

대사증후군의 진단에 있어 생체 전기저항 분석법에 의해 추정된 비만지표들의 유용성

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The Usefulness of Indices for Central Obesity Estimated by Bioelectrical Impedance Analysis in the Diagnosis of Metabolic Syndrome

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Background: Recently-developed equipment based on bioelectrical impedance analysis (BIA) not only measures total body fat but also displays several estimated indicators that reflect intra-abdominal fat, such as waist circumference (WC) and waist-to-hip ratio (WHR). This study examined the usefulness of these indicators in the diagnosis of metabolic syndrome (MS).

Methods: A total of 632 people over 20 years of age (355 men and 277 women, mean age 48.61±11.08 years, mean BMI 23.62±3.00 kg/m², 117 MS patients) were enrolled in the study. Measurements of WC and hip circumference were measured by one individual, and WHR was calculated. BIA was performed to estimate waist circumference (BIAWC) and waist-to-hip ratio (BIAWHR). Receiver operating characteristic (ROC) curve analysis was used to examine the usefulness of BIAWC and BIAWHR in diagnosing MS.

Results: The areas under the curve (AUCs) were 0.836 (95% CI 0.805-0.864) for WC, 0.814 (95% CI 0.782-0.844) for BIAWC, 0.815 (95% CI 0.782-0.844) for WHR, and 0.805 (95% CI 0.772-0.835) for BIAWHR. The difference between the AUCs of WC and BIAWC (0.022, 95% CI -0.004 to 0.048) and the difference between the AUCs of WHR and BIAWHR (0.010, 95% CI -0.015 to 0.034) were not significant.

Conclusions: The indices for central obesity estimated by BIA had high agreement with the direct method, and they were not inferior to direct measured indices for predicting metabolic syndrome.

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Keywords: Bioelectrical impedance, Abdominal obesity, Metabolic syndrome, Waist circumference, Waist-to-hip ratio

INTRODUCTION

Because obesity is not defined as simple weight gain but rather as over-accumulation of body fat, body composition assessment is a crucial step in weight management intervention. Knowing the body fat distribution, as well as

total amount of body fat, is important,¹⁾ and visceral fat is a stronger predictor of health-related risks than subcutaneous fat.²⁻⁴⁾ However, the 'gold standard' measures of visceral fat area, such as computed tomography (CT) or magnetic resonance imaging (MRI), are not practical for large-scale research studies or as clinical tools, due to limitations associated with cost, availability, and/or radiation exposure. In contrast, anthropometric measurements, such as waist circumference (WC) or waist-to-hip ratio (WHR), for assessment of visceral fat accumulation are simple and noninvasive. WC, in particular, holds a pivotal position in current definitions of metabolic syndrome

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(MS),⁵⁾ and is widely used in clinical practice as a surrogate for central obesity in assessing health status.³⁾

Bioelectrical impedance analysis (BIA), dual energy x-ray absorptiometry and underwater weighing are the useful methods for assessing human body composition.

Because BIA offers the advantages of being inexpensive, noninvasive, and operationally simple, it has been used in large-scale epidemiologic studies.⁶⁾ Segmental BIA has been introduced in recent decades, and indices (e.g., BIAWC, waist circumference calculated by BIA; BIAWHR, waist-to-hip ratio calculated by BIA) for regional fat distribution, as well as total body fat measures have been presented.^{7,8)}

However, to the best of our knowledge, very few studies have investigated the clinical implications of the indices of BIA. We performed a preliminary study for gauging the clinical significance of BIAWHR in 132 persons, and obtained results that demonstrated that BIAWHR is not inferior to WC in diagnosing MS.⁹⁾ According to this preliminary result, we attempted to compare the usefulness of BIAWC and BIAWHR with that of actual measurements in diagnosing MS using a larger group.

METHODS

1. Subjects

Participants in the current study included 632 persons (355 men, 277 women) 20 years of age and older who visited the health promotion centre at Gachon University Gil Hospital in March and April of 2009. All participants provided written informed consent, and all aspects of this study were in accordance with the Declaration of Helsinki of the World Medical Association.

2. Estimation of WC and WHR by BIA

Subjects wore light indoor clothing, including shorts/trousers to ensure that the legs were not in contact with skin at any point. Prior to measuring, subjects were asked to void in order to minimize measurement errors. They stood barefoot on the four foot electrodes on the platform of the analyzer, gripping the two palm and thumb electrodes. Foot electrodes were placed between the medial and lateral malleoli of both ankles of the subjects.

Estimates of body components¹⁰⁾ were derived from calculations using the manufacturer's software. A detailed description of the sequence of measurements has been described.¹¹⁾ WC and WHR estimated by InBody720 (Biospace Co., Seoul, Korea) were displayed by the machine and printed out.

3. Laboratory and anthropometric measurements

All blood samples were obtained from antecubital veins on the morning after a 12-h overnight fast. Height and weight were measured using an automatic digital stadiometer (InBody BSM330, Biospace, Co., Seoul, Korea) while subjects wore a lightweight gown and stood bare foot. Based on the WHO (World Health Organization) protocol, WC was measured at the midpoint between the inferior costal margin and the superior border of the iliac crest along the mid-axillary line, and hip circumference was measured at the widest circumference of the hip.¹²⁾ WHR was then calculated. One individual performed all measurements of central obesity indices using a non-stretchable standard tape. Measurements were recorded to the nearest decimal place. To assess intra-observer variability in measurement of waist and hip circumference, a pilot test was carried out in a small group (n=13), where measurements were performed by both the measurer and by the BIA equipment on separate occasions within 30 minutes of the initial measurement.

4. Definition of MS

We used the revised NCEP (National Cholesterol Education Program) criteria proposed by the AHA/NHLBI (American Heart Association/National Heart, Lung, and Blood Institute),¹³⁾ which require at least three of five metabolic components. The cutoff point for waist circumference was defined according to central obesity for Koreans, men ≥ 90 cm, women ≥ 85 cm.¹⁴⁾

5. Sample size estimation and statistical analyses

The sample size estimate of 114 for the MS group was based on our preliminary results, which would lead to an alpha level of 0.01 and a beta level of 0.10. In our preliminary study, the areas under the curves (AUCs) were 0.764

for WC and 0.837 for BIAWHR. Spearman's rank correlation coefficient of WC and BIAWHR was 0.616 in the MS group and 0.726 in the non-MS group.

Data were expressed as mean±S.D. or number (%). Independent two sample *t*-test and χ^2 test were used to compare factors associated with MS in patients with MS and those without.

Received operating characteristics (ROC) curve analysis was used to evaluate and compare four indices of central obesity, i.e. WC, WHR, BIAWC, and BIAWHR in diagnosing metabolic syndrome. AUC of each index was compared. Non-inferiority would be claimed if the upper two-sided 95% confidence intervals (CIs) of AUC of BIAWC and BIAWHR were more than the lower two-sided 95% CI of AUC of WC, and the difference of AUCs between BIAWC and WC was less than 0.05.

Statistical analyses were performed using R: A language and environment for statistical computing (version 2.9.2, R Development Core Team (2009). R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL <http://www.R-project.org>) and MedCalc for Windows, version 11.0.0 (MedCalc Software, Mariakerke, Belgium).

RESULTS

1. Reproducibility of measurements

The reproducibility of WC, WHR, BIAWC, and BIAWHR

was very high. Intra-class correlation coefficients (ICCs) for intra-observer reliability of WC, WHR, BIAWC, and BIAWHR were 0.959, 0.940, 1.000, and 0.998, respectively (Figure 1). Data on BIAWC and BIAWHR, in particular, show accurate reproducibility of WC and WHR estimation using BIA equipment.

2. General characteristics of subjects

Table 1 provides the general characteristics of the 632 subjects. Within the study sample, 117 (18.5%) were diagnosed as MS. The prevalence rate of MS in our study was 23.4% for men and 12.3% for women, which is lower than the most recent report of the Korean population (men 30.7%, women 31.6%).¹⁵⁾ The mean age of participants was 48.61±11.08 years (48.79±10.22 years for men and 48.38±12.12 years for women). Age in the MS group was higher than in the non-MS group for both men and women. The age of women in the MS group (57.88±10.12 years) was higher than that of men (51.34±9.70 years, *P*=0.001). Mean body mass index of participants was 23.62±3.00 kg/m².

3. WC, WHR, BIAWC, and BIAWHR

The four indices of central obesity, WC and WHR, and WC and WHR estimated by BIA, were higher in the MS group than in the non-MS group for both men and women

Table 1. Basic characteristics of study subjects

	Men		Women	
	Non-MS ^a	MS ^a	Non-MS ^a	MS ^a
N (%)	272 (76.6)	83 (23.4)	243 (87.7)	34 (12.3)
Age (years)	48.01±10.27	51.34±9.70	47.05±11.79	57.88±10.12
BMI (kg/m ²)	23.44±2.69	26.02±2.62	22.71±2.92	25.75±2.78
WC (cm)	82.70±7.11	90.92±6.14	74.12±7.29	85.61±8.12
Waist-to-hip ratio	0.89±0.05	0.94±0.04	0.81±0.06	0.90±0.08
BIAWC	84.77±6.91	92.00±5.89	81.42±7.85	91.21±7.26
BIAWHR	0.90±0.04	0.94±0.03	0.87±0.06	0.94±0.05
Number of subjects having each metabolic component (%)				
WC	29 (10.7)	59 (71.1)	16 (6.6)	19 (55.9)
Blood pressure	96 (35.3)	61 (73.5)	57 (23.5)	26 (76.5)
Triglyceride	73 (26.8)	70 (84.3)	20 (8.2)	23 (67.6)
HDL-cholesterol	22 (8.1)	38 (45.8)	50 (20.6)	25 (73.5)
Fasting glucose	72 (26.5)	59 (71.1)	40 (16.5)	24 (70.6)

Abbreviations: MS, metabolic syndrome; BMI, body mass index; WC, waist circumference; BIAWC and BIAWHR, waist circumference and waist-to-hip ratio estimated by bioelectrical impedance analysis; HDL, high density lipoprotein. Significance differences were noted in whole variables by independent two sample *t*-test or χ^2 test (*P*<0.01).

^aDiagnosis was made using the 2005 AHA/NHLBI modified ATP III definition, and cutoff values of waist circumference were 90 cm for men and 85 cm for women based on the Korean society for the study of obesity.

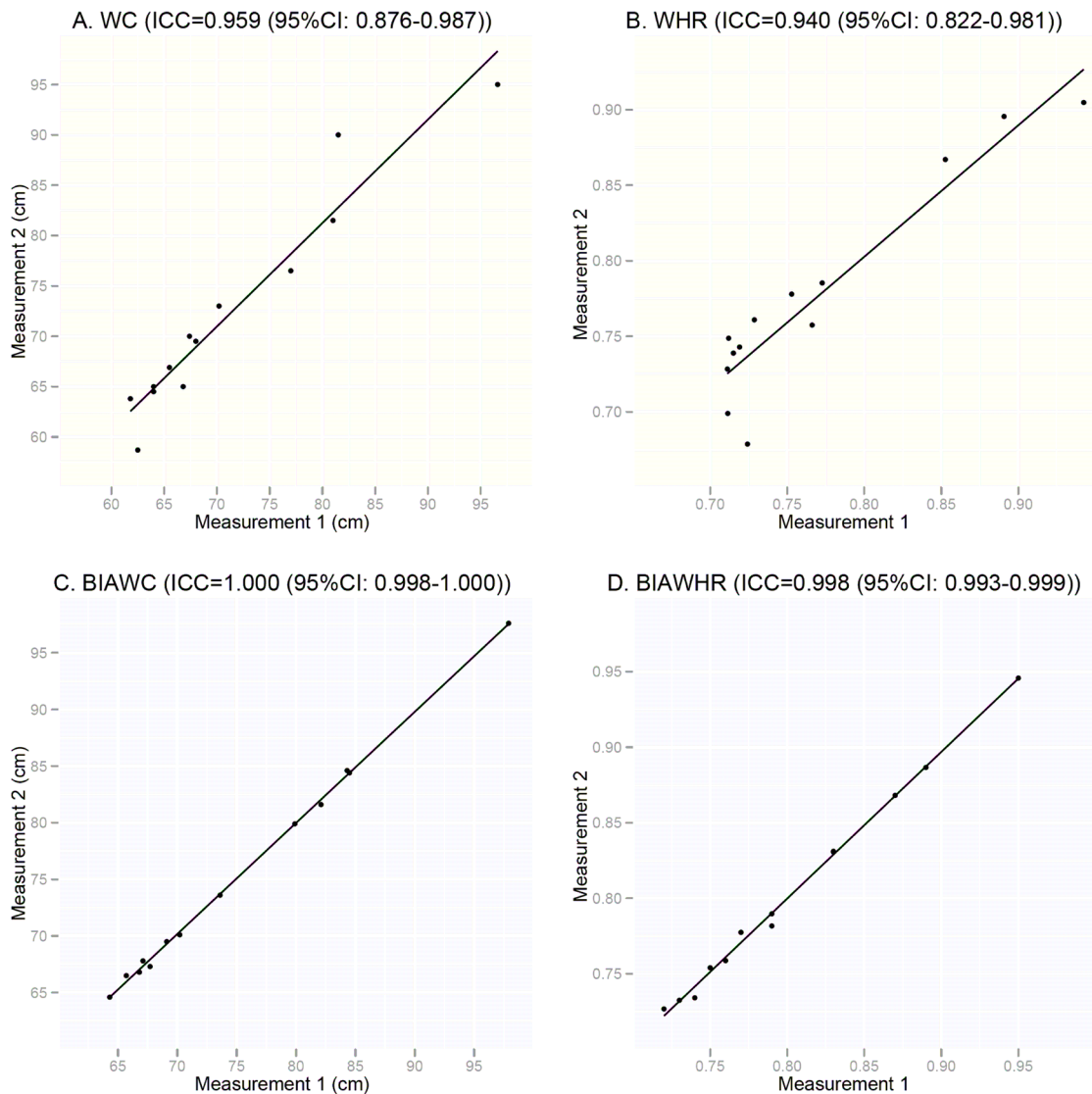


Figure 1. Scatter plots of waist circumferences and waist-to-hip ratios for separate measurements taken by direct measurement and bioelectrical impedance analysis (A and B: measured waist circumference and waist-to-hip ratio, C and D: estimated waist circumference and waist-to-hip ratio by bioelectrical impedance analysis).

Abbreviations: ICC, intra-class correlation coefficient; CI, confidential interval; WC, waist circumference; WHR, waist-to-hip ratio; BIAWC and BIAWHR, waist circumference and waist-to-hip ratio estimated by bioelectrical impedance analysis.

(Table 1, $P<0.001$).

Agreement between WCs by direct measurement and BIA equipment was good. However, agreement between WHRs by direct measurement and BIA equipment was not as good. ICC between WC and BIAWC was 0.766 (95% CI 0.731-0.796) and ICC between WHR and BIAWHR was 0.561 (95% CI 0.505-0.612) (Figure 2).

The estimated value of WC by BIA was significantly higher than that of directly measured WC in all subjects (difference 4.14 (95% CI 3.79-4.49), $P<0.001$), the male group [difference 1.84 (95% CI 1.50-2.17), $P<0.001$], and

the female group [difference 7.09 (95% CI 6.61-7.57), $P<0.001$]. The estimated value of WHR by BIA was also significantly higher than that of directly measured WHR in all subjects [difference 0.032 (95% CI 0.028-0.037), $P<0.001$], the male group [difference 0.009 (95% CI 0.005-0.014), $P=0.004$], and the female group [difference 0.062 (95% CI 0.055-0.068), $P<0.001$].

4. ROC analysis for diagnostic prediction of MS

AUCs of ROC curves were 0.836 for WC, 0.814 for

BIAWC, 0.815 for WHR, and 0.805 for BIAWHR in all subjects. In all subjects, the male group and the female

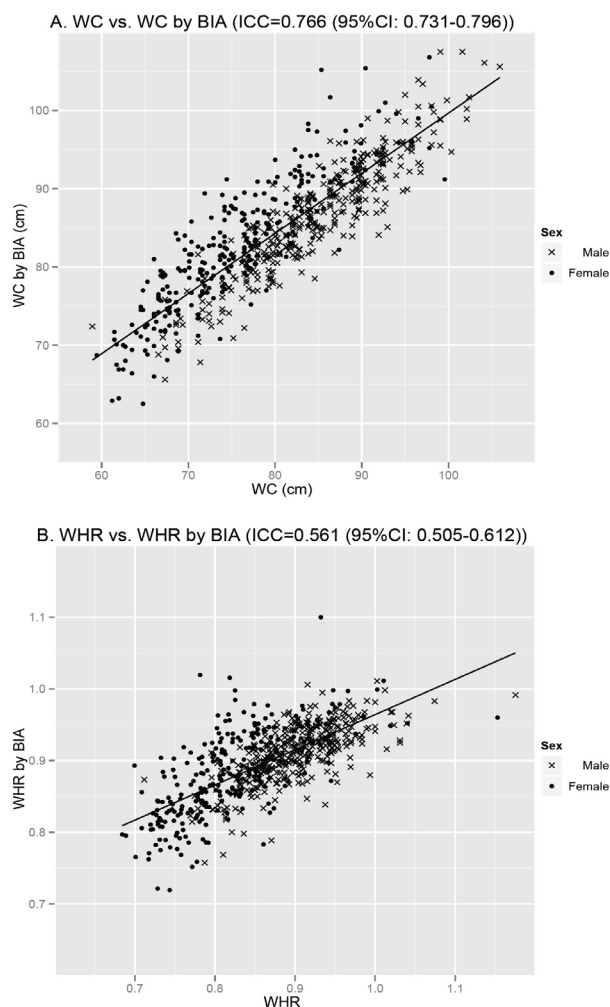


Figure 2. Scatter plots of waist circumference and waist hip ratio (A: measured waist circumference vs. estimated waist circumference by bioelectrical impedance analysis, B: waist-to-hip ratio obtained through direct measurement vs. estimated waist-to-hip ratio by bioelectrical impedance analysis).

Abbreviations: ICC, intra-class correlation coefficient; CI, confidential interval; WC, waist circumference; WHR, waist-to-hip ratio; BIA, bioelectrical impedance analysis.

group, all AUCs of ROC curves for BIAWC and BIAWHR were above 0.805, which was the lowest value of the lower 95% CI of AUCs of WC (Table 2).

The difference between the AUCs of WC and BIAWC was not significant (0.022, 95% CI -0.004 to 0.049), and the difference between the AUCs of WHR and BIAWHR was also not significant (0.010, 95% CI -0.034 to 0.054) (Figure 3A). The difference between the AUCs of WC and BIAWC (0.021, 95% CI -0.008 to 0.050 for male; 0.030 95% CI -0.018 to 0.077 for female) and between the AUCs of WHR and BIAWHR (0.007, 95% CI -0.046 to 0.059 for male; 0.033, 95% CI -0.055 to 0.120 for female) were also not significant in the male and female groups (Figure 3B and C).

5. Comparison of ROC curves in each index for central obesity

The upper two-sided 95% CI of the AUC of BIAWC and BIAWHR were more than the lower two-sided 95% CI of the AUC of WC. The difference between the AUCs of WC and BIAWC was less than 0.05. The difference of the AUCs between WHR and BIAWHR was also less than 0.05. This is not only true for all subjects, but also for the male and female subgroups (Table 2, Figure 3).

DISCUSSION

In this study, the indices for central obesity estimated by BIA were not inferior to those of direct measurement in predicting MS. BIA devices, including the *InBody720* used in this study, have been used to estimate body composition in adults.¹⁶⁻¹⁸⁾ Scharfetter et al.¹⁹⁾ initially introduced local bioimpedance analysis for assessing abdominal fat in 2001. Ryo et al.²⁰⁾ then reported excellent

Table 2. Comparison of 4 indices for central obesity in diagnosing metabolic syndrome^a

Indices	Total (n=632)			Male (n=355)			Female (n=277)		
	AUC	SE	95% CI	AUC	SE	95% CI	AUC	SE	95% CI
WC	0.836	0.021	0.805-0.864	0.823	0.028	0.779-0.861	0.851	0.035	0.804-0.891
BIAWC	0.814	0.021	0.782-0.844	0.802	0.028	0.757-0.842	0.821	0.034	0.771-0.865
WHR	0.815	0.020	0.782-0.844	0.785	0.026	0.739-0.827	0.850	0.034	0.802-0.890
BIAWHR	0.805	0.020	0.772-0.835	0.792	0.027	0.746-0.833	0.817	0.034	0.767-0.861

Abbreviations: AUC, area under the curve; SE, standard error; BIAWC and BIAWHR, waist circumference and waist-to-hip ratio estimated by bioelectrical impedance analysis; WHR, waist-to-hip ratio; WC, waist circumference.

^aMetabolic syndrome was diagnosed according to the 2005 AHA/NHLBI modified ATP III definition; cutoff values of waist circumference were 90 cm for men and 85 cm for women based on the Korean society for the study of obesity.

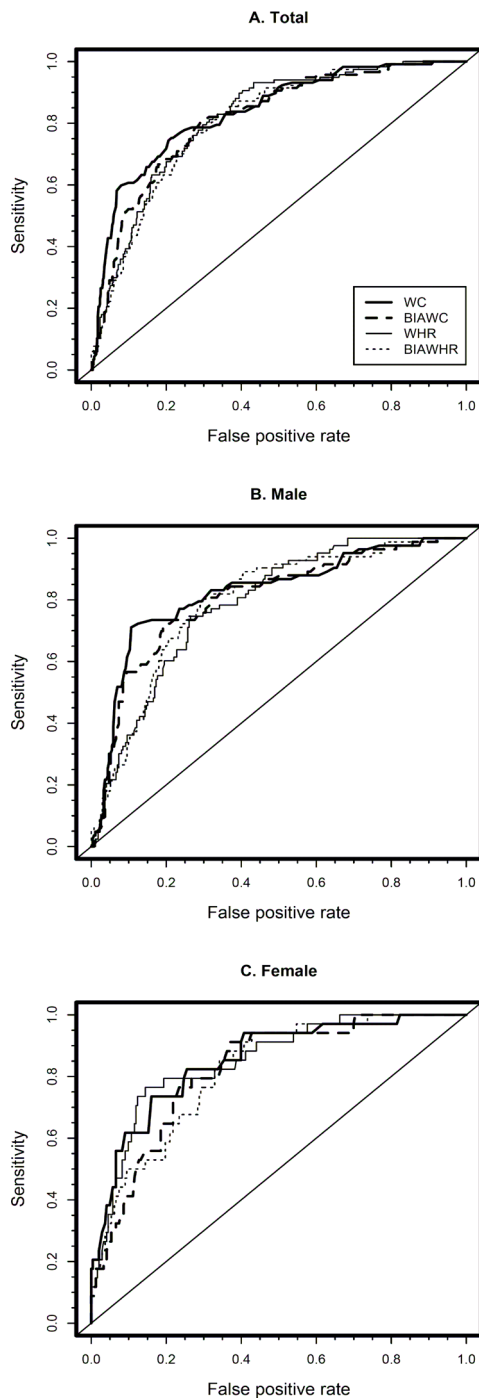


Figure 3. Received operating characteristics (ROC) curve and area under the curve (AUC) of 4 indices of metabolic syndrome (A: total, B: male, C: female). Metabolic syndrome was diagnosed according to the 2005 AHA/NHLBI modified ATP III definition; cutoff value for waist circumference is 90 cm for men and 85 cm for women based on the Korean society for the study of obesity.

Abbreviations: BIAWC, waist circumference estimated by bioelectrical impedance analysis; BIAWHR, waist-to-hip ratio estimated by bioelectrical impedance analysis; WC, waist circumference; WHR, waist-to-hip ratio.

correlation between BIA and CT scan in estimating visceral fat accumulation. However, to the best of our knowledge, few studies have reported on matters of clinical implication for central obesity indices estimated by devices based on BIA methods.

WC measurement has limitations. WC is known as a strong predictor for obesity-related morbidity and mortality, and routine measurement of WC is strongly recommended in clinical practice.²¹⁻²³⁾ Measurement protocols have been based principally on anatomical landmarks. Commonly used landmarks include the midpoint between the lower border of the rib cage and the iliac crest (WHO guidelines), the superior border of the iliac crest (National Institutes of Health guidelines), and the umbilicus.^{12,24,25)} In some studies, researchers regarded the smallest circumference of the trunk as the WC.²⁶⁻²⁸⁾ No consensus, as of yet, exists on the optimal protocol for this measurement, and no scientific rationale has been provided for any of the measurement protocols recommended by leading health authorities.²⁹⁾

On the other hand, the BIA method for estimating WC can be consistent. In contrast to the WC measurement for analysis of body composition, the BIA method is a highly reliable method with a very small inter- or intra-observer error.^{30,31)} Estimation of WC or WHR by BIA is somewhat different from body fat composition analysis by BIA. However, data from this study show that intra-observer errors in estimating WC and WHR by BIA are very small.

The errors of direct measurement were small in this study. The aim of this study was to examine the usefulness of BIAWC and BIAWHR in diagnosing MS. Waste circumference is a key element of MS diagnosis; therefore, accurate measurement is essential. According to some study results on the three methods of measuring WC, we consider the WHO protocol to be an appropriate method.^{32,33)} Moreover, considering that inter-observer errors of waist and hip circumference are significant, we trained only one observer to measure all waist and hip circumferences in this study.³⁴⁾ ICCs of WC and WHR measurement were satisfactory.

Although agreement between direct measurement and BIA assumption for WC and WHR was not good, the reproducibility of BIA was excellent. Figure 2 A shows the relationship between WC and BIAWC. In this study,

BIAWC was larger than WC. The difference between BIAWC and WC was 4.14 ± 4.44 cm for all subjects, 1.84 ± 3.19 cm for the male group, and 7.09 ± 4.01 cm for the female group. CT and MRI are the 'gold standard' methods for assessing visceral fat. The WC and WHR are used only as indices of central obesity, not as gold standards. In a recent study, Nagai et al. reported no difference between the mean visceral fat area (VFA) seen on CT and that estimated by multi-frequency BIA.³⁵⁾ Moreover, regardless of high accuracy, test results that cannot be reproduced lose their value and usefulness.³⁶⁾ The aims of this study were not to exhibit agreement between WC and BIAWC, but rather to compare their predictabilities for MS. Accurate estimation of VFA by the BIA method and its high reproducibility may make it more likely to predict MS. The results from this study show that we can use the BIA method to measure WC or WHR for diagnosing MS. However, we do not insist that the BIA method is superior to direct measurement. Although BIA equipment is not expensive, the BIA method consumes more cost and time than direct WC measurement, particularly for large populations. Moreover, a large number of studies on MS and its cardio-vascular disease (CVD) risk assessment are based on direct WC measurement. However, fellow workers who use BIA equipment in obesity clinics or in research may use their central obesity indices data from BIA equipment in their work on CVD risk assessment.

There are two limitations to our study. First, most participants were middle-aged, and few were morbidly obese. Second, although the BIA method itself has high reproducibility, there are no data, as of yet, on the cross-reliability and cross-validity among the several types of BIA equipment in current use. Therefore, we are not certain whether our results are applicable to both younger and older people, or to morbidly obese people, or to other BIA equipment.

However, this is an uncommon study that investigates the clinical significance of assumed WC and WHR using the BIA method. In conclusion, central obesity indices estimated by BIA were highly correlated with these of direct measuring, and they were not inferior to direct measured WC or WHR in predicting metabolic syndrome.

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요 약

연구배경 최근에 개발된 생체전기저항 분석기기(Bioelectric impedance analysis, BIA)는 총지방량뿐 아니라, 허리둘레나 허리-엉덩이 둘레비와 같이 내장지방을 반영하는 지표를 제시한다. 본 연구는 대사증후군을 진단하는 데 있어 그러한 지표들의 유용성에 대해 살펴보았다.

방법 20세 이상의 남녀 632명을 대상으로 하였다. 허리둘레(waist circumference, WC)와 엉덩이 둘레는 한 명의 연구자에 의해 측정되었고, 허리-엉덩이 둘레비(waist to hip ratio, WHR)를 계산하였다. 대사증후군을 진단하는 데 있어, InBody 720을 통해 유추된 허리둘레(BIAWC) 및 허리-엉덩이 둘레비(BIAWHR)를 실제 측정한 비만지표들과 비교하기 위해 received operating characteristics (ROC) 분석법을 사용하였다.

결과 ROC분석에서 area under the curve (AUC)는 WC 0.836, BIAWC 0.814, WHR 0.815, 그리고 BIAWHR 0.805였다. 동일지표 간 AUC의 차이는 허리둘레의 경우 0.022 (95% CI -0.004-0.048)이었고, 허리-엉덩이 둘레비의 경우 0.010 (95% CI -0.015-0.034)이었다.

결론 BIA에 의해 유추된 복부비만 지표들은 직접 측정된 지표와 상관성이 높았고, 대사증후군을 진단하는 데 있어 직접 측정한 값에 비해 열등하지 않았다.

중심단어 생체전기저항 분석, 복부비만, 대사증후군, 허리둘레, 허리-엉덩이 둘레비

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