Comparison of Three Bioelectrical Impedance Methods with DXA in Overweight and Obese Men

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Abstract

PATEYJOHNS, IAN R., GRANT D. BRINKWORTH, JONATHAN D. BUCKLEY, MANNY NOAKES, AND PETER M. CLIFTON. Comparison of three bioelectrical impedance methods with DXA in overweight and obese men. *Obesity.* 2006;14:2064–2070.

Objective: To compare bioelectrical impedance analysis (BIA) of body composition using three different methods against DXA in overweight and obese men.

Research Methods and Procedures: Forty-three healthy overweight or obese men (ages 25 to 60 years; BMI, 28 to 43 kg/m^2) underwent BIA assessment of body composition using the ImpediMed SFB7 (version 6; ImpediMed, Ltd., Eight Mile Plains, Queensland, Australia) in multifrequency mode (Imp-MF) and DF50 single-frequency mode (Imp-SF) and the Tanita UltimateScale (Tanita Corp., Tokyo, Japan). Validity was assessed by comparison against DXA using linear regression and limits of agreement analysis.

Results: All three BIA methods showed good relative agreement with DXA [Imp-MF: fat mass (FM), $r^2 = 0.81$; fat-free mass (FFM), $r^2 = 0.81$; percentage body fat (BF%), $r^2 = 0.69$; Imp-SF: FM, $r^2 = 0.65$; FFM, $r^2 = 0.76$; BF%, $r^2 = 0.40$; Tanita: BF%, $r^2 = 0.44$; all $p < 0.001$]. Absolute agreement between DXA and Imp-MF was poor, as indicated by a large bias and wide limits of agreement (bias, ±1.96 standard deviation; FM, −6.6 ± 7.7 kg; FFM, 8.0 ± 7.1 kg; BF%, −7.0 ± 6.6%). Imp-SF and Tanita exhibited a smaller bias but wide limits of agreement (Imp-SF: FM, −1.1 ± 8.5 kg; FFM, 2.5 ± 7.9 kg; BF%, −1.7 ± 7.3%; Tanita: BF%, 1.2 ± 9.5%).

Discussion: Compared with DXA, Imp-MF produced large bias and wide limits of agreement, and its accuracy estimating body composition in overweight or obese men was poor. Imp-SF and Tanita demonstrated little bias and may be useful for group comparisons, but their utility for assessment of body composition in individuals is limited.

Key words: multifrequency, single-frequency, body composition, bioelectrical impedance analysis, body fat

Introduction

DXA is used extensively for the assessment of body composition and is considered valid and reliable (1). However, the wide application of this method is limited by requirements for expensive equipment, trained technicians, and dedicated facilities. Consequently, there is a need for accurate and reliable techniques for measuring body composition that are less expensive, simpler, and less invasive than DXA.

Bioelectrical impedance analysis (BIA)[1] represents a simple, inexpensive, and noninvasive means of assessing body composition that has broad application in research laboratories, hospitals, private clinics, and health centers (2). BIA is based on the underlying principle that resistance or impedance to the flow of an electrical current through the body is dependent on three variables: the length of the conductive path, the volume of the conductive material, and the resistivity of the conductive material (3). In the human system, only body water, with its dissolved electrolytes, will conduct a current. Hence, using the assumption that the resistivity of the conductive material is constant, and estimating the length of the conductive path from an individu-

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[1] Nonstandard abbreviations: BIA, bioelectrical impedance analysis; TBW, total body water; SF, single-frequency; MF, multifrequency; FM, fat mass; FFM, fat-free mass; BF%, percentage body fat; Imp-MF and Imp-SF, MF and SF modes of ImpediMed unit.

al's height, total body water (TBW) can be estimated by measuring impedance to the flow of a small current (3). Assuming that TBW constitutes a fixed percentage of lean mass (usually 73%), body composition can be estimated. Specific prediction equations have been developed to evaluate body composition from height, weight, and impedance (3).

Early BIA systems inferred TBW from whole-body resistance to conductance of a single-frequency (SF) current of 50 kHz (i.e., SF-BIA) and then used empirical equations to predict body composition (4,5). Although SF-BIA has been shown to be a valid and reliable means of assessing body composition in healthy populations with stable water and electrolyte balance (3), alterations in body geometry and particularly in body water distribution in obese people (6), with the hydration factor of fat-free mass (FFM) being higher in obese than in non-obese subjects (7,8), suggest that this method may not be valid in obese populations (7,9).

The recent development of multifrequency (MF) BIA spectroscopy techniques may permit a more comprehensive approach to the assessment of TBW and, therefore, the estimation of body composition in obesity (10). Whereas, at a single low frequency, an electrical current will not fully penetrate the cell membrane, passing instead through the extracellular water, at high frequencies current will penetrate the cell membrane and conduct through total body water (11). By measurement of the components of impedance, reactance and resistance, across a range of frequencies, a mathematical model can be used to predict TBW and extracellular water, thereby allowing body composition to be determined without the use of population-specific algorithms (11). Therefore, MF-BIA may be more appropriate for estimating body composition in overweight and obese individuals (12). A recent study demonstrated that this method provides a more accurate estimate of fluid volume in obese individuals than traditional regression equations (13). However, compared with SF-BIA, there is limited information regarding the validity of MF-BIA and a lack of studies comparing BIA with appropriate reference methods for determining body composition in overweight or obese populations. In a recent study, Sun et al. (14) compared measures of body composition using an MF device (QuadScan 4000; Bodystat, Ltd., Isle of Man) that used hand-to-foot electrodes, with DXA as the reference method. This study showed that MF-BIA provided a relatively good estimation of percentage body fat (BF%) when subjects were within normal body fat range, but it tended to underestimate BF% by 4.32% in a group of obese men.

The objective of the present study was to test the accuracy of a new BIA device (ImpediMed SFB7, version 6; ImpediMed, Ltd., Eight Mile Plains, Queensland, Australia), which is capable of both MF-BIA and SF-BIA analysis, and a separate SF-BIA device (Tanita UltimateScale; Tanita Corp., Tokyo, Japan) in assessing body composition in a group of overweight and obese men, using DXA as a reference. This was done to determine whether BIA represents a viable alternative to DXA for the assessment of body composition in overweight and obese individuals. DXA is arguably one of the best reference methods available, having been validated against other methods of body composition analysis, and has been shown to have minimal bias based on age, sex, physical activity level, race, or proportion of body fat (15).

Table 1. Subject characteristics

Characteristic	Mean	SD	Range
Age (years)	44.9	8.4	25–60
Weight (kg)	106.7	12.2	77.2–128.4
Height (cm)	176.4	6.3	160–189.5
BMI (kg/m^2)	34.3	3.8	28.1–42.6

SD, standard deviation.

Research Methods and Procedures

Subjects

Forty-three men (ages 25 to 60 years; BMI, 28 to 43 kg/m^2) were recruited by public advertisement. Subject characteristics are presented in Table 1. Subjects attended the laboratory after a 2-hour minimum fast and were asked to refrain from participating in strenuous exercise or consuming alcohol for 12 hours before testing to avoid perturbation of hydration status. On arrival, each subject emptied his bladder, after which height and weight were measured immediately before assessment of body composition by BIA, first with the Tanita UltimateScale and then with the ImpediMed unit using the DF50 SF mode first and then the MF mode. Within 30 minutes, body composition was assessed using DXA. The study protocol was approved by the Human Ethics Committees of the Commonwealth Scientific and Industrial Research Organisation–Human Nutrition and the University of South Australia, and all subjects provided written informed consent before participation.

Height and Weight

Body weight was measured to the nearest 0.1 kg using an electronic scale (Tanita UltimateScale 2000), with subjects wearing minimal clothing and without shoes. Height was measured to the nearest 0.5 cm freestanding without shoes using a stadiometer (Seca, Hamburg, Germany). BMI was calculated as weight (kg) divided by height (m) squared.

DXA

DXA assessments of fat mass (FM) and FFM were conducted using a General Electric Lunar Prodigy scanner

(Lunar Radiation Corp., Madison, WI) with Encore 2003 software (version 7.52.002). The reliability of assessment for this model of DXA scanner has been previously reported as 0.4% for fat tissue and 4.5% for lean tissue (16). BF% was calculated manually by expressing FM as a percentage of total body mass (including bone mineral mass).

BIA

ImpediMed SFB7, Version 6. For the ImpediMed SFB7 unit (version 6), measurements were carried out with subjects lying supine on a flat, nonconductive examination table. Subjects were positioned with their arms by their sides, separated from their body, with palms down, and legs slightly apart. The ImpediMed SFB7 utilizes a tetrapolar system with two source and two sensor leads connected to four electrodes (3M Red Dot Ag/AgCl; 3M Health Care, St. Paul, MN). All electrode sites were shaved and cleaned with an alcohol swab before attachment. Two electrodes were placed on the right hand/wrist: one on the dorsal surface of the hand 1 cm proximal to the third metacarpophalangeal joint, and the other centrally on the dorsal side of the wrist in line with the ulnar head. Two electrodes were placed on the right foot/ankle: one on the dorsal surface of the foot 1 cm proximal to the second metatarsophalangeal joint, and the other centrally on the dorsal surface of the ankle between the lateral and medial malleoli. All electrodes were placed at least 5 cm apart. FM, FFM, and BF% were determined with both the MF-BIA and SF-BIA modes according to the manufacturer's standard operating procedures. Measurements were repeated twice in each mode, and the average of each was taken as the measured value. For convenience, measurements using the ImpediMed unit will be referred to as the Imp-MF and Imp-SF for its MF and SF modes, respectively. According to the manufacturer's instructions, the SF mode measures impedance to a 50-kHz current and estimates body composition using the Segal algorithm (9) for obese individuals (BMI ≥30) and the Lukaski algorithm (17) for non-obese adults. The MF mode uses 256 frequencies between 4 and 1024 kHz and estimates body composition using mathematical modeling based on a Cole–Cole plot and Hanai mixture theory (11).

Tanita UltimateScale

The Tanita UltimateScale is an SF-BIA device that uses a tetrapolar footpad-style electrode arrangement. In accordance with the manufacturer's manual, the subjects stood on the metal contacts in bare feet, and BF% was determined. The measurement was repeated twice, and the average value of each was taken as the criterion measure to be used for analysis. For convenience, the Tanita UltimateScale will be referred to as Tanita.

Statistical Analysis

One-way ANOVA was used to compare differences among the body composition values determined using the different techniques. Where ANOVA showed a statistically significant main effect, Tukey's test of honestly significant differences was used to determine differences among means. Regression analysis was used to determine the level of relative agreement among the different techniques. Bland–Altman analysis (18) was used to determine absolute limits of agreement between the body composition variables assessed by DXA and the BIA methods. An α level of $p < 0.05$ was considered statistically significant. Statistical analyses were performed using SPSS for Windows software, version 11.5.0 (SPSS, Inc., Chicago, IL). Values are reported in the text as mean ± standard deviation.

Table 2. Fat-free mass, fat mass, and percentage body fat measured by BIA and DXA

Method	FM (kg)	FFM (kg)	BF%
DXA	35.3 ± 7.4	70.1 ± 8.2	33.5 ± 4.8
Imp-MF	28.7 ± 8.6*	78.1 ± 8.3*	26.5 ± 6.1*
Imp-SF	34.2 ± 6.3	72.6 ± 6.8*	31.8 ± 3.0†
Tanita			34.7 ± 6.5

Values are means ± standard deviation.
* $p < 0.001$ significantly different from DXA.
† $p < 0.05$ significantly different from DXA.

Results

Imp-MF

There was good relative agreement between DXA and all assessments of body composition using Imp-MF (FM, $r^2 = 0.81$; FFM, $r^2 = 0.81$; BF%, $r^2 = 0.69$; all $p < 0.001$). Compared with DXA, in absolute terms, Imp-MF underpredicted FM by 6.59 kg and BF% by 7.0%, and it overpredicted FFM by 7.97 kg, with wide limits of agreement for each variable (FM, −14.25 to 1.06 kg; FFM, 0.83 to 15.12 kg; BF%, −13.62 to −0.38%) (Table 2; Figure 1). No systematic error between Imp-MF and DXA was evident for FFM ($r^2 = 0.02$, $p > 0.05$), but systematic errors were observed for FM ($r^2 = 0.10$, $p < 0.05$) and BF% ($r^2 = 0.15$, $p < 0.01$), with the difference between the two methods decreasing as BF% and FM increased.

Imp-SF

DXA and Imp-SF demonstrated good relative agreement for all measures of body composition (FM, $r^2 = 0.65$; FFM, $r^2 = 0.76$; BF%, $r^2 = 0.40$; all $p < 0.001$). Compared with DXA, in absolute terms, Imp-SF underpredicted FM by 1.1 kg and BF% by 1.74%, and it overpredicted FFM by 2.50 kg (Table 2; Figure 2). Although this indicates that, on average, there was good absolute agreement between

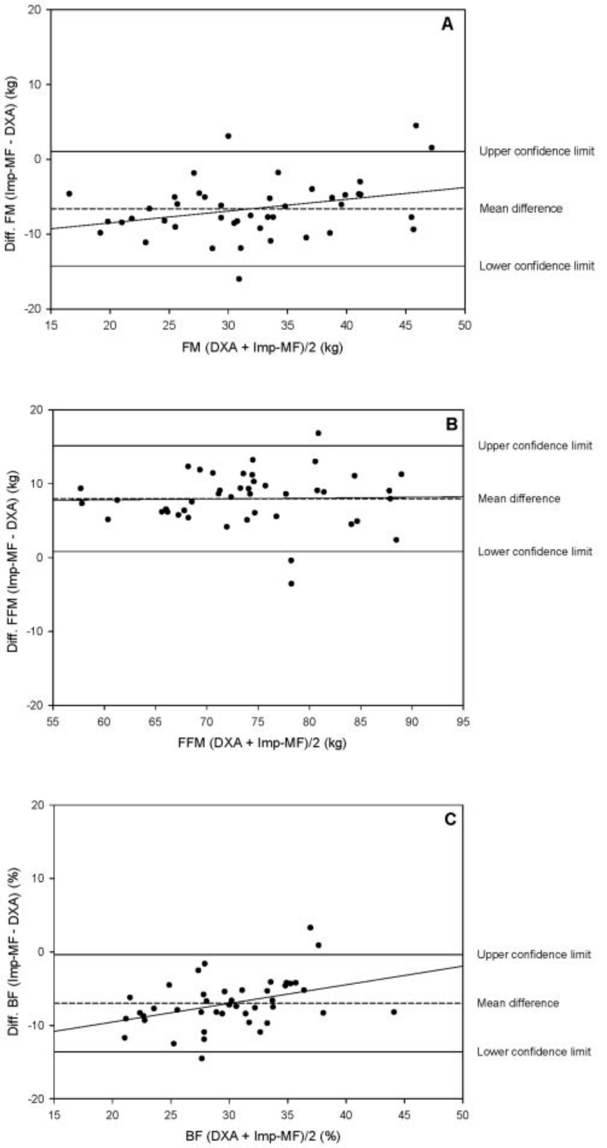

Figure 1: Bland–Altman plots comparing FM (A), FFM (B), and BF% (C), as determined by MF-BIA with Imp-MF and DXA.

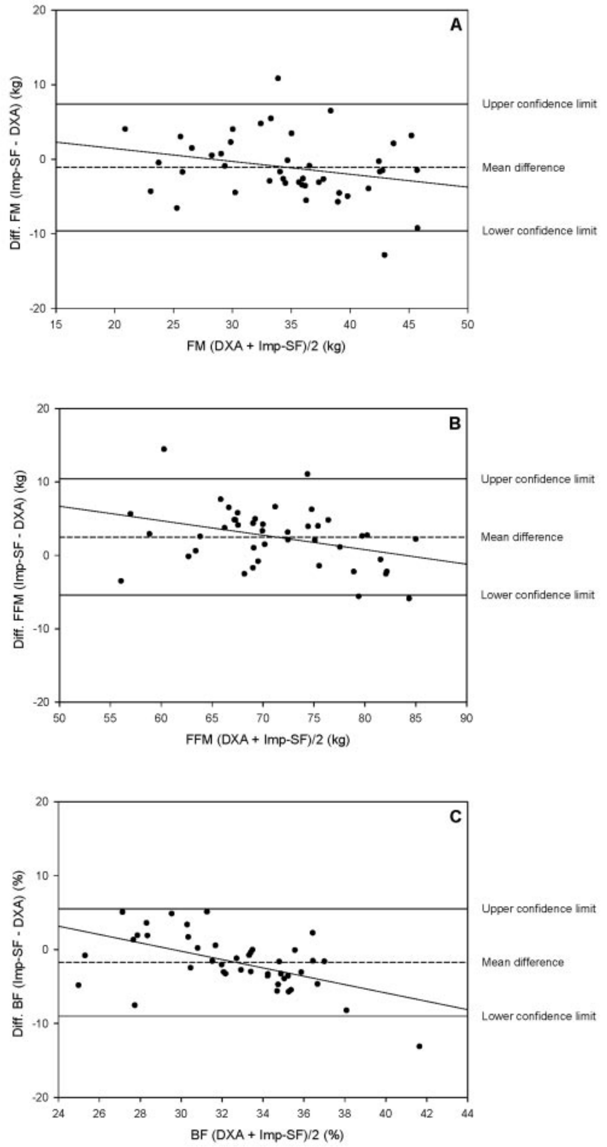

Figure 2: Bland–Altman plots comparing FM (A), FFM (B), and BF% (C), as determined by SF-BIA with Imp-SF and DXA.

Imp-SF and DXA, the limits of agreement were wide, ranging from −9.61 to 7.4 kg for FM, −5.43 to 10.4 kg for FFM, and −9.0 to 5.52% for BF% (Figure 2). There was no systematic error between the two methods for FM ($r^2 = -0.04$, $p < 0.1$), but systematic errors were evident for FFM ($r^2 = -0.12$, $p < 0.05$) and BF% ($r^2 = -0.28$, $p < 0.01$), with the difference between the two methods decreasing as FFM increased and BF% decreased. This indicated that the underestimation of BF% by Imp-SF became greater as BF% increased (Figure 2).

Tanita UltimateScale

Values for BF% provided by DXA and Tanita were significantly related ($r^2 = 0.44$, $p < 0.001$), indicating good relative agreement between the techniques. In absolute terms, there was no difference in measured values between DXA or Tanita for BF% (Table 2; Figure 3), indicating good absolute agreement. However, the limits of agreement were wide, ranging from −8.34 to 10.7% (Figure 3). A systematic error was evident between the two methods ($r^2 = 0.15$, $p < 0.05$), with the difference becoming larger

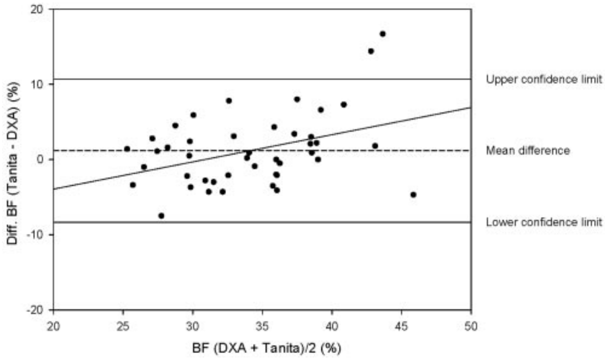

Figure 3: Bland–Altman plots comparing BF% as determined by SF-BIA with Tanita UltimateScale and DXA.

as BF% increased. Thus, compared with DXA, the Tanita method tended to overestimate BF% more as BF% increased (Figure 3).

Discussion

The principal finding of this study was that, in a group of overweight and obese men, both MF-BIA and SF-BIA assessments of body composition provided good relative agreement with DXA, as indicated by high correlation coefficients. However, in absolute terms, despite all BIA methods being associated with wide limits of agreement, MF-BIA substantially underestimated FM and BF% and overestimated FFM compared with DXA, whereas SF-BIA methods provided good absolute agreement.

For the BIA methods examined in the present study, the correlations with DXA for FFM, FM, and BF% were generally good, with Imp-MF demonstrating the highest correlation coefficients. This finding is comparable with previous studies, which have reported high correlations between DXA and BIA in overweight or obese populations (14,19–21). However, although high correlation coefficients indicate good relative agreement, correlational analysis alone is not sufficient to verify the degree of coincidence among the methods (18). Whereas MF-BIA demonstrated the strongest correlation with DXA, it provided the poorest absolute level of agreement, with a large bias in underestimating body fat content (by ~7%) and overpredicting FFM. This finding is consistent with the results of two previous studies (14,22), which indicated that MF-BIA significantly underpredicted body fat content in obese men (14) and obese children (22), compared with DXA. The results of this study and of the two previous studies (14,22) indicate that MF-BIA provides a poor level of absolute agreement with DXA, indicating that MF-BIA may not be suitable for the measurement of body composition in clinical research.

On the other hand, the bias for the absolute differences between DXA and the two SF-BIA methods was small, with Imp-SF underestimating BF% by 1.7% and Tanita overestimating BF% by 1.2% (not statistically significant). These findings are in general agreement with a number of other studies conducted in overweight and obese subjects that have shown relatively small absolute biases between DXA and SF-BIA devices (19,23). These findings of good absolute agreement between SF-BIA and DXA, taken together with the high correlations among methods, indicate that SF-BIA is a reliable method for assessing body fat at the group level in obese populations. However, the wide limits of agreement limit the utility of this technique for accurately determining body composition in any given individual, and its use, therefore, seems limited in the clinical setting. These wide limits of agreement are in accordance with previous reports (7,14,21,24–26), which may reflect an inherent problem with BIA. It is noteworthy that systematic errors between BIA and DXA were present for all three BIA methods. Imp-MF tended to underestimate FM and BF% less as body fat levels increased. This is in contrast to the results reported by other studies using MF-BIA (14) or SF-BIA (21), including the present results for SF-BIA, which overestimated body fat at lower levels and underestimated it in subjects with higher levels of body fat.

The systematic errors between DXA and MF-BIA may be due, in part, to differences in hydration status that occur with varying levels of body fat. Previous reports indicate that TBW and relative extracellular water are greater in obese subjects compared with normal-weight individuals (6,26). Given that DXA is less sensitive than BIA to differences in hydration (1), it could be expected that this would affect the agreement between these methods at different body fat levels. The effect of body geometry may also have contributed to the systematic differences in BIA and DXA values. The extremities are relatively long with a small diameter, resulting in higher impedance values, whereas the trunk contains approximately one-half the conductive mass but contributes minimally to total body impedance (27). In obese subjects, a greater proportion of water (and, therefore, FFM) is located in the trunk, which would lower total body impedance, resulting in an underestimation of FFM. Because this would be the case especially in individuals exhibiting android obesity, such as men who preferentially accumulate fat in the abdominal region (28), it is likely that this effect was accentuated in the population examined in the present study. The effects of hydration status and body geometry with increasing obesity may explain the systematic bias observed with Imp-MF and Tanita in the present study, since, with greater obesity, a greater percentage of TBW is located in the trunk, leading to the smaller underestimation of BF% and FM observed with Imp-MF and the greater overestimation of BF% with Tanita. However, it was interesting to note that Imp-SF demonstrated the opposite trend; the reason for this result is unknown at this time. Nevertheless, Deurenberg (7) has suggested that the net effect of these geometrical and hydration changes associated with obesity is a tendency for BIA to underestimate BF% and FM, as was generally the case in this study, as well as in others (14,21).

It should also be noted that there were several limitations to this study. DXA was used as the criterion measure for body composition, rather than hydrodensitometry, TBW, or multicompartment models. Although DXA has been found to provide results that are comparable with these other techniques (29–34), it is acknowledged that some of the error among the techniques may have been due to errors in the estimation of body composition by DXA. Nevertheless, comparability of DXA with the other reference techniques, combined with the relative simplicity of DXA, has resulted in a number of other investigations similar to the present study using DXA as a criterion method for comparison with BIA (14,21). Another limitation of the present study is that the study population consisted of a fairly small, homogeneous group of apparently healthy, overweight and obese, white adult men. Therefore, the results should not be generalized to other overweight or obese populations. Further investigations to evaluate the validity of BIA techniques in overweight and obese adults, including subjects of both sexes and from diverse age groups and ethnic backgrounds, are required.

In conclusion, whereas all three of the assessed BIA methods provided good relative agreement with DXA, SF-BIA (i.e., Imp-SF and Tanita) also demonstrated good absolute agreement, MF-BIA showed poor absolute agreement, and all BIA methods had wide limits of agreement. This suggests that SF-BIA methods may be useful for group comparisons; however, the wide limits of agreement for all BIA techniques indicate that the use of BIA as an alternative to DXA in a clinical setting for assessment of an individual's body composition in overweight and obese populations is limited.

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