

ORIGINAL ARTICLE

Associations between abdominal visceral fat and surrogate measures of obesity in Japanese men with spinal cord injury

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Study design: Cross-sectional study.

Objectives: There are ethnic differences in the distribution of abdominal obesity associated with metabolic disorders. In Japan, the appropriate reference values for abdominal obesity have not been established in individuals with spinal cord injury (SCI), although there are a number of studies in Western countries. This study evaluates the associations between visceral fat area (VFA), waist circumference (WC) and body mass index (BMI), to examine cutoffs and estimate the error for WC and BMI equivalent to 100 cm² VFA in Japanese men with SCI.

Setting: National Rehabilitation Center for Persons with Disabilities, Japan.

Methods: Seventy-four men (aged 45.6 (s.d. 14.3) years) participated in the study. VFA was quantified using computed tomography at the level of the umbilicus, and associations were determined using nonlinear regression analysis. The error of the estimates from the regression equation was assessed using a Bland–Altman plot.

Results: The mean VFA was 101.2 (s.d. 53.0) cm² and 32 subjects had a VFA \geq 100 cm². The cutoffs for a VFA of 100 cm² were WC, 81.3 cm and BMI, 22.5 kg m⁻². The relationship between the estimated and actual values showed that the error increased as VFA increased, which resulted in a negative proportional bias.

Conclusion: The suggested cutoff for Japanese men with SCI is a VFA of 100 cm², which is lower than that in the healthy able-bodied population for both WC and BMI. Further investigation is needed to determine the reference value for estimating SCI-specific VF accumulation.

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INTRODUCTION

Wheelchair users because of spinal cord injury (SCI) have a higher risk of metabolic disorders than do those who do not require a wheelchair because of a lower level of physical activity and adverse body compositional changes.¹ Many people with SCI participate socially (for example, study and work) while leading an unassisted home life. Early risk assessment for metabolic disorders can help to maintain and enhance health in community-dwelling individuals with SCI. Caring for SCI individuals' health in their homes requires the development of indicators to easily assess the risk of metabolic disorders.

People with metabolic disorders have an elevated risk of developing arteriosclerotic disease.² The risk factors include elevated blood pressure, dyslipidaemia (elevated triglycerides and low high-density lipoprotein cholesterol), high fasting glucose and abdominal obesity. Abdominal obesity is a major risk factor for metabolic syndrome and is characterized by an accumulation of visceral fat (VF) in the abdominal cavity.^{3,4}

Waist circumference (WC) is used as a surrogate measure of abdominal obesity. There are several recommended cutoffs for WC to estimate abdominal obesity in people of European origin (Europids): \geq 94 cm in men and \geq 80 cm in women (International Diabetes Federation, World Health Organization); \geq 102 cm in men and

\geq 88 cm in women (American Heart Association/National Heart, Lung, and Blood Institute); and \geq 88 cm in women and \geq 102 cm in men (National Cholesterol Education Program Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III)).⁵ In comparison, the cutoffs for Asians are \geq 90 cm in men and \geq 80 cm in women.⁶ The International Diabetes Federation also incorporates different WC cutoffs by sex and ethnicity.⁵

In Japan, the criteria for metabolic syndrome are as follows: elevated WC; triglyceride level \geq 150 mg dl⁻¹; high-density lipoprotein cholesterol $<$ 40 mg dl⁻¹; elevated blood pressure: systolic \geq 130 mm Hg and/or diastolic \geq 85 mm Hg; and fasting glucose \geq 110 mg dl⁻¹.^{7,8} similar to the criteria used in the NCEP ATP III definition.² However, the Japanese criteria for abdominal obesity are as follows: visceral fat area (VFA) \geq 100 cm², determined by computed tomography (CT) at the umbilical level and WC \geq 85 cm in men and \geq 90 cm in women.^{7–9} Alternatively, in studies without data for WC, it has been demonstrated that body mass index (BMI) \geq 25.0 kg m⁻² can be used.¹⁰ These values differ from those of both European and other Asian countries. Furthermore, there are also ethnic differences in BMI and obesity index. In Japan, the cutoff for obesity is a BMI of 25 kg m⁻²,^{8,10} whereas World Health Organization has defined obesity

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as BMI ≥ 30 kg m⁻².¹¹ The prevalence of obesity in Japan is relatively low compared with Western populations. According to the Japanese National Health and Nutrition Survey,¹² 25 and 17% of adult men and women had a BMI of 25–30 kg m⁻², and 3 and 3% had a BMI ≥ 30 kg m⁻², respectively.

The body composition of SCI individuals differs from that of the healthy able-bodied population.^{13–15} An increasing number of studies conducted in Western countries have shown that body fat topography in persons with SCI is an important factor associated with metabolic disorders.^{16–23} These studies used dual-energy X-ray absorptiometry,^{16–19} magnetic resonance imaging^{20–22} and ultrasonography.²³ However, these laboratory tools are not suitable for routine clinical practice. In addition, in Japan, studies on abdominal obesity and VF accumulation using CT in individuals with SCI are limited.²⁴ It is necessary to devise an evidence-based approach for the evaluation of VF accumulation specific to each country.

The purpose of this study was to examine abdominal VF and surrogate measures of abdominal obesity in community-dwelling Japanese men with SCI as follows: to determine the distribution of VFA in Japanese men with SCI; to evaluate the associations between VFA, WC and BMI; and to examine the cutoffs and estimate the error for WC and BMI equivalent to 100 cm² VFA.

MATERIALS AND METHODS

Subjects and procedures

We used a cross-sectional design. The subjects were wheelchair users with chronic SCI living independently treated at the National Rehabilitation Center for Persons with Disabilities (Tokorozawa, Japan) and who underwent medical examination, such as multiphasic health screening, between July and December 2006. A consent form and information on the study were mailed to 102 patients before the study. The study information explained the aims and purpose of the study, measurement items and methods, advantages and disadvantages of participating in the study, potential risks, and the management and publication of data. Eight men did not submit the consent form. Seventy-four men were included in the analysis from the seventy-seven men and seventeen women who submitted a completed written consent form. Three men who had no data for VFA or WC were excluded; all of the women were excluded from the analysis because of inadequate numbers.

Measurements

Upon arrival at the rehabilitation center, participants were asked to change into light clothes. Participants were then weighed to the nearest 0.1 kg using a wheelchair weigh scale with participants in their wheelchairs, and then transferred from their wheelchair to the bed with the investigator's assistance to measure their height and WC. The weights of the wheelchair and clothing were deducted from the total weight. Height was measured to the nearest 0.1 cm as the length from the head to the heel in the supine position using an inelastic tape measure. For participants with contractures preventing the straightening of their legs, height was measured in segments from the head to the heel. BMI was calculated as the weight divided by the height squared. WC was measured using a flexible inelastic tape measure to the nearest 0.1 cm at the level of the umbilicus. The measurements were taken twice after normal expiration without compressing the skin in the supine position. All measurements were obtained by the same investigator.

VFA was determined using the method described by Tokunaga *et al*,²⁵ by which the total cross-sectional area, subcutaneous fat area and intra-abdominal VFA were measured at the level of the umbilicus in the supine position. Once transferred to the CT scanning table with investigator's assistance, patients' knees and feet were strapped to ensure a neutral position inside the CT scanning table and to avoid incidental movement due to spasms. Arms were placed across the chest because of range of motion limitations. All CT scans were performed following standard procedures²⁶ according to the manufacturer's guidelines using a HiSpeed Advantage CT Scanner (General Electric Medical Systems, Milwaukee, WI, USA) with the following parameters: X-ray

generator, 120 kVp and 400 mAs (200 mA \times 2 s); slice thickness, 10 mm; and scanning time, 2 s. The measurement was taken at the end of normal expiration to reduce respiratory motion artifact. Single-slide images were downloaded to a disk and analyzed using the specifically programmed software, FAT Scan (N2 System Co., Osaka, Japan).²⁶ A trained radiology technician performed the CT measurements. We collected the following characteristic data: age, lesion type, the number of years after injury and the presence or absence of an exercise habit.

Statistical analysis

Nominal scales were expressed as the numbers of subjects (rate). Interval scales were expressed as the mean (s.d., 95% confidence interval) and median (25th–75th percentile range). As VFA did not follow a normal distribution using the Shapiro–Wilk test, the Kruskal–Wallis test and Mann–Whitney *U*-test were used to compare VFA by age (≤ 30 , 31–45, 46–60 and ≥ 61 years), number of years after injury (≤ 10 , 11–20 and ≥ 21 years), lesion type (cervical cord, thoracic cord and lumbar cord) and the presence or absence of an exercise habit. The associations between VFA, and WC and BMI were determined using nonlinear regression analysis. WC and BMI equivalent to 100 cm² VFA were calculated using regression equations. The sensitivity and specificity of WC cutoffs of 85 and 81.3 cm or BMI cutoffs of 25 and 22.5 kg m⁻² were analyzed, relative to the VF accumulation of 100 cm². WC cutoffs of 81.3 cm or BMI cutoffs of 22.5 kg m⁻² were determined from the VFA data using nonlinear regression. The relationships between the estimates and actual values were examined using Bland–Altman plots and Pearson product–moment analysis. Statistical analyses were carried out using IBM SPSS Statistics, v.21 (IBM Japan Inc., Tokyo, Japan). The level of statistical significance was set at 5% for two-tailed tests.

Statement of ethics

This study was approved by the ethical committee of the National Rehabilitation Center for Persons with Disabilities before initiation. We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during the course of this research.

RESULTS

The subjects' characteristics are shown in Table 1. Thirty-two subjects (43%) had a VFA ≥ 100 cm². Forty-two subjects (57%) had cervical cord injury in Table 2. Neurologically motor complete or incomplete lesions were present in 7 and 18 subjects, respectively. The remaining 49 subjects failed to respond to the section of the questionnaire that defined the completeness of the lesion. There was no difference in VFA with respect to the number of years after injury, lesion type or the presence or absence of an exercise habit (Table 2).

The nonlinear regression analysis showed significant associations between VFA and both WC (Figure 1a) and BMI (Figure 1b) ($P < 0.001$), respectively). The coefficients of determination (r^2) for WC and BMI were 0.604 and 0.439, respectively, indicating that WC data are more accurate than BMI data. The cutoffs for a VFA of 100 cm², which were estimated from the regression equation, were 81.3 cm for WC and 22.5 kg m⁻² for BMI.

Assuming that a VFA ≥ 100 cm² confers an increased risk of metabolic syndrome, we examined the sensitivity and specificity of the VF accumulation using CT. When the WC reference value for Japan (85 cm) was applied, 22% of subjects with a WC < 85 cm were misclassified as low risk, even though they had a VFA ≥ 100 cm². However, when the WC cutoff was set at 81.3 cm, 14% of subjects were misclassified as low risk. The sensitivity changed from 66 to 81% with a WC cutoff of 81.3 cm (Table 3).

When the BMI reference value was ≥ 25 kg m⁻², 31% of subjects with a BMI < 25 kg m⁻² were misclassified as low risk, even though they had a VFA ≥ 100 cm². However, when the BMI cutoff was set at 22.5 kg m⁻², 20% of subjects were misclassified as low risk.

The sensitivity changed from 44 to 72% with a BMI cutoff of 22.5 kg m⁻² (Table 3).

Figure 2 shows the differences between the estimates and actual values based on the regression equations obtained from the nonlinear regression analysis along with the plots of both means. The estimates based on WC and BMI had greater error when the VFA was ≥ 100 cm². The difference between the estimates and actual values as well as the correlation coefficients of the means of the estimates and actual values were significant for WC ($r = -0.374$, $P = 0.001$) and BMI ($r = -0.491$, $P = 0.001$), indicating a negative proportional bias.

Table 1 Participant characteristics ($n = 74$)

	Mean	s.d.	Median	25th–75th percentile range
Age (years)	45.6	14.3	43.0	33.8–59.3
Number of years after injury (years) ^a	14.6	10.3	13.9	5.3–21.6
Height (cm)	170.1	6.6	169.5	165–175
Weight (kg)	63.3	11.4	61.6	54.9–71.3
BMI (kg m ⁻²)	21.8	3.6	21.3	19.2–24.7
Waist circumference (cm)	80.3	10.0	79.5	73.4–87.0
Visceral fat area (cm ²)	101.2	53.0	88.3	64.2–125.6

	n	Rate (%)
BMI		
< 18.5 kg m ⁻²	13	18
≥ 18.5 to < 25 kg m ⁻²	45	61
≥ 25 kg m ⁻²	16	22
Waist circumference		
< 85 cm	51	69
≥ 85 cm	23	31
Visceral fat		
< 100 cm ²	42	57
≥ 100 cm ²	32	43

Abbreviation: BMI, body mass index.

^a $n = 73$.

Table 2 Age, years after injury, lesion type and exercise habit-related differences in visceral fat area in participants

Variables	Group	n	Rate (%)	Mean	s.d.	95% CI	P ^a
Age	≤ 30 Years	10	14	62.1	28.5	41.8–82.5	0.008
	31–45 Years	33	45	96.7	47.1	80.0–113.4	
	46–60 Years	14	19	123.1	63.0	86.8–159.5	
	≥ 61 Years	17	23	114.8	55.4	86.3–143.2	
Number of years after injury ^b	≤ 10 Years	30	41	84.7	39.6	70.0–99.5	0.053
	11–20 Years	24	32	111.8	64.0	84.8–138.9	
	≥ 21 Years	19	26	112.8	53.4	87.1–138.6	
Lesion type	Cervical cord injury	42	57	99.1	45.4	85.0–113.3	0.483
	Thoracic cord injury	28	38	108.1	64.7	83.0–133.2	
	Lumbar cord injury	4	5	74.1	30.4	25.8–122.5	
Exercise habit	Presence	43	58	94.6	44.1	81.0–108.2	0.346
	Absence	31	42	110.3	62.8	87.3–133.4	

Abbreviation: CI, confidence interval.

^aVisceral fat area did not follow a normal distribution. P -value was determined using Kruskal–Wallis test (age, number of years after injury and lesion type) and Mann–Whitney U -test (exercise habit).

^b $n = 73$.

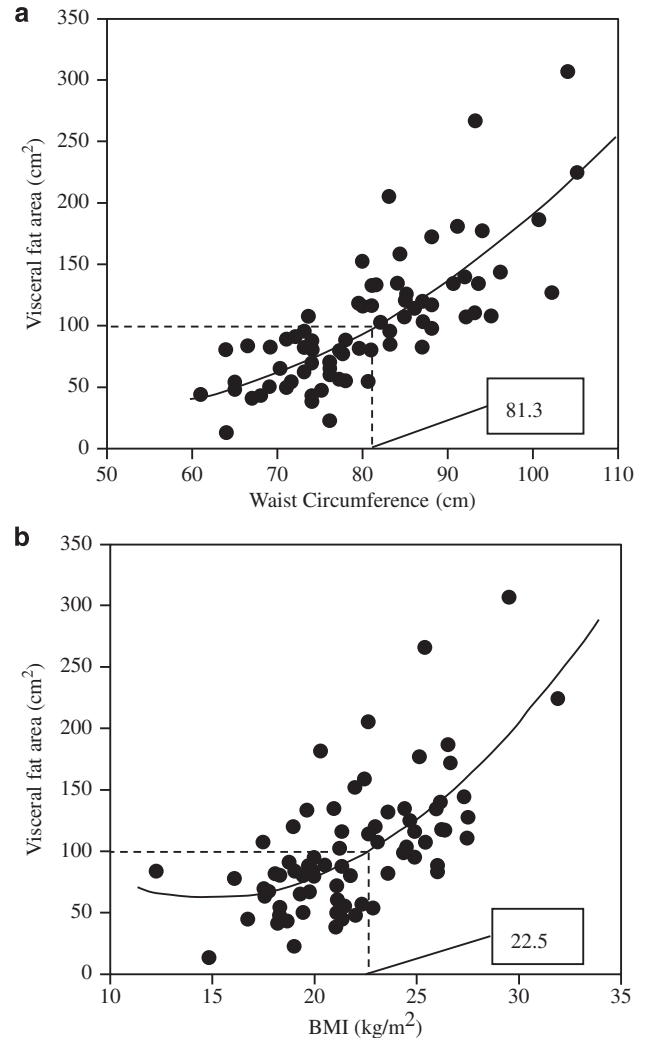


Figure 1 Visceral fat area in relation to waist circumference and BMI for men with spinal cord injury. (a) Dependent variable, waist circumference. $y = 143.482 - 5.007x + 0.055x^2$ ($r^2 = 0.604$, $P < 0.001$). (b) Dependent variable, BMI. $y = 200.047 - 18.645x + 0.630x^2$ ($r^2 = 0.439$, $P < 0.001$).

Table 3 Sensitivity, specificity and predictive value positive for visceral fat accumulation using BMI and waist circumference in participants

		Visceral fat area (≥ 100 cm ²)		Visceral fat area (≥ 100 cm ²)			
		Visceral fat accumulation ^a	No visceral fat accumulation ^a	Visceral fat accumulation ^a	No visceral fat accumulation ^a		
WC (≥ 85.0 cm)	Positive ^a	21	2	WC (≥ 81.3 cm)	Positive ^a	26	4
	Negative ^a	11	40		Negative ^a	6	38
	Sensitivity ^c		66%		Sensitivity ^c		81%
	Specificity ^d		95%		Specificity ^d		90%
	Positive predictive value ^b		91%		Positive predictive value ^b		87%
BMI (≥ 25.0)	Positive ^a	14	2	BMI (≥ 22.5)	Positive ^a	23	6
	Negative ^a	18	40		Negative ^a	9	36
	Sensitivity ^c		44%		Sensitivity ^c		72%
	Specificity ^d		95%		Specificity ^d		86%
	Positive predictive value ^b		88%		Positive predictive value ^b		79%

Abbreviations: BMI, body mass index; WC, waist circumference.

^an. Number of subjects.

^bPositive predictive value = true-positive/(true-positive+false-positive).

^cSensitivity = true-positive/(true-positive+false-negative).

^dSpecificity = true-negative/(false-positive+true-negative).

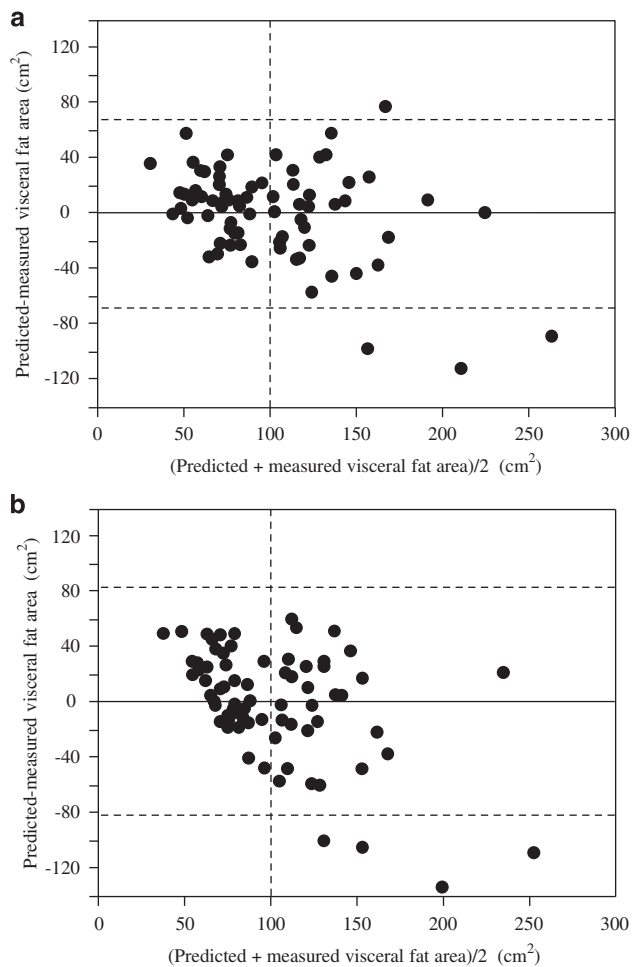


Figure 2 Bland–Altman plot. The differences between measured and predicted visceral fat area using waist circumference/BMI were plotted against the measured and predicted mean visceral fat area. (a) Predicted visceral fat area using waist circumference. (b) Predicted visceral fat area using BMI. —, mean; - - -, 2 s.d.

DISCUSSION

Our results suggest that the cutoffs of both WC and BMI for the screening of VF accumulation in community-dwelling Japanese men with SCI are lower than those in the healthy able-bodied population. WC is a more accurate predictor of VFA than BMI. However, a negative proportional bias exists for both WC and BMI, suggesting that the error of the estimate might increase as the risk of VF accumulation increases. In Japan, there are few reports of VF accumulation in individuals with SCI.²⁴ Forty-three percent of the participants in this study had a VFA ≥ 100 m², and our results show that reference values specific to individuals with SCI are required to estimate VF accumulation.

VF accumulation is a risk factor for metabolic disorders^{3–5,7–9} and WC has been shown in large epidemiologic studies of able-bodied populations to be strongly significantly and independently correlated with metabolic diseases.²⁷ In Japan, a WC > 85 cm has been reported to be a good surrogate for a VFA of 100 cm² determined with CT in able-bodied men.^{7–9} However, this reference value should not be considered for SCI individuals. When we used a WC of 81.3 cm as a cutoff in our study population, the sensitivity of the WC cutoff changed from 60 to 81%. Several reports have suggested that WC has the potential to be a useful tool for estimating obesity/VF accumulation in individuals with SCI.^{14,23} Conversely, Gorgey *et al.*²² reported that WC was related to subcutaneous adipose tissue volume but not to visceral adipose tissue volume. Buchholz and Bugaresti¹³ noted that WC is associated with a risk of chronic heart disease and recommended that the accuracy and reliability of WC as a surrogate measure of VF accumulation and chronic heart disease risk be determined in men and women with long-term paraplegia and tetraplegia.

In Japan, a BMI cutoff of ≥ 25 kg m⁻² as a measure of VF accumulation has been used in individuals without data for WC.¹⁰ In our study participants, the correlation of BMI with VFA was statistically significant (Figure 1), and when we used a BMI of 22.5 kg m⁻² as a cutoff, the sensitivity of the BMI cutoff changed from 44 to 72%. BMI is often used as a surrogate measure of obesity and several reports have indicated that BMI cutoff values for

able-bodied individuals often underestimate obesity in individuals with SCI.^{16,17,28} Laughton *et al.*²⁸ reported that BMI values $>22 \text{ kg m}^{-2}$ should be considered a high risk for obesity and obesity-related chronic diseases for individuals with chronic SCI. Buchholz and Bugaresti¹³ noted that BMI has low sensitivity as an indicator of obesity in individuals with SCI and recommended that SCI-specific BMI classifications be determined. Because of differences in physique and body composition between populations, it is difficult to directly compare our results with those of previous studies in other countries.

The differences between the actual VFA values and the estimates obtained from the nonlinear regression analysis as well as the scatterplot of the mean values (Figure 1) suggest that the error of estimates using WC and BMI might increase as VFA increases, indicating a negative proportional bias (Figure 2). Therefore, estimating abdominal VFA using the surrogate measures of BMI and WC tends to underestimate values. Spungen *et al.*¹⁶ reported that BMI might be a less accurate measure of obesity using dual-energy X-ray absorptiometry because it has been shown to underestimate the degree of total body adiposity. Gorgey *et al.*²² reported the effects of SCI on the association between abdominal adiposity and metabolic profile using magnetic resonance imaging. CT and magnetic resonance imaging are considered the 'gold standard' methods for measuring VF; however, these methods are not feasible for routine assessment because of high costs, highly specialized instrumentation and radiation exposure (CT). The use of ultrasonography²³ for the clinical assessment of body composition or abdominal adiposity are noninvasive, simple and inexpensive modalities. However, these laboratory tools are not suitable for routine health-care practice for community-dwelling individuals in their homes. Related to these issues, Gorgey *et al.*¹⁹ reported the significance of body weight itself for predicting whole-body fat-free mass. Therefore, misclassification is much less likely when using WC to estimate the risk of VF accumulation than when using BMI. Appropriate surrogate measures of VF accumulation are needed to manage body weight for SCI individuals in their homes.

This study has several limitations. First, it should be noted that we did not obtain data for the levels of injury for American Spinal Injury Association classification A or B (motor complete SCI). It is not clear that the level of injury influences the distribution of VF accumulation in Japan and more research is needed. Second, the sample size was relatively small. An investigative study with a sample size suitable for stratified examination is needed, for example, to examine the differences among subgroups such as age group, level of lesion and duration of injury. Third, it was difficult to assess several other factors related to VF accumulation, such as muscle atrophy, exercise and dietary habits, excessive energy intake, and disruption in autonomic nervous system function because of a lack of data related to these details. Fourth, female subjects had to be excluded from the analysis because very few underwent medical examination. Fifth, we measured WC at the level of the umbilicus in the supine position. However, a number of issues pertaining to WC measurement need to be addressed.¹³ Finally, the cross-sectional study design prevents drawing conclusions on the effectiveness of the studied reference parameters in primary health care in individuals with SCI in Japan.

Despite these limitations, our findings suggest that to more accurately predict elevated abdominal VFA, the cutoff values for WC and BMI in community-dwelling Japanese men with SCI are lower than values generally used in able-bodied individuals. For primary care practice and health-promotion strategies, it is important to develop a gender and ethnic group-specific indicator; however, except for Western SCI individuals, the appropriate information to

determine surrogate measures of abdominal obesity is still not available.

In conclusion, community-dwelling Japanese men with SCI have a suggested cutoff for VFA of 100 cm^2 , which is lower than that in the healthy able-bodied population with respect to both WC and BMI. Further investigation is needed to determine the reference value for estimating SCI-specific VF accumulation and to develop simple and easy methods to assess the risk of metabolic disorders.

DATA ARCHIVING

There were no data to deposit.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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