shown in the PRISMA [Table/Fig-2] for five diseases [24,25]. Bioimpedance analysis contributes to measuring BC to assess the periodic change in patients' nutritional situation and observe nutritional risks in the outpatient setting. Moreover, BIA indicated that various diseases' information measurement should be continuous in diagnosis [26]. Accordingly, BIA was utilised in many diseases, and the feedback was reasonable compared to other devices such as Dual-Energy X-Ray Absorptiometry (DEXA), Magnetic Resonance Imaging (MRI), and skinfold measurements, body density [27]. BIA is a practical tool in clinical health intended to enhance BC prediction. The five diseases are illustrated with several examples in more detail, explaining how these diseases are influenced by bio-impedance measurement.



[Table/Fig-2]: PRISMA Study selection flowchart through a literature search.

1. BIA in COPD

The BIA is reasonably simple and non-invasive method; it may be a valuable tool for calculating BC in COPD. Three COPD papers are covered in this section, shown in [Table/Fig-3] [28-30].

I. Faisy C and Rabbat A found that BIA estimates the nutritional impact. They included 51 Intensive Care Unit (ICU) COPD patients, their testing showed inconsistent findings in the study of bio-impedance and anthropometric measurements. They concluded that BIA contributes to imprecise anthropometric findings for invasively ventilated patients. BIA is a valuable measure of malnourishment [28].

II. De Blasio F et al., study included 237 COPD patients (161 males and 76 females). Their study showed different diagnostic criteria. They determined that BIA helped to distinguish nutritional phenotypes such as wasting or loss of muscle in COPD patients. They concluded that BIA could be suitable for diagnosing nutritious phenotypes, for example cachexia or sarcopenia in COPD patients [29].

III. Rutten EP et al., showed that BIA could be used to diagnose muscle deterioration in COPD. They studied Fat Free Mass (FFM) BIA along with FFM DEXA in 1087 COPD participants. BIA is the first postulate to detect muscle homicide in COPD patients [30].

The BIA was considered for determining nutritional phenotypes such as deterioration or muscle loss in COPD patients [31-33]. These studies' outcomes indicated that BIA using the two-electrode and the two-frequency approach is suitable for evaluating the nutritional status and COPD patients' prediction. Thus, BC estimated by BIA and FFM proved to be a liberated predictor of mortality in COPD.

2. BIA in CKD

Extensive research has been conducted on the containment of hydration status and fluid compartments, particularly in patients with dialysis. Consequently, different models of biofluids have been proposed to characterise the whole body or the corresponding organs. In practice, the bioimpedance technique is used to assess the BC of CKD. Three CKD papers will be covered in this section, shown in [Table/Fig-4] [34-36].

I. Saxena A and Sharma R (2005) discussed BIA as a screening tool for CKD. They mentioned BIA could estimate clearance and Glomerular Filtration Rate (GFR) and creatinine release in CKD. BIA can be carefully cast off for prediction [34].

II. Satirapoj B et al., (2006) examined GFR in 79 non-diabetic Asian patients with CKD. They proposed that BIA-GFR in non-diabetic CKD patients was similar to creatinine clearance and urea clearance (Ccr-Cu-GFR), particularly in phase three CKD patients. Hence, BIA can be considered an assessment tool for the same [35].

No.	Author's name	Sample size	Age (years)	Body weight (kg)	BIA parameters	Remarks	Journal's name
1	Faisy C and Rabbat A et al., 2000 [28]	51	69±11	61±14	BMI 22±5.1 FM 15.3±7.8, FFM 45.6±9.3	A decrease in BIA-derived active cell mass was suggested as a reasonable prediction of malnutrition and a significantly reduced assumption in acute respiratory failure patients with COPD.	Intensive Care Medicine
2	De Blasio et al., 2017 [29]	237	70.4±7.5	69.9±16.8	BMI 25.5±5.5 FM 23.0±9.6 MM 23.0±2.9	BIA is helpful to differentiate dietary phenotypes such as waste or muscle weakness in patients suffering from COPD.	European Journal of Clinical Nutrition
3	Rutten EP et al., 2010 [30]	1087	63.5±9.8	69.4±15.1	BMI 24.6±4.6 FFMI 16±4.6	Recognise the importance of explicitly standing in observance limits before application of clinical practices to find muscle degenerative. BIA is a good definition of muscle weakening in patients with COPD.	Clinical nutrition supplements

[Table/Fig-3]: Descrption: COPD disease diagnosis by using BIA [28-30].
BMI: Body mass index; FM: Fat mass; FFM: Fat-free mass; FFMI: Fat free mass index; MM: Muscle mass

Sl. No.	Author's name	Sample size	Age (y)	Body weight (kg)	BIA parameters	Remarks	Journal's name
1	Saxena A and Sharma R, 2005 [34]	38	NA	NA	TBW r=0.94, SEE=0.7L	BIA may be used for the prediction of creatinine rescue as a method for displaying CKD.	Indian Journal of Nephrology
2	Satirapoj B et al., 2006 [35]	79	59.8±14.7	63.27±12.04	BMI 23.90±3.84 BCM 34.63 ±14.8	BIA predicted that non-diabetic CKD patients would have a greater risk of adverse effects.	J Med Assoc Thai
3	Thanakitcharu P and Jirajan B, 2014 [36]	69	52.5±18.1	62.8±15.0	BMI 24.7±4.8 FFM 51.2+10.9 ICW/ECW 1.52+0.07	MF-BIA is accurate. Acute kidney failure is sure to become apparent in the early stages.	J Med Assoc Thai

[Table/Fig-4]: Description: CKD disease diagnosis by using BIA [34-36].
TBW: Total body water; SEE: Standard error of the estimate; BCM: Body cell mass; MF: Multifrequency

III. Thanakitcharu P and Jirajan B suggested the early discovery of sub-clinical oedema in CKD through BIA. They enrolled CKD patients for 12 months. A 69 CKD patients were compared with 48 healthful volunteers. The current study established that the calculation of body fluid supply by multifrequency-BIA was a substantial measure. Sub-clinical oedema primarily ensued in CKD's early stages before detecting visible oedema by physical examination [36].

BIA is considered to detect a vital chronic modification in BC altered by adjusted hydration of lean mass, confined fluid amassing or loss, and the capacity to accurately evaluate water allocation between ICW and ECW compartments of CKD patients. Hence, BIA can critically predict creatinine performance as an instrument for diagnosing CKD [29].

3. BIA in Pregnancy

Differences in BC during pregnancy and their influence on pregnancy results indicate great importance in perinatal medicine. The measurement that uses BIA during pregnancy is an easy, quick, and non-invasive way to assess the water distribution in cells [Table/Fig-5] [37-39] shows three BIA studies.

I. Berlit S et al., (2013) enrolled 90 German healthy pregnant women to investigate the reference values of BIA. The results show that this method indicates a more accurate evaluation of BIA indices in pregnant women compared to natural stratification by General Technology (GT) [37].

II. Valensise H et al., (2000) examined 173 healthy pregnant women in three trimesters. They suggested that MF-BIA can be used to observe an alteration in pregnant women's body fluid segments [38].

III. da Silva EG et al., (2010) examined 51 healthy pregnant and 65 pre-eclamptic in the third trimester. They found that BIA can help differentiate among pre-eclamptic and healthy pregnant women, and also the pre-eclampsia can change the body parts [39].

MF-BIA is a considerable technique to check longitudinal alteration in pregnant women's fluid body compartments. An increase in total body water is accountable for a significant weight gain ratio during pregnancy [39].

4. BIA HF

BIA is found beneficial to check the pathophysiology of Acutely Decompensated Heart Failure (ADHF). Earlier Bioelectrical Vectorial Impedance Analysis (BIVA) and the Phase Angle (PA) were able to discern significant differences in hydration during ADHF. However, several experiments have shown that combined serial BIVA measurements help achieve a sufficient fluid balance in ADHF patients and can be used in medical treatment. [Table/Fig-6] [40-44] shows four such articles.

I. Sakaguchi T et al., (2015) studied multi-frequency BIA in 130 patients with ADHF. They suggested that the analysis of BIA provides valuable information for the review of the pathophysiology of ADHF also it is one of the best and cheapest devices [40].

II. Rabelo-silva SER et al., (2014) studied 57 patients of ADHF. A 61% of the patients with high congestion by BIVA had lost more weight and progressed to dyspnoea. They concluded that BIVA and PA could detect weight and hydration adjustments during ADHF [41].

III. Edwardson M et al., (2000) studied BIA to improve congestive HF management. Fifty patients were tested and found that the fat-free (FFM) extracellular water ratio (ECS) derived from BIA is more objective than traditional techniques to measure fluid overload. In modern management programs, the BIA telemedicine equipment can be integrated [42].

IV. Castillo Martínez L et al., (2007) assessed MF-BIA in 243 cases. Their outcome was equally HF categories, reactance, and PA was meaningfully lesser. They concluded that the BIA permits ease of BC, which helps stratify HF's severity [43].

BIA provides valuable information for the analysis of the pathophysiology of ADHF and is one of the cheapest devices. The BIA device applied to a PA can sense significant hydration status variations throughout ADHF [41]. Hence, BIA is a valuable clinical health device shown to improve BC prediction [42]. Consequently, BIA enables a clear BC and is most valuable to stratify HF's severity [43].

Sl. No.	Author's name	Name of diagnosis and parameter	Sample size	Age (years)	Body weight (kg)	BIA parameters	Remarks	Journal's name
1	Berlit S et al., 2013 [37]	Pregnancy BIA	90	29.5±5.8	75.8±16.6	BMI 27.9±5.9 TBW(l)^2 r^2=19.01	The gap between BIA and General Technology (GT) indices in pregnant women to stratification by the general was higher than average.	In Vivo
2	Valensise H et al., 2018 [38]	Pregnancy MF-BIA	175	34.20±5.90	77.1±16.8	TBW(%)^2 23.42±11.5	MF-BIA is a convenient tool to evaluate fluid body volume for pregnant women.	Am J Clin Nutr
3	da Silva EG et al., 2010 [39]	Pregnancy BIA	116	26.30±7.30	75.±12	BMI 29.75±4.17 TBW (%)^2 47.20±3.89	Enabled pre-eclampsia for stable pregnant women to be separated.	Hypertens Pregnancy

[Table/Fig-5]: Description: Pregnancy diagnosis by using BIA [37-39].

Sl. No.	Author's name	Sample size	Age (years)	Body weight (kg)	BIA parameters	Remarks	Journal's name
1	Sakaguchi T et al., 2015 [40]	130	74±11	59.8±16.2	ECW (r=0.766)	BIA provides beneficial information for the analysis of the pathophysiology of ADHF. Cheapest devices used in the treatment of ADHF	Circulation Journal
2	Rabelo-silva SER et al., 2014 [41]	57	61±13	70.2±14	PA VA +0.8 (0.15;1.4)	BIA instrument using PA was able to sense meaningful variations in hydration status throughout ADHF.	Nutrition
3	Edwardson M, et al., 2000 [42]	50	NA.	NA	ECW/ICW, FFM	BIA is a practical clinical health instrument established to improve the prediction of BC.	Computers in Cardiology IEEE
4	Castillo Martínez L et al., 2007 [43]	243	59.5±16.8	74.9±15.9	BMI 26.2±4.8 PA 4.97±0.92	BIA authorisations a simple of BC, and this strength be most valuable to stratify the severity of HF.	Nutrition

[Table/Fig-6]: Description: Heart Failure (HF) disease diagnosis by using BIA [40-43].

S.No.	Author's name	Name of disease and parameter	Sample size	Age (years)	Body weight (kg)	BIA parameters	Remarks	Journal's name
1	Azevedo et al., 2016 [44]	SCI. BIA	39	32±6.06	80.8±17.1	BMI 24.77±4.2 TBW% 73.08±4.6	BIA's existence a more reliable physical measurement.	Journal of Electrical Bioimpedance
2	Panisset et al., 2017 [45]	SCI BIA	20	42.5±5.3	78.25±12	BMI 24.65±4.3 FFM 55.6±15	Bioimpedance-based interpretations of assessing FFM in SCI in group comparisons.	International Spinal Cord Society
3	Buchholz AC et al., 2003) [46]	SCI BIA, MF.	94	33.9±9.2	65.5±16.3	BMI 24.3±6.0 BCM 35.9±8.1 FFM 69.2±8.7	TBW, FFM, FM, and ECW, ICW, BMI, PA can suitably predict BC by applying SF- BIA in SCI patients.	Arch Phys Med Rehabil
4	Yoshida D et al., 2014 [47]	SCI BIA	250	73.5±5.6	57.0±10.6	BMI 23.4±3.4 BF (%) 24.9±6.8 SMM 17.8±3.8	These new estimates recommend validating choice for assessing appendicular "skeletal muscle mass" SMM in Japanese adults.	Geriatrics and Gerontology International

[Table/Fig-7]: Description: SCI disease diagnosis by using BIA [44-47].
BMI: Body mass index; FFM: Fat-free mass; BF: Body fluid; SCI: Spinal cord injury; BIA: Bioelectric impedance analysis; MF: Multifrequency; TBW: Total-body water; ECW: Extracellular water; ICW: Intracellular Water; BCM: Body cell mass; SMM: Skeletal muscle mass; PA: Phase angle; VA: vector analysis

5. BIA in SCI

The BC of people with SCI was different from persons without SCI due to the injury itself, an inoperative lifestyle, and a diet difference. Furthermore, the BIA technique appears to be a viable approach for evaluating the BC of SCI. Thus, BMI, TBW, FFM, FM, and ECW can be predicted reasonably through SF or MF. [Table/Fig-7] [44-48] shows four articles.

I. Azevedo E, et al., (2016) BC composition calculation by BIA and Body Mass Index (BMI) in people with chronic SCI in 39 patients. Patients were segregated into paraplegia or tetraplegia as per injury level. Their investigation discovers conflicting outcomes in the SCI populace. BMI does not gain enough refinement stoutness, being a progressively reliable physiological estimation. BIA's existence is a more reliable physical measurement [44].

II. Panisset MG et al., (2017) studied quantification of FFM in acute SCI using BIA on 20 patients. They found that bioimpedance created estimations for assessing FFM in acute SCI for group comparisons [45].

III. Buchholz AC et al., (2003) used BIA to estimate fluid sections in cases with chronic paraplegia. Their examination included a total of 94 patients where 32 patients were with paraplegia and 62 were healthy subjects. They connected single recurrence and various frequencies. The results of TBW, FFM, FM, and ECW can be considered as anticipated by utilising SF [46].

IV Yoshida D et al., (2014) studied appendicular SMM's growth in 250 Japanese adults. Individuals' different results offer a good choice for assessing attached skeletal bulk in Japanese grown-ups [47].

Through SF's application in SCI patients, TBW, FFM, FM, and ECW, ICW, BMI, PA could correctly predict BC [47]. BIA parameters reflect disease cruelty and afford the best analysis for patients' existence [48].

Limitation(s)

The BIA has some limitations that apply to accepting and classifications of restrictions. The first relates to the anatomy of the human body: the human body is not a cylinder. Instead, five cylinders joined in a better sequence may be defined as (legs and trunk, arms, except for the head) [49]. We still need to remember that electrophysical patterns are developing and that biological transmitters are not stable. It can differ based on the exact composition of the muscles, the hydration state, and the distribution of the electrolytic atoms [50]. Moreover, BIA's main limitation of utilising TBW evaluation is that this approach implies that the hydration condition is set. Unfortunately, pregnancy, disease cases, obesity, cancer, malnutrition, and race may interfere with the water situation [51]. Hence, various body build distribution (mainly in those who are obese in the abdomen) will occur in estimating body fat percentage [52-54].

CONCLUSION(S)

BIA practice is utilised as non-invasive health monitoring for BC. The systematic review has discussed the technical characteristics of some significant diseases diagnosed randomly, such as SCI, CKD, COPD, HF, and pregnancy. A new equation may be required. Nevertheless, results were produced from <1% to approximately 20%, and the matched impedance meter cables can offer additional capacitance depending upon the condition of the device. It is found that BIA has been practised by several researchers and physicians for diagnosis and therapy as well. Most of the significant research

proved that BIA is a practical, non-invasive, and inexpensive method. Moreover, BIA parameters estimated that disease prognosis analysis was beneficial reasonably predictable to both patient's status and healthcare. Nevertheless, this paper recommends using further research on BIA to improvise a medical equation in BC assessment. Also, BIA is a simple method. It gives accurate results, portable, quick, easy, and low cost.

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