International Journal of Obesity (2008) 32, S58–S65

0307-0565/08 $32.00
www.nature.com/ijo

ORIGINAL ARTICLE

Harmonization process and reliability assessment of anthropometric measurements in a multicenter study in adolescents

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The Healthy Lifestyle in Europe by Nutrition in Adolescence Study aims to describe total body fat percentage and anthropometric indices of body fat distribution in European adolescents.

Objective: To describe the standardization process and reliability of anthropometric and bioelectrical impedance analysis (BIA) measurements. We examined both intra- and interobserver errors for skinfolds, circumferences and BIA.

Methods: For the intraobserver error assessment, first of all, 202 adolescents in the pilot study (110 boys, 92 girls, aged 13.64 ± 0.78 years) were assessed. For the second intraobserver and interobserver assessments, 10 adolescents were studied (5 boys and 5 girls).

Results: The pilot study's intraobserver technical errors of measurement (TEMs) were between 0.12 and 2.9 mm for skinfold thicknesses, and between 0.13 and 1.75 cm for circumferences. Intraobserver reliability for skinfold thicknesses was greater than 69.44% and beyond 78.43% for circumferences. The final workshop's intraobserver TEMs for skinfold thicknesses and circumferences were smaller than 1; for BIA resistance TEMs were smaller than 0.1 Ω and for reactance they were smaller than 0.2 Ω. Intraobserver reliability values were greater than 95, 97, 99 and 97% for skinfold thicknesses, circumferences, BIA resistance and reactance, respectively. Interobserver TEMs for skinfold thicknesses and circumferences ranged from 1 to 2 mm; for BIA they were 1.16 and 1.26 Ω for resistance and reactance, respectively. Interobserver reliability for skinfold thicknesses and circumferences were greater than 90%, and for BIA resistance and reactance they were greater than 90%.

Conclusions: After the results of the pilot study, it was necessary to optimize the quality of the anthropometric measurements before the final survey. Significant improvements were observed in the intraobserver reliabilities for all measurements, with interobserver reliabilities being higher than 90% for most of the measurements.

International Journal of Obesity (2008) **32,** S58–S65; doi:10.1038/ijo.2008.184

Keywords: skinfold thickness; circumference; bioelectrical impedance analysis; technical error of measurement; reliability

Introduction

An excess in body weight has been shown to be an independent risk factor related to chronic diseases. Recently, the importance of total body fat and body fat distribution has been highlighted as a major risk factor for both adults and children.[1] Central adiposity has a negative impact on health that may be distinct from the known effects of

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[11]See Appendix at the end of the supplement on page S82.

generalized obesity, although the involved mechanisms remain to be fully elucidated.[2] Furthermore, the risks associated with android obesity (excess in body fat, primarily abdominal) are distinctly higher than those associated with gynoid obesity (excess in body fat, primarily in peripheral depots such as the thighs and the legs).

This has created a need for accurate assessment of body composition and fat distribution in epidemiological studies aiming to study the interaction of behavioral, environmental and genetic indices in the development and progression of chronic diseases. The most precise methods for assessing body composition, as well as local distribution of fat mass and fat-free mass are dual X-ray absorptiometry (DXA),[3] underwater weighing,[4] air displacement plethysmography, computer tomography and nuclear magnetic resonance.[5] However, these techniques are expensive and require sophisticated laboratory settings, which make them inappropriate to use in large epidemiological studies.

For these reasons, researchers have tried to develop alternative methods and techniques that could not only provide accurate and similar information, but also be feasible to use in large cohorts. The most widely used of these methods includes anthropometric measurements, which include the determination of height, weight, skinfold thicknesses, circumferences and bioelectrical impedance analysis (BIA). Anthropometric measurements can be translated into indices of fat mass, fat-free mass and their distribution in the human body. The precision of these measurements plays an important role in delivering meaningful information for the subjects' nutritional status. The extent to which measurement error can influence both measurement and interpretation of nutritional status is usually neglected, beyond the determination of measurement error for training. As with any use of quantitative biological measures, it is important to minimize error, and to know and understand the various ways in which it is estimated and assessed.[6]

Reliability is the degree to which within-subject variability is due to factors other than measurement error. The lower the variability between repeated measurements of the same subject by one (intraobserver differences) or two or more observers (interobserver differences), the greater is the precision. Determination of intra- and interobserver variability is important in improving measurement precision and reliability.[7] This may provide insight into the type and extent of possible measurement error that may arise both as random and systematic error from inadequate training and measurement difficulties. Unreliable measurement of the exposure variable can dilute or attenuate the observed association of exposure with the disease of interest, thereby reducing the power of the study to detect a true association.[6]

The Healthy Lifestyle in Europe by Nutrition in Adolescents (HELENA) Study aims to describe the total body fat percentage and anthropometric indices of body fat distribution of European adolescents from skinfolds and BIA. As in large size cohorts in which data collection is performed by several researchers, the chances for systematic and random errors increase; it was decided before the implementation of the HELENA Study to proceed with the harmonization of anthropometric measurements as an essential factor to ensure high reliability measurements among all observers participating in the study. The aim of this paper is, therefore, to describe the standardization process and reliability of anthropometric measurements carried out in the pilot study and during the final workshop, examining both intra- and interobserver errors for skinfolds, circumferences and BIA.

Methods

Population and design

In January 2006, a training session in Zaragoza (Spain) was organized, by the coordinator of HELENA, with the 10 field workers who planned to perform anthropometric measurements. The aim of the training was to familiarize researchers with the exact protocol to be used for anthropometric measurements in HELENA and to perform the 1st approach to assess the intra-observer technical error. In April 2006, pilot studies were conducted in 10 cities and included 202 adolescents. In October 2006, a workshop was organized in Pécs (Hungary), the aim of which was to assess the intraobserver (2nd time) and interobserver (1st time) technical error of measurements (TEMs) as well as the reliability (%R) of anthropometry and BIA measurements. Following this workshop, the fieldwork of the HELENA Cross-Sectional Study was conducted from November 2006 to May 2007. All applicable institutional and governmental regulations concerning the ethical issue of human volunteers were followed during this research.

Anthropometric methods

Weight was measured in underwear and without shoes with an electronic scale (Type SECA 861) to the nearest 0.1 kg, and height was measured barefoot in the Frankfort plane with a telescopic height measuring instrument (Type SECA 225) to the nearest 0.1 cm. Body mass index was calculated as body weight (without shoes) divided by the square of height in meters.

In the pilot study, anthropometric measurements (except height and weight) were carried out three times, but not consecutively; all the anthropometric variables were measured in order, and then the same measurements were repeated two more times. A set of skinfold thicknesses (biceps, triceps, subscapular, suprailiac, thigh) and circumferences (relaxed arm, flexed upper arm, waist, hip, upper thigh) were measured three consecutive times on the left side of the body, with a Holtain caliper (to the nearest 0.2 mm) and with a non-elastic tape (Seca 200) to the nearest 0.1 cm, respectively, according to Lohman's anthropometric standardization reference manual.[8,9]

Table 1 The main characteristics of the pilot study of adolescents

	Athens		*Dortmund*		*Heraklion*		*Gent*		*Lille*	
	Mean	*s.d.*	*Mean*	*s.d.*	*Mean*	*s.d.*	*Mean*	*s.d.*	*Mean*	*s.d.*
Male/Female	5/6		11/15		15/17		9/0		7/9	
Weight (kg)	61.24	8.63	52.37	8.89	59.73	13.17	57.43	24.44	51.54	7.80
Height (cm)	166.86	7.27	159.38	6.43	158.66	9.14	161.99	12.09	163.21	6.30
BMI (kg/m^2)	22.03	3.16	20.57	3.04	23.69	4.56	21.24	6.66	19.27	2.06
	Pécs		*Rome*		*Stockholm*		*Vienna*		*Zaragoza*	
	Mean	*s.d.*	*Mean*	*s.d.*	*Mean*	*s.d.*	*Mean*	*s.d.*	*Mean*	*s.d.*
Male/female	10/10		11/7		11/15		16/12		9/7	
Weight (kg)	54.59	10.85	56.80	10.30	58.73	6.94	49.98	11.35	65.70	5.84
Height (cm)	162.90	7.83	164.54	8.59	169.32	7.60	159.51	8.24	162.85	53.06
BMI (kg/m^2)	20.41	3.05	20.86	2.43	20.48	2.00	19.43	2.88	20.05	1.74

Abbreviations: BMI, body mass index; s.d., standard deviation.

Table 2 The main characteristics of the Pécs meeting of adolescents

	Intraobserver				*Interobserver*			
	Males (n = 5)		*Females* (n = 5)		*Males* (n = 5)		*Females* (n = 5)	
	Mean	*s.d.*	*Mean*	*s.d.*	*Mean*	*s.d.*	*Mean*	*s.d.*
Weight (kg)	51.14	15.93	58.88	9.90	58.42	6.27	49.90	9.21
Height (cm)	159.26	9.80	160.82	4.02	169.74	7.81	161.78	5.99
BMI (kg/m^2)	19.76	4.18	22.65	2.73	20.30	2.18	18.92	2.21

Abbreviations: BMI, body mass index; s.d., standard deviation. This meeting was carried out for the final training and harmonization of the field researches.

For BIA measurements, a classical tetrapolar technique was used by means of BIA 101 AKERN SRL. Standard instructions for BIA measurements were followed.[10]

Intraobserver assessment

For the calculation of intra- and interobserver TEMs, at least 10 subjects need to be measured.[6] In the pilot study, 202 adolescents from 10 European cities were studied (110 boys, 92 girls, aged 13.64 ± 0.78 years). The main characteristics of the pilot study of adolescents are shown in Table 1.

During the final Workshop at Pécs, 10 adolescents (5 boys and 5 girls, 14-year-olds) were measured in October 2006. The main characteristics of these adolescents are shown in Table 2.

Before the survey, the adolescents and the parents were informed by letter about the nature and purpose of the study. After receiving their written consent, the adolescents were involved in the pilot study. The protocols of the HELENA Study were approved by the Ethical Committee of each European city involved in the HELENA Cross-Sectional Study.

Interobserver assessment

For interobserver assessment, 10 adolescents from Pécs, different from those who took part in the intraobserver assessment, were studied (5 boys and 5 girls, 14-year-olds). The main characteristics of these adolescents are shown in Table 2. On the same morning, all the 10 researchers performed anthropometry and BIA measurements, twice by each researcher on each adolescent.

Statistical analysis

TEM is the most commonly used indicator of precision. It was obtained by performing three measures in the cases of the skinfold thicknesses and circumferences, and two by measures in the case of the BIA measurements by the same observer (intraobserver variability), or two measurements by each observer on the same adolescent (interobserver variability). TEM was calculated with the commonly used formula.[6]

Reliability (%R), which shows the proportion of between-subject variance in a measured population that is free from measurement error, was calculated with the widely used equation.[6]

To assess whether the variation was higher for the highest measurements than for the lowest ones, correlations between the mean values of each measurement and their corresponding standard deviations for the intra- and interobserver results were calculated.

Results

Table 3 shows the intraobserver TEM and %R for the pilot study. The intraobserver TEMs for skinfold thicknesses ranged between 0.12 and 2.9 mm, and for circumferences between 0.13 and 1.75 cm. Intraobserver reliability for skinfold thicknesses and circumferences was greater than 69 and 78%, respectively.

Table 4 shows the intraobserver TEM and %R for each anthropometric measurement obtained during the final

Table 3 Intraobserver technical errors of measurement (TEM) and coefficients of reliability (%R) for the pilot study measurements

Anthropometry	Athens		*Dortmund*		*Heraklion*		*Gent*		*Lille*	
	TEM	*%R*	*TEM*	*%R*	*TEM*	*%R*	*TEM*	*%R*	*TEM*	*%R*
Skinfold thickness (mm)										
Biceps	0.55	100.00	**1.11**	91.59	0.36	99.60	**1.40**	97.04	**1.10**	**88.95**
Triceps	0.48	100.00	0.81	97.27	0.44	99.47	0.93	98.48	**1.54**	**89.33**
Subscapular	0.34	100.00	0.76	97.12	0.24	99.83	0.91	99.29	0.57	97.92
Suprailiac	0.41	100.00	**1.01**	95.48	0.36	99.77	0.71	99.54	0.44	98.86
Thigh	0.48	100.00	**1.56**	92.09	0.85	99.30	**2.09**	93.71	0.94	98.04
Calf	0.46	100.00	0.53	98.65	0.31	99.89	0.93	99.08	0.73	97.85
Circumference (cm)										
Arm	0.27	100.00	0.27	99.09	0.16	99.83	0.13	99.94	0.46	96.08
Biceps	0.18	100.00	0.20	99.45	0.19	99.75	0.23	99.80	0.34	97.50
Waist	0.65	100.00	0.93	98.51	0.43	99.83	0.66	99.85	0.92	96.97
Hip	0.98	100.00	0.38	99.74	0.48	99.64	0.71	99.77	**1.27**	96.88
Proximal thigh	0.41	100.00	0.70	98.20	0.28	99.79	0.58	99.66	0.71	95.98

Anthropometry	*Pécs*		*Rome*		*Stockholm*		*Vienna*		*Zaragoza*	
	TEM	*%R*	*TEM*	*%R*	*TEM*	*%R*	*TEM*	*%R*	*TEM*	*%R*
Skinfold thickness (mm)										
Biceps	0.74	94.92	0.15	99.76	**1.76**	**85.62**	0.36	98.88	0.50	94.64
Triceps	**1.16**	95.72	0.12	99.96	0.68	97.22	**1.23**	92.68	0.60	97.76
Subscapular	0.75	98.17	0.32	99.75	**1.07**	**82.18**	0.98	95.18	0.47	96.96
Suprailiac	1.05	97.85	0.22	99.93	**1.33**	91.80	0.51	99.43	0.42	99.00
Thigh	0.97	98.51	0.36	99.79	**2.90**	**69.44**	**1.10**	96.30	0.75	98.73
Calf	**1.11**	97.62	0.25	99.87	**1.35**	98.87	**1.47**	97.37	0.70	97.81
Circumference (cm)										
Arm	0.22	99.56	0.18	99.62	0.20	99.18	0.22	99.55	0.26	97.84
Biceps	0.23	99.55	0.31	98.71	0.15	99.61	0.21	99.58	0.26	97.26
Waist	0.53	99.41	0.37	99.72	0.98	97.79	0.54	99.36	**1.75**	**78.43**
Hip	0.42	99.71	0.42	99.37	0.93	98.23	0.63	99.44	0.50	99.05
Proximal thigh	0.21	99.84	0.26	99.71	0.51	99.71	0.56	99.45	0.62	96.88

Boldface indicates $P<0.005$.

workshop. In general, TEMs were smaller than 1 mm for skinfold thicknesses, smaller than 1 cm for circumferences, smaller than 0.1 Ω for BIA resistance and smaller than 0.2 Ω for reactance. In most of the cases, intraobserver reliability for skinfold thicknesses was higher than 95%. The %R was greater than 97% for circumferences, whereas %R for BIA resistance was greater than 99% and for reactance higher than 97%.

In the case of the intraobserver assessment, correlation was found between means and standard deviations for skinfold thicknesses and circumferences (arm, biceps, waist), and no correlations were found for BIA. (All correlations found in the 10 cities are shown in Table 5.)

Table 6 shows the interobserver TEM and %R for skinfold thickness, circumferences and BIA. The interobserver TEMs for skinfold thicknesses and for circumferences ranged from 1 to 2 mm, and for BIA they were 1.16 and 1.26 Ω for resistance and reactance, respectively. Interobserver reliabilities for skinfold thicknesses and circumferences were always greater than 90%; for BIA resistance and reactance, %R was also higher than 90%.

For the interobserver assessment, correlations between means and standard deviations for skinfold thicknessess, circumferences and BIA are shown in Table 7. Significant correlations were found between the means and standard deviations in cases of the subscapular, suprailiac, thigh and calf skinfold thicknesses.

Discussion

One of the main objectives of the HELENA Cross-Sectional Study was to obtain reliable and comparable data of an important sample of European adolescents. To reach this aim, a great emphasis was put on the harmonization and standardization of measurements.

The most adequate methods for epidemiological studies with a high number of subjects are anthropometry and BIA. Reliability of body fat and fat distribution methods is extremely important to be defined.

Reliability is the degree to which within-subject variability is due to factors other than measurement error variance or

Table 4 Intraobserver technical errors of measurement (TEM) and coefficients of reliability (%R) in the final training workshop

Anthropometry	*Athens*		*Dortmund*		*Heraklion*		*Gent*		*Lille*	
	TEM	*%R*	*TEM*	*%R*	*TEM*	*%R*	*TEM*	*%R*	*TEM*	*%R*
Skinfold thickness (mm)										
Biceps	0.24	99.97	0.66	96.30	0.34	98.26	0.77	94.75	0.70	98.52
Triceps	0.23	99.83	0.53	98.98	0.43	99.05	0.41	99.28	0.51	98.76
Subscapular	0.75	97.36	0.79	98.10	0.41	98.82	0.67	98.06	0.56	98.81
Suprailiac	0.30	99.59	0.67	97.43	0.34	99.56	0.64	98.58	0.66	98.34
Thigh	0.45	98.08	0.79	98.36	0.63	98.86	**1.09**	97.52	0.82	98.62
Calf	0.35	98.26	0.63	98.72	0.27	99.52	0.46	99.59	0.86	98.66
Circumference (cm)										
Arm	0.19	99.81	0.15	99.89	0.20	99.60	0.14	99.90	0.26	99.67
Biceps	0.19	99.83	0.20	99.82	0.34	99.65	0.17	99.91	0.14	99.70
Waist	0.29	99.85	0.48	99.54	0.84	99.63	0.30	99.95	0.81	99.96
Hip	0.17	99.96	0.63	99.48	0.62	98.55	0.41	99.88	0.70	99.12
Proximal thigh	0.35	99.74	0.56	99.29	0.33	98.64	0.32	99.63	0.79	98.93
Bioelectrical impedance (Ω)										
Resistance	0.04	99.88	0.06	99.74	0.08	99.55	0.06	99.73	0.06	99.75
Reactance	0.05	99.39	0.06	99.24	0.14	98.19	0.08	98.76	0.06	99.34

Anthropometry	*Pécs*		*Rome*		*Stockholm*		*Vienna*		*Zaragoza*	
	TEM	*%R*	*TEM*	*%R*	*TEM*	*%R*	*TEM*	*%R*	*TEM*	*%R*
Skinfold thickness (mm)										
Biceps	0.14	99.74	0.42	98.49	**1.55**	86.64	0.65	99.06	0.29	99.40
Triceps	0.40	98.44	0.36	99.62	0.75	98.26	0.49	99.33	0.49	99.27
Subscapular	0.19	99.71	0.26	99.85	0.70	97.83	0.23	99.80	0.27	99.87
Suprailiac	0.35	99.04	**1.20**	97.31	0.70	98.02	0.66	97.64	0.67	99.14
Thigh	0.19	99.73	0.81	99.00	**1.06**	97.93	0.28	99.01	0.54	99.77
Calf	0.21	99.90	0.42	99.81	**1.05**	98.45	0.45	99.64	0.78	99.08
Circumference (cm)										
Arm	0.19	99.81	0.20	99.82	0.44	99.03	0.17	99.85	0.25	99.73
Biceps	0.15	99.89	0.13	99.82	0.91	99.15	0.17	99.86	0.15	99.90
Waist	0.25	99.73	0.60	99.97	0.92	97.93	0.59	99.94	0.42	99.87
Hip	0.17	99.96	0.59	99.54	0.41	98.78	0.63	99.53	0.30	99.97
Proximal thigh	0.32	99.63	0.51	99.22	0.61	99.62	0.44	99.14	0.49	99.61
Bioelectrical impedance (Ω)										
Resistance	0.05	99.83	0.02	99.97	0.07	99.64	0.03	99.93	0.07	99.68
Reactance	0.06	99.45	0.05	99.57	0.12	97.59	0.03	99.82	0.06	99.09

Boldface indicates $P<0.005$.

physiological variation. The lower the variability between repeated measurements of the same subject by one (intra-observer differences) or two or more (interobserver differences) observers, the greater is the precision. The most commonly used measures of precision are TEM and the coefficient of reliability (R).[6,7,11–13] R reveals the proportion of between-subject variance in a measured population that is free from measurement error. Measures of R can be used to compare the relative reliability of different anthropometric measurements as well as of the same measurements in different age groups, and to estimate sample size requirements in anthropometric surveys. A generous allowance for measurement error might be up to 10% of the observed variance; this is equivalent to an R value of 90% or more. Although this might be an acceptable lower limit, even at R values of approximately 95%, there is occasional gross measurement error, which is likely to have important consequences. Only when R is in the region of 99% is such error unlikely. Acceptable levels of measurement error are difficult to ascertain because TEM is related to the anthropometric characteristics of the group or population under investigation. However, $R>95\%$ should be sought where possible.

Another form of unreliability is undependability. This is because of variation in some biological characteristic of the individual being measured, which results in variation in the measurement, even if the technique used is exactly replicated each time. Size of skinfold measurement in any individual may vary according to the duration and level of compression during measurement, which can vary according to the level of tissue hydration. It has been suggested that there are two components for skinfold compressibility:

Table 5 Correlations between means and standard deviations for the intraobserver reliability study during the final workshop, for skinfold thickness, circumference and bioelectrical impedance analysis (BIA)

Anthropometry	*Athens*		*Dortmund*		*Heraklion*		*Gent*		*Lille*	
	r	P	*r*	P	*r*	P	*r*	P	*r*	P
Skinfold thickness (mm)										
Biceps	0.111	0.760	**0.766**	**0.010**	0.292	0.412	**0.789**	**0.006**	0.544	0.104
Triceps	0.227	0.529	0.648	0.043	0.618	0.057	0.145	0.689	0.102	0.779
Subscapular	0.703	0.023	**0.953**	**0.000**	**0.678**	**0.031**	**0.931**	**0.000**	0.754	0.012
Suprailiac	**0.859**	**0.001**	0.713	0.021	0.595	0.069	**0.872**	**0.001**	0.220	0.542
Thigh	0.425	0.221	**0.880**	**0.001**	0.218	0.431	**0.861**	**0.001**	0.687	0.028
Calf	0.405	0.246	**0.789**	**0.007**	0.041	0.909	0.661	0.037	0.766	0.010
Circumference (cm)										
Arm	0.753	0.012	0.424	0.222	0.193	0.594	0.521	0.122	0.621	0.056
Biceps	0.516	0.127	0.115	0.752	0.294	0.409	0.265	0.460	0.252	0.482
Waist	0.384	0.273	0.258	0.472	0.045	0.901	0.395	0.258	0.255	0.478
Hip	0.403	0.248	0.461	0.179	0.338	0.339	0.178	0.623	0.132	0.716
Proximal thigh	0.148	0.683	0.048	0.895	0.129	0.723	0.346	0.327	0.701	0.024
Bioelectrical impedance (Ω)										
Resistance	0.220	0.542	0.105	0.773	0.614	0.059	0.207	0.567	0.096	0.791
Reactance	0.164	0.651	0.108	0.767	0.542	0.106	0.453	0.189	0.387	0.269
Anthropometry	*Pécs*		*Rome*		*Stockholm*		*Vienna*		*Zaragoza*	
	r	P	*r*	P	*r*	P	*r*	P	*r*	P
Skinfold thickness (mm)										
Biceps	0.040	0.912	0.343	0.331	0.805	0.005	0.478	0.163	0.462	0.179
Triceps	0.076	0.835	**0.947**	**0.000**	0.132	0.716	0.177	0.624	**0.871**	**0.001**
Subscapular	0.419	0.228	0.264	0.461	0.412	0.236	0.054	0.883	0.113	0.757
Suprailiac	0.107	0.768	**0.844**	**0.002**	0.320	0.368	0.087	0.811	**0.923**	**0.000**
Thigh	0.173	0.632	**0.836**	**0.003**	0.038	0.916	0.456	0.217	0.341	0.335
Calf	0.147	0.685	**0.936**	**0.000**	0.751	0.012	0.019	0.959	**0.956**	**0.000**
Circumference (cm)										
Arm	0.753	0.012	**0.774**	**0.009**	0.062	0.866	0.751	0.012	**0.769**	**0.009**
Biceps	**0.774**	**0.009**	0.315	0.375	0.077	0.833	0.173	0.632	0.298	0.403
Waist	**0.769**	**0.009**	0.178	0.623	0.032	0.931	0.130	0.721	0.354	0.315
Hip	0.403	0.248	0.105	0.773	0.430	0.215	0.302	0.397	0.204	0.571
Proximal thigh	0.346	0.327	0.059	0.872	0.113	0.756	0.067	0.853	0.111	0.761
Bioelectrical impedance (Ω)										
Resistance	0.019	0.958	0.111	0.761	0.166	0.646	0.133	0.715	0.348	0.324
Reactance	0.426	0.220	0.481	0.160	0.500	0.141	0.000	1.000	0.481	0.159

Boldface indicates $P<0.005$.

dynamic and static. Dynamic compressibility is probably due to the expulsion of water from the subcutaneous tissue, whereas static compressibility is a function of the tension and thickness of the skin and subcutaneous tissue, as well as the distribution of fibrous tissue and blood vessels. Skinfold thicknesses are affected by individual and regional differences in compressibility that vary with age, gender and recent weight loss. When a skinfold thickness is measured, the pressure exerted by the calipers displaces some extracellular fluid. In addition, pressure from skinfold calipers may force some adipose tissue lobules to slide into areas of lesser pressure; this sliding may be more marked for thick skinfolds in which the adipose tissue contains little connective tissue. The conformist view is that intersite and intersubject differences in skinfold compressibility reduce the utility of skinfold thicknesses. However, if variations in compressibility reflect differences in the fluid content of uncompressed skinfolds, the reduction of these differences by compression might increase the validity of skinfold thicknesses as measures of regional fatness.

Anthropometry and BIA measurements are relatively simple techniques that have correlation with the amount of body fat;[14–16] therefore, they are widely used in epidemiological studies.[15–18] BIA aims to estimate the total body water, and then the fat-free mass. Therefore, the result of the measurement can be influenced by the water regime of the subject.

Anthropometric measurement error is unavoidable and should be minimized by paying close attention to every aspect of the data collection process. Regardless of the

Table 6 Interobserver technical errors of measurement (TEM) and coefficients of reliability (%R) for the measurements obtained during the final workshop

Anthropometry	*TEM*	*%R*
Skinfold thickness (mm)		
Biceps	1.17	90.31
Triceps	1.45	90.71
Subscapular	1.08	91.13
Suprailiac	1.23	95.89
Thigh	1.96	91.57
Calf	1.28	92.28
Circumference (cm)		
Arm	1.01	90.09
Biceps	1	90.8
Waist	1.69	90.52
Hip	1.45	95.87
Thigh	1.62	90.88
Bioelectrical impedance analysis (Ω)		
Resistance	1.26	90.1
Reactance	1.16	90.3

Table 7 Correlations between means and standard deviations for the interobserver reliability study during the final workshop, for skinfold thickness, circumference and bioelectrical impedance analysis (BIA)

	r	P-*value*
Skinfold thickness (mm)		
Biceps	0.185	0.065
Triceps	0.231	0.021
Subscapular	**0.031**	**0.001**
Suprailiac	**0.420**	**0.000**
Thigh	**0.309**	**0.002**
Calf	**0.400**	**0.000**
Circumference (cm)		
Arm	0.128	0.205
Biceps	0.257	0.010
Waist	0.064	0.529
Hip	0.070	0.487
Proximal thigh	0.110	0.278
Bioelectrical Impedance (Ω)		
Resistance	0.225	0.025
Reactance	0.250	0.012

Interobserver correlations between means and standard deviations for skinfold thickness, circumference and BIA. Boldface indicates $P<0.005$.

measurement made and the size of the error, it is better to know the size of error, as this will not only determine the confidence one has in the different measurements made, but will also influence the interpretation of anthropometric data collected. It is also recommended that replicate measurements of anthropometric variables be made.

In HELENA's pilot study, the intraobserver TEM values for skinfolds and circumferences were frequently above, whereas %R was below the required levels. On the basis of these results, it was decided to improve the researchers' technique and to measure the intraobserver TEMs again in a final workshop. At the end of the standardization process, the intra- and interobserver TEMs and %R for skinfold thicknesses, circumferences and BIA were better than the required levels, assuring the comparability of the data obtained in different cities.

So far, there has not been any study in Europe aiming to determine the nutritional status and body composition of adolescents. In the framework of the AVENA Study, 101 Spanish 16-year-old adolescents were measured in the anthropometric reliability study. In this study, TEMs for skinfolds and circumferences were less than 1, and %R was greater than 95%.[5]

For skinfold thicknesses, other authors (reviewed by Ulijaszek and Kerr[6]) reported interobserver reliabilities ranging from 49 to 98% for biceps, 48 to 99% for triceps, 60 to 99% for subscapular, 56 to 97% for suprailiac and 81 to 99% for calf skinfold. Interobserver reliabilities for circumferences observed by other authors (reviewed by Ulijaszek and Kerr[6]) ranged from 94 to 100% for arm, 86 to 99% for waist and 68 to 99% for hip circumference. Interobserver error is a major issue in measuring skinfolds. Standardized methodology, including positioning of the instrument and the subject, a well-trained data collector and practicing until results are consistent, can increase reproducibility. Special attention to locating the site, grasping the skin and assuring that the caliper is at a 90-degree angle relative to the grasped skinfold are essentials for high reproducibility. Circumferences are more reliable than skinfolds, and they can always be measured regardless of body size and fatness. Reproducibility of circumferences can be increased by giving special attention to positioning of the subject, using anatomic landmarks to locate measuring sites, taking readings in millimeters with the tape measure directly in contact with the subject's skin without compression, and keeping the tape at 90° to the long axis of the region of the body under the measured circumference.

Anthropometric measurement error cannot be avoided but should be minimized as much as possible by paying close attention to every aspect of the data collection process. Conducting reliable measurements of body fat and fat distribution are important in epidemiological surveys. The training in Zaragoza (Spain), the pilot study and workshop in Pécs (Hungary) were necessary and successful for harmonizing the anthropometric measurements in the HELENA Cross-Sectional Study. There was a significant improvement in the intraobserver reliability for all the measurements, with interobserver reliability being higher than 90% for most of the measurements. The performed harmonization process assured the comparability of the anthropometric data from the 10 European cities.

Acknowledgements

The authors thank all the adolescents who took part in the first training workshop in the Zaragoza (IES Grande Covián, Zaragoza, Spain) pilot study in all the 10 European cities, and especially those from the Bártfa Street Elementary School (Pécs, Hungary) who participated in the second intra- and interobserver assessments. The HELENA Study took place with the financial support of the European Community Sixth RTD Framework Programme (Contract FOOD-CT-2005-007034). The contents of this article reflect only the authors' views, and the European Community is not liable for any use that may be made of the information contained therein. F.B.O. is supported by CSD (Ref: 109/UPB31/03 and 13/UPB20/04) and the FPU-Spanish Ministry of Education (Ref: AP-2004-2745) grants. The researchers from the University of Zaragoza, Spain (G.V.-R. and L.A.M.) are complementarily supported by FUNDACIÓN MAPFRE (Spain).

Conflict of interest

The authors state no conflict of interest.

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