



**HAL**  
open science

## Is the 1975 Reference Man still a suitable reference?

Manfred J. Müller, Wiebke Later, A Bosy-Westphal, Elke Kossel, Claus-C. Glüer, Martin Heller

► **To cite this version:**

Manfred J. Müller, Wiebke Later, A Bosy-Westphal, Elke Kossel, Claus-C. Glüer, et al.. Is the 1975 Reference Man still a suitable reference?. *European Journal of Clinical Nutrition*, 2010, 10.1038/ejcn.2010.125 . hal-00560304

**HAL Id: hal-00560304**

**<https://hal.science/hal-00560304>**

Submitted on 28 Jan 2011

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

## Is the 1975 Reference Man still a suitable reference?

Wiebke Later <sup>1</sup>(PhD), Anja Bosy-Westphal <sup>1</sup>(PhD), Elke Kossel <sup>2</sup> (PhD), Claus-C. Glüer <sup>2</sup> (MD), Martin Heller <sup>3</sup> (MD), and Manfred J. Müller<sup>1</sup> (MD)

<sup>1</sup> Institute of Human Nutrition and Food Science, Christian-Albrechts University, Kiel, Germany

<sup>2</sup> Division of Medical Physics, Clinic for diagnostic radiology, University Medical Center Schleswig-Holstein, Kiel, Germany

<sup>3</sup> Clinic for Diagnostic Radiology, University Medical Center Schleswig-Holstein, Kiel, Germany

### **Corresponding author:**

Prof. Dr. med. Manfred James Müller

Institut für Humanernährung und Lebensmittelkunde

Christian-Albrechts Universität zu Kiel

Düsternbrooker Weg 17-19

D-24105 Kiel, Germany

Tel: 0431 8805670, Fax: 0431 8805679

E-Mail: [mmueller@nutrfoodsc.uni-kiel.de](mailto:mmueller@nutrfoodsc.uni-kiel.de)

Short running head title: Reference for body composition

*Funding:* DFG

1 **Background:** In 1975 a *Reference Man* for the estimation of radiation doses without  
2 adverse health effects was created. However, during the past decades considerable  
3 changes in body weight and body composition were observed and new *in vivo*  
4 technologies of body composition analysis are available. Thus, the *Reference Man*  
5 might be outdated as adequate standard to assess medication and radiation doses.

6 **Objective:** To compare body composition of an adult population with 1975  
7 *Reference Man* data **questioning its value as a suitable reference.**

8 **Methods:** Body composition was assessed in 208 healthy, Caucasian subjects (105  
9 males, 103 females) aged 18-78 years with a BMI range of 16.8-35.0 kg/m<sup>2</sup>. Fat  
10 mass (FM) and muscle mass (MM) were assessed by Dual X-ray Absorptiometry  
11 (DXA), organ masses (OM) were measured by Magnetic Resonance Imaging (MRI).

12 **Results:** There was a considerable variance in body weight and body composition.  
13 When compared with *Reference Man*, great differences in body composition were  
14 found. Men and women of the study population were heavier, taller and had more  
15 FM, MM and higher masses of brain, heart and spleen. These differences did not  
16 depend on age. Relationships between body weight and body composition were  
17 investigated by general linear regression models whereby deviations in FM, MM and  
18 heart mass disappeared, while differences in brain and spleen mass persisted.

19 **Conclusions:** **Our data indicate the need of a modern *Reference Man* and thus a re-**  
20 **calculation of medical radiation doses and medication.**

21 **Keywords:** *Reference Man*; body composition; organ mass; magnetic resonance  
22 imaging

## 23 Introduction

24 Based on the increasing exposure of humans to radiation due to occupational, public  
25 and medical reasons and procedures the „*Task Group on Reference Man*“ created a  
26 *Reference Man* and a *Reference Woman* in 1975. This was based on analyses of  
27 anatomic databases. Considering this *Reference Man* lowest radiation doses were  
28 estimated for the planning and the application of medical radiation that do not cause  
29 harm in humans (Snyder et al 1975). The *Reference Man* established quantified  
30 constraints, or limits, on individual doses from medical sources. The limitation of this  
31 approach is obvious with regard to the combination of data sets from a multitude of  
32 several studies from different countries and geographic zones all over the world,  
33 which included results of hundreds of patients at different times. A  
34 representativeness of a certain population or population group is therefore not given  
35 for the *Reference Man*. However, the statistically precise definition as average men  
36 was not the aim of the “*Task Group on Reference Man*” (Snyder et al 1975).

37 It is well known that body composition of men and women had changed since 1975  
38 and that obesity has reached epidemic proportions (Lahti-Koski et al 2009, Ogden et  
39 al 2006, Roche 1979, Wardle and Boniface 2008, World Health Organisation 2000).  
40 This is especially true in rich countries due to changes in life style, eating behaviour,  
41 living conditions and working demands. Thus, we hypothesize that the estimated  
42 radiation or medication doses based on the *Reference Man* and the *Reference*  
43 *Woman*, respectively, might no longer be reasonable and appropriate for a current  
44 population.

45 The aim of our study was to compare body composition data of the *Reference Man*  
46 from 1975 with recent data measured by state of the art *in vivo* methods in a  
47 representative healthy Caucasian population with a normal distribution of age and  
48 BMI. **Based on this comparison a re-evaluation of the *Reference Man* is intended.**

49

## 50 **Subjects and Methods**

51 The study population consisted of 208 healthy, Caucasian volunteers (103 females  
52 and 105 males) aged 18 to 78 years with a BMI range of 16.8 to 35.0 kg/m<sup>2</sup>.  
53 Participants were recruited from students and staff at the University of Kiel and by  
54 notice board postings in local supermarkets and pharmacies. All subjects were non-  
55 smokers and took no medication known to influence body composition. Subjects with  
56 splenomegaly (enlargement of the spleen > 350g) were excluded from analyses. The  
57 study protocol was approved by the local ethical committee of the Christian-  
58 Albrechts-Universität zu Kiel. Each subject provided informed written consent before  
59 participation.

60

### 61 Study protocol

62 All participants arrived at the metabolic unit of the Institute of Human Nutrition and  
63 Food Science in the morning at 0730h after an over night fast of >8h.

64

### 65 Body composition analysis

#### 66 *Anthropometrics*

67 Body height was measured to the nearest 0.5 cm with subjects in underwear and  
68 without shoes (stadiometer Seca, Vogel & Halke, Germany). Weight was assessed  
69 by an electronic scale (TANITA, Japan).

70

#### 71 *Dual-energy X-ray absorptiometry (DXA)*

72 Whole body measurement by DXA was performed using a Hologic absorptiometer  
73 (QDR 4500A, Hologic Inc., MA, USA). Scans were carried out by a licensed  
74 radiological technician. Manufactures' software (version V8.26a:3) was used for the

75 analyses of whole body and regional bone mineral content (BMC), lean soft tissue  
76 (LST) and percentage fat mass (FM). Skeletal muscle mass (MM) was calculated  
77 from the sum of appending LST (e.g.  $LST_{arms} + LST_{legs}$ ), using the formula of Kim et  
78 al. (Kim et al 2002).

79

### 80 *Magnetic resonance imaging (MRI)*

81 The volumes of 5 internal organs (brain, heart, liver, kidneys and spleen) were  
82 measured by transversal MRI images. Scans were obtained by a 1.5T scanner  
83 (Magnetom Vision Siemens, Erlangen, Germany). Brain and abdominal organs were  
84 examined by a T1-weighted sequence (FLASH) (TR: 177.8ms (abdominal organs);  
85 TR: 170.0ms (brain); TE: 4.1ms/echo). ECG-triggered, T2-weighted turbo spin-echo  
86 ultrashot scans (HASTE) (TR: 800.0ms; TE: 43ms/echo) were used to examine the  
87 heart. The slice thickness ranged from 6mm for brain (1.2mm interslice gap) to 7mm  
88 for the heart (2.1mm interslice gap) and 8mm the internal organs (2.4mm interslice  
89 gap). Cross-sectional organ areas were determined manually using a segmentation  
90 software (SliceOmatic, version 4.3, TomoVision Inc. Montreal, Canada). Volume data  
91 were transformed into organ masses using the following densities:  $1.036\text{g/cm}^3$  for  
92 brain,  $1.06\text{ g/cm}^3$  for heart and liver,  $1.05\text{ g/cm}^3$  for kidneys and  $1.054\text{ g/cm}^3$  for  
93 spleen (Duck 1990).

94

### 95 Data analysis

96 Descriptive subject data are given as means  $\pm$  SDs and range. Statistical analyses  
97 were performed using SPSS© for Windows 13.0 (SPSS Inc., Chicago, IL, USA).  
98 Deviations between means are given as percent ( $\Delta$  mean [%]) and a cut-off of <10%  
99 differences was accepted as data agreement. Influences of varying body height were  
100 analysed by comparison of within group height-tertiles in men (Group 1: <1.74m;

101 Group 2: 1.74 – 1.83m; Group 3: >1.83m) and women (Group 1: <1.64m; Group 2:  
102 1.64 – 1.72m; Group 3: >1.72m). Multiple stepwise regression analyses was used to  
103 estimate the explained variances in body composition parameters given as  $R^2$ .  
104 Values of standardized beta coefficients and SEE are presented for each of the  
105 developed regression models. Relationships between body composition and body  
106 mass or age are shown as general linear models and linear regression equation were  
107 used to calculate body composition parameters. Differences between sexes were  
108 analysed using the independent t-test. All tests were 2-tailed and a P-value <0.05  
109 was accepted as the limit of significance.

110

## 111 **Results**

### 112 **Comparison of body composition between *Reference Man* and study** 113 **population**

114 In **Table 1** body composition of the study population is compared with mean data of  
115 *Reference Man* and *Reference Woman*. When compared with the reference subjects  
116 of the study population were heavier, taller and had more FM, MM and organ masses  
117 (brain, heart (in women only), spleen). No differences were found for liver and kidney  
118 masses ( $\Delta < 10\%$ ). When compared with women men had significantly higher BMI,  
119 MM and OM and less FM ( $P < 0.01$ ) but sex had no effect on the difference between  
120 measured values and the reference. **Considering the influence of age on body**  
121 **composition a subgroup of young subjects (20 - 30 years) was compared to**  
122 ***Reference Man* and *Reference Woman* (Table 1). This approach revealed similar**  
123 **results, i.e. higher weight, FM, MM and OM (except liver and kidney mass). Also**  
124 **significant sex differences in FM, MM and OM were found ( $P < 0.01$ ).**

### 125 **Impact of age on variance in body composition**

126 In **Figure 1 A-G** age is plotted against organ and tissue masses for men (closed  
127 circles) and women (open circles). The mean age of men and women is given as  
128 continuous vertical line, while the age range of *Reference Man* and *Woman* is  
129 presented by shaded areas. Mean organ and tissue masses are given as continuous  
130 (study population) or dashed horizontal (*Reference Man* and *Woman*) line. Results of  
131 organ and tissue masses showed only small differences between the “younger”  
132 reference subjects and the “older” study population. Thus, there was no significant  
133 influence of age on the variance of the data.

#### 134 **Influence of body weight, height and age on variances on body composition**

135 Using a stepwise multiple regression analyses explained variance in body  
136 composition parameters is shown in **Table 2**. Weight, height and age were used as  
137 independent variables within different models. Except for brain mass variance in  
138 organ and tissue masses was mainly explained by body weight alone in men (FM:  
139 77%; MM: 54%; heart: 9%; liver: 43%; kidneys: 16%) and in women (FM: 81%; MM:  
140 35%; heart: 14%; liver: 36%; kidneys: 24%; spleen: 18%). In addition, body height  
141 explained further variance in FM (men: 2%; women: 7%), MM (women: 6%), liver  
142 (women: 4%) and kidneys (men: 4%). Furthermore, age contributed significantly to  
143 explained variance in MM (5%) and spleen mass (8%) in men, and in variance in  
144 brain (4%) and spleen mass (5%) in women. **No significant correlation were found**  
145 **between body weight and age, both in men and women (data not shown)**. Based on  
146 the significant contribution of body height to the variance in body composition (**Table**  
147 **2**) the study population was categorized into body height-tertiles to analyse  
148 differences between actual and reference data (**Table 3**). When compared to tall  
149 subjects deviations between measured data and *Reference Man* and *Reference*  
150 *Woman*, respectively, in weight, height, MM (and FM in men) were lower for smaller  
151 people (Group 1). In addition, brain, heart and spleen mass (and kidney mass in

152 men) of smaller subjects showed the highest agreement with the *Reference Man* and  
153 *Reference Woman*. In general, most body composition data were consistent to  
154 reference data ( $\Delta < 10\%$ ) in small men and women when compared with taller  
155 subjects (Group 2 and 3) showing a higher difference in weight, height, FM, MM,  
156 brain, heart and spleen mass (and liver and kidney mass in men) (**Table 3**). Within  
157 different height-tertiles these findings were also true in young subjects (20 - 30 years)  
158 (data not shown).

### 159 **Relationship between body mass and organ / tissue masses**

160 The relationship between body weight and organ / tissue masses is given in **Figure 2**  
161 **A-G**. The mean body weight of *Reference Man* (70 kg) and *Reference Woman* (58  
162 kg) is shown as dashed vertical line within the figures. A horizontal line is presenting  
163 the calculated tissue mass for the reference subjects using the regression equations  
164 given in **Table 4**. For both sexes highest  $R^2$  were found between fat mass and body  
165 mass (men  $R^2 = 0.88$ ; women  $R^2 = 0.89$ ;  $p < 0.01$ ) while a weak or no relationship was  
166 seen between body mass and brain mass (men  $R^2 = 0.21$ ,  $P < 0.05$ ; women  $R^2 = ns$ ).

### 167 **Calculation of organ and muscle mass based on body mass**

168 Linear regression equations calculated from the relationship between body mass and  
169 body composition (**Figure 2 A-G**) are presented in **Table 4**. Based on these  
170 regression equations the masses of brain, heart, liver, kidneys and spleen, fat and  
171 muscle were calculated for a man (with a body weight of 70 kg  $\approx$  body weight of the  
172 *Reference Man*) and a woman (with a body weight of 58 kg  $\approx$  body weight of the  
173 *Reference Woman*), respectively. The estimated tissue masses of the study  
174 population (measured by MRI and DXA) and the reference subjects (autopsy data)  
175 with identical body weights were compared. There were considerable differences in  
176 brain and spleen mass (and MM in women) with an overestimation of these masses

177 in reference subjects. By contrast, FM and liver mass in men and kidney mass in  
178 women were underestimated in *Reference Man* and *Reference Woman*, respectively.

179

## 180 **Discussion**

181 The primary purpose of this study was to compare reference data from 1975 with  
182 recent database based on *in vivo* measurements of body composition in a greater  
183 group of healthy subjects. Considerable differences in body composition were found,  
184 with today's men and women being heavier, taller and having more FM and MM when  
185 compared with *Reference Man* and *Reference Woman*, respectively. Furthermore,  
186 organ masses of brain, heart and spleen of the study population differed. These  
187 findings were independent of age and gender. Accounting for differences in body  
188 weight deviations in FM, MM (for men only) and heart mass disappeared whereas  
189 differences in brain and spleen mass remained. Comparing different height groups  
190 revealed highest agreement in body composition for small people while taller  
191 subjects showed higher percentage deviations. The latter finding is in line with data  
192 of Heymsfield et al. (Heymsfield et al 2007).

193 Differences in body composition between actual data and the 1975 reference  
194 subjects may be partly caused by methodical issues. While in the present study  
195 masses of internal organs have been measured *in vivo* using MRI, data of the  
196 *Reference Man* were based on autopsy post-mortem analyses and organ weighing,  
197 i.e. the organs were removed from the body followed by exclusion of remaining tissue  
198 before weighing. It is well known that during the first 15 minutes after extraction from  
199 the body the organ loses significant weight. On the other hand considerable  
200 differences in *in vivo* organ weight estimates might be due to segmentation  
201 techniques. E.g., analysing brain mass cerebrospinal fluid has been excluded by  
202 manual slice segmentation. In accordance, gallbladder, portal vein and other big

203 blood vessels were excluded from the liver mass which were included within post-  
204 mortem organ weighing. Thus, organ masses of *Reference Man* und *Reference*  
205 *Woman* might not resemble metabolic active organ mass, but remaining fluid within  
206 the organ and thus add to systematic differences between results of the two  
207 measurement procedures.

208 Comparing MM as assessed in autopsy studies with MM measured by DXA also  
209 implicates method-based inaccuracies. DXA has a great precision of soft tissue  
210 composition measurement although it includes some assumptions which should be  
211 taken into account, e.g. constant attenuation of fat mass (Lohman and Chen 2005).  
212 Another assumption is that DXA-measurements are not affected by the  
213 anteroposterior thickness of the human body. However, previous studies found  
214 slightly overestimated fat and lean masses due to thickness less than 20cm (Laskey  
215 et al 1992). In addition, the accuracy of DXA may differ with tissue. E.g., in the thorax  
216 DXA has limits to distinguish between bone and soft tissue, thus, estimations of  
217 thoracic composition tend to be imprecise (Roubenoff et al 1993). However,  
218 advances of the DXA technique prevail. In research and clinical settings DXA is a  
219 non-invasive, accurate and reproducible tool for assessing body composition with  
220 minimal radiation doses superior to many other method (Brownbill and Ilich 2005,  
221 Gately et al 2003, Slosman et al 1992). There are high correlations between DXA  
222 and Computer Tomography (CT) estimates of lean mass and MM (Visser et al 1999).  
223 However, there may be a small influence of different measurement techniques on  
224 deviations found in *in vivo* body composition and the *Reference Man*.

225 We hereby present data of a large homogeneous Caucasian study population with a  
226 wide range in age and BMI (18-78 years, 16.8-35.0 kg/m<sup>2</sup>). Due to the limited  
227 recruitment area of our sample we do not consider our data as representative. To get  
228 an idea we compared our data to the dataset of the second national nutrition survey

229 (NVSII) conducted by the Federal Research Centre for Nutrition and Food in  
230 Germany (Max Rubner Institute 2008). High agreements were found in BMI (men:  
231 26.9kg/m<sup>2</sup> vs. 26.4kg/m<sup>2</sup>; women: 26.1kg/m<sup>2</sup> vs. 24.4kg/m<sup>2</sup>) and body weight (men:  
232 84.6kg vs. vs. 84.3kg; women: 69.9kg vs. 68.7kg) (Max Rubner Institute 2008). Thus,  
233 with respect to BMI our study population was similar to the representative NVSII  
234 population.

235 Our body composition data were also compared with previous detailed *in vivo* body  
236 composition studies on smaller populations. In these studies, FM, MM and OM were  
237 measured using the same *in vivo* methods, e.g. DXA, MRI or CT (Bosy-Westphal et  
238 al 2004, Gallagher et al 1998, Sparti et al 1997). When compared with these previous  
239 BCA data, men and women of our study population were older, had slightly higher  
240 body weights and FM compared to other populations (Gallagher et al 1998, Sparti et  
241 al 1997). Excluding subjects >50 years from our present analysis, weight, BMI, FM  
242 and MM were in good agreement with previous data (Bosy-Westphal et al 2004,  
243 Gallagher et al 1998, Sparti et al 1997). In addition, differences in liver and kidneys  
244 masses (Gallagher et al 1998) might be explained by methodical differences in  
245 different segmentation procedures. Contrary to previous data in the present study  
246 renal pelvis and portal vein were not included within the calculation of organ volume.  
247 Taken as a whole we found good agreements between our estimates of body  
248 composition and the results of previous studies.

249 When compared with data observed in Caucasians, ethnic differences in body  
250 composition have been reported (Gasperino 1996, Rahman et al 2009): Afro-  
251 Americans have more bone mass and MM, but less OM and FM than Caucasians  
252 (Aloia et al 1999, Gallagher et al 2006, Weinsier et al 2001, Wu et al 2007). These  
253 differences remained after controlling for differences in age, weight, and height  
254 (Gasperino 1996). When compared with the *Reference Man* from 1975, Afro-

255 Americans had higher FM (+0.6kg - +10.8kg) (Aloia et al 1999, Gallagher et al 2006,  
256 Weinsier et al 2001). Concomitantly, MM was considerably higher (+7kg) in black  
257 women when compared with the *Reference Woman* (Aloia et al 1999). Race-  
258 dependent differences in body composition argue in favour to develop a *Reference*  
259 *Men* and a *Reference Women* for various ethnic groups.

260 In conclusion, we found considerable differences in current *in vivo* estimates of body  
261 composition and *Reference Man* and *Reference Woman*, with present men and  
262 women being heavier, taller and having higher FM and MM. Substantial differences  
263 were also found for OM of brain, heart and spleen, whereas no difference occurred  
264 for liver and kidney mass in both gender. Comparing subjects with identical body  
265 weight deviations in FM, MM (only in men) and heart mass disappeared whereas  
266 differences in brain and spleen mass persisted. Considering different height groups  
267 revealed lowest deviations to reference values for small people (men < 1.74m;  
268 women < 1.64m).

269 Based on considerable differences in body composition between the present results  
270 and the 1975 *Reference Man* a modern *Reference Man* is needed as a basis to  
271 estimate accurate medical radiation doses and to calculate medication application  
272 (e.g. doses of drugs).

273

#### 274 **Acknowledgements**

275 Authors contributions: Data collection (WL, ABW), data analysis (WL, ABW), writing  
276 of the manuscript (WL, ABW, MJM), study design (ABW, MJM), DXA and MRI  
277 protocol (EK, CCG, MH). There are no conflicts of interest.

## References

Aloia JF, Vaswani A, Mikhail M, Flaster ER (1999). Body composition by dual-energy X-ray absorptiometry in black compared with white women. *Osteoporos Int* **10**: 114-119.

Bosy-Westphal A, Reinecke U, Schlorke T, Illner K, Kutzner D, Heller M *et al* (2004). Effect of organ and tissue masses on resting energy expenditure in underweight, normal weight and obese adults. *Int J Obes Relat Metab Disord* **28**: 72-79.

Brownbill RA, Ilich JZ (2005). Measuring body composition in overweight individuals by dual energy x-ray absorptiometry. *BMC Med Imaging* **5**: 1.

Duck FA (1990). *Physical properties of tissue* Academic Press: New York.

Gallagher D, Belmonte D, Deurenberg P, Wang Z, Krasnow N, Pi-Sunyer FX *et al* (1998). Organ-tissue mass measurement allows modeling of REE and metabolically active tissue mass. *Am J Physiol* **275**: E249-258.

Gallagher D, Albu J, He Q, Heshka S, Boxt L, Krasnow N *et al* (2006). Small organs with a high metabolic rate explain lower resting energy expenditure in African American than in white adults. *Am J Clin Nutr* **83**: 1062-1067.

Gasperino J (1996). Ethnic differences in body composition and their relation to health and disease in women. *Ethn Health* **1**: 337-347.

Gately PJ, Radley D, Cooke CB, Carroll S, Oldroyd B, Truscott JG *et al* (2003). Comparison of body composition methods in overweight and obese children. *J Appl Physiol* **95**: 2039-2046.

Heymsfield SB, Gallagher D, Mayer L, Beetsch J, Pietrobelli A (2007). Scaling of human body composition to stature: new insights into body mass index. *Am J Clin Nutr* **86**: 82-91.

Kim J, Wang Z, Heymsfield SB, Baumgartner RN, Gallagher D (2002). Total-body skeletal muscle mass: estimation by a new dual-energy X-ray absorptiometry method. *Am J Clin Nutr* **76**: 378-383.

Lahti-Koski M, Seppanen-Nuijten E, Mannisto S, Harkanen T, Rissanen H, Knekt P *et al* (2009). Twenty-year changes in the prevalence of obesity among Finnish adults. *Obes Rev*.

Laskey MA, Lyttle KD, Flaxman ME, Barber RW (1992). The influence of tissue depth and composition on the performance of the Lunar dual-energy X-ray absorptiometer whole-body scanning mode. *Eur J Clin Nutr* **46**: 39-45.

Lohman TG, Chen Z (2005). Dual-Energy X-Ray Absorptiometry. In: Heymsfield SB, T.G. L, Wang Z, Going SB (eds). *Human Body Composition*. Human Kinetics: Champaign.

Max Rubner Institute FRCfNaF. Ergebnisbericht Teil 1, Nationale Verzehrsstudie II. Karlsruhe, 2008.

Ogden CL, Carroll MD, Curtin LR, McDowell MA, Tabak CJ, Flegal KM (2006). Prevalence of overweight and obesity in the United States, 1999-2004. *JAMA* **295**: 1549-1555.

Rahman M, Temple JR, Breitkopf CR, Berenson AB (2009). Racial differences in body fat distribution among reproductive-aged women. *Metabolism* **58**: 1329-1337.

Roche AF (1979). Secular trends in human growth, maturation, and development. *Monogr Soc Res Child Dev* **44**: 1-120.

Roubenoff R, Kehayias JJ, Dawson-Hughes B, Heymsfield SB (1993). Use of dual-energy x-ray absorptiometry in body-composition studies: not yet a "gold standard". *Am J Clin Nutr* **58**: 589-591.

Slosman DO, Casez JP, Pichard C, Rochat T, Fery F, Rizzoli R *et al* (1992). Assessment of whole-body composition with dual-energy x-ray absorptiometry. *Radiology* **185**: 593-598.

Snyder WS, Cook MJ, Nasset ES, Karhausen LR, Howells GP, Tipton IH (1975). *Report of the Task Group on Reference Man*. Pergamon Press: Oxford.

Sparti A, DeLany JP, de la Bretonne JA, Sander GE, Bray GA (1997). Relationship between resting metabolic rate and the composition of the fat-free mass. *Metabolism* **46**: 1225-1230.

Visser M, Fuerst T, Lang T, Salamone L, Harris TB (1999). Validity of fan-beam dual-energy X-ray absorptiometry for measuring fat-free mass and leg muscle mass. Health, Aging, and Body Composition Study--Dual-Energy X-ray Absorptiometry and Body Composition Working Group. *J Appl Physiol* **87**: 1513-1520.

Wardle J, Boniface D (2008). Changes in the distributions of body mass index and waist circumference in English adults, 1993/1994 to 2002/2003. *Int J Obes (Lond)* **32**: 527-532.

Weinsier RL, Hunter GR, Gower BA, Schutz Y, Darnell BE, Zuckerman PA (2001). Body fat distribution in white and black women: different patterns of intraabdominal and subcutaneous abdominal adipose tissue utilization with weight loss. *Am J Clin Nutr* **74**: 631-636.

World Health Organisation (2000). Obesity: preventing and managing the global epidemic. *Report of a WHO consultation on Obesity*. WHO Technical Report Series Geneva.

Wu CH, Heshka S, Wang J, Pierson RN, Jr., Heymsfield SB, Laferrere B *et al* (2007). Truncal fat in relation to total body fat: influences of age, sex, ethnicity and fatness. *Int J Obes (Lond)* **31**: 1384-1391.

## Figure legends

**Figure 1 A-E** Age-dependent changes in masses of brain (A), heart (B), liver (C), kidneys (D), spleen (E), skeletal muscle (F) and fat mass (G) for women (open circles) and men (closed circles). Mean tissue and organ masses are shown as horizontal line for reference subjects (dashed) and for men and women of the study population (continuous).

**Figure 2 A-E** Weight-dependent changes in masses of brain (A), heart (B), liver (C), kidneys (D), spleen (E), skeletal muscle (F) and fat mass (G) for women (open circles) and men (closed circles). Weight of *reference woman* (58kg) and *reference man* (70kg) is shown as dashed vertical line and the calculated organ mass as dashed horizontal line.

**Table 1** Comparison of body composition between the study population (n = 208) and younger subjects (n= 63) [mean  $\pm$  SD, range] and the *reference man* and *reference woman* from 1975 [mean]

	<b>men</b>	<b>(n = 105)</b>	<b>young men</b>	<b>(n = 26)</b>	<b>reference man <sup>1</sup></b>	<b>vs. men</b>	<b>vs. young men</b>
	<b>mean <math>\pm</math> SD</b>	<b>range</b>	<b>mean <math>\pm</math> SD</b>	<b>range</b>	<b>mean</b>	<b><math>\Delta</math> mean [%]</b>	<b><math>\Delta</math> mean [%]</b>
<b>age</b> [years]	45.4 $\pm$ 15.3	18 - 72	26.7 $\pm$ 2.4	20 - 30	20 - 30		
<b>weight</b> [kg]	84.3 $\pm$ 13.0 *	58.2 - 116.8	78.1 $\pm$ 13.2 <sup>†</sup>	58.2 - 107.8	70	+ 20.4	+ 11.6
<b>height</b> [m]	1.79 $\pm$ 0.06 *	1.61 - 1.95	1.78 $\pm$ 0.06 <sup>†</sup>	1.68 - 1.89	1.70	+ 5.3	+ 4.8
<b>BMI</b> [kg/m <sup>2</sup> ] <sup>2</sup>	26.4 $\pm$ 3.7 *	18.3 - 34.9	24.5 $\pm$ 3.3	19.0 - 34.3	24.2	+ 9.1	+ 1.4
<b>FM</b> [kg] <sup>3</sup>	18.8 $\pm$ 8.2 *	4.3 - 43.7	14.5 $\pm$ 7.7 <sup>†</sup>	4.3 - 29.5	13.5	+ 39.3	+ 8.0
<b>MM</b> [kg] <sup>4</sup>	31.9 $\pm$ 3.7 *	22.1 - 39.6	31.6 $\pm$ 3.7 <sup>†</sup>	26.1 - 39.6	28	+ 13.9	+ 12.7
<b>brain</b> [g]	1606 $\pm$ 100 *	1343 - 1872	1613 $\pm$ 94 <sup>†</sup>	1469 - 1872	1400	+ 14.7	+ 15.2
<b>heart</b> [g]	357 $\pm$ 76 *	211 - 631	366 $\pm$ 82 <sup>†</sup>	283 - 567	330	+ 8.4	+ 11.2
<b>liver</b> [g]	1708 $\pm$ 291 *	1048 - 2466	1602 $\pm$ 261 <sup>†</sup>	1161 - 2290	1800	- 6.2	- 11.0
<b>kidneys</b> [g]	326 $\pm$ 58 *	202 - 488	312 $\pm$ 60 <sup>†</sup>	202 - 443	310	+ 5.2	+ 0.9
<b>spleen</b> [g]	24 $\pm$ 67 *	86 - 347	263 $\pm$ 55 <sup>†</sup>	174 - 347	180	+ 34.4	+ 46.3
	<b>women</b>	<b>(n = 103)</b>	<b>young women</b>	<b>(n = 37)</b>	<b>reference woman <sup>1</sup></b>	<b>vs. women</b>	<b>vs. young women</b>
	<b>mean <math>\pm</math> SD</b>	<b>range</b>	<b>mean <math>\pm</math> SD</b>	<b>range</b>	<b>mean</b>	<b><math>\Delta</math> mean [%]</b>	<b><math>\Delta</math> mean [%]</b>
<b>age</b> [years]	41.2 $\pm$ 15.4	22 - 78	25.5 $\pm$ 1.8	20 - 30	20 - 30		
<b>weight</b> [kg]	68.7 $\pm$ 11.3	44.0 - 97.1	67.4 $\pm$ 11.3	44.7 - 97.1	58	+ 18.4	+ 16.2
<b>height</b> [m]	1.68 $\pm$ 0.06	1.48 - 1.83	1.69 $\pm$ 0.06	1.54 - 1.83	1.60	+ 5.0	+ 6.2
<b>BMI</b> [kg/m <sup>2</sup> ] <sup>2</sup>	24.4 $\pm$ 3.9	16.8 - 34.3	23.3 $\pm$ 3.7	16.8 - 33.3	22.7	+ 7.5	+ 2.8
<b>FM</b> [kg] <sup>3</sup>	22.9 $\pm$ 8.8	4.2 - 50.8	20.8 $\pm$ 8.6	8.5 - 50.9	16	+ 43.1	+ 30.2
<b>MM</b> [kg] <sup>4</sup>	21.2 $\pm$ 2.9	15.2 - 29.7	21.7 $\pm$ 2.9	16.2 - 28.2	17	+ 24.1	+ 27.5
<b>brain</b> [g]	1428 $\pm$ 95	1239 - 1689	1456 $\pm$ 98	1248 - 1689	1200	+ 19.0	+ 21.4
<b>heart</b> [g]	267 $\pm$ 60	172 - 437	261 $\pm$ 60	172 - 401	240	+ 11.5	+ 8.7
<b>liver</b> [g]	1422 $\pm$ 236	944 - 2165	1433 $\pm$ 219	944 - 1918	1400	+ 1.6	+ 2.3
<b>kidneys</b> [g]	255 $\pm$ 47	159 - 366	254 $\pm$ 49	161 - 350	275	- 8.2	- 8.5
<b>spleen</b> [g]	193 $\pm$ 58	82 - 334	194 $\pm$ 56	103 - 334	150	+ 28.8	+ 29.8

significant differences between sexes (t-test), \* study population, † younger subjects (20 - 30 years),  $P < 0.01$ , <sup>1</sup> Snyder et al., Report of the Task Group on Reference Man, 1975; <sup>2</sup> body mass index; <sup>3</sup> fat mass; <sup>4</sup> muscle mass

**Table 2** Explained variance in body composition of men and women (n = 208) using a multiple stepwise regression analyses

<b>men (n = 105)</b>			<b>R<sup>2</sup></b>	<b>β-Coeff.</b>	<b>SEE</b>
<b>FM [kg]</b> <sup>1</sup>	1	weight	0.77	0.936	3.951
	2	height	0.79	-0.124	3.863
<b>MM [kg]</b> <sup>2</sup>	1	weight	0.54	0.757	2.514
	2	age	0.59	-0.196	2.420
<b>brain [g]</b>	1	height	0.10	0.310	0.096
<b>heart [g]</b>	1	weight	0.09	0.302	0.072
<b>liver [g]</b>	1	weight	0.43	0.654	0.222
<b>kidneys [g]</b>	1	weight	0.16	0.494	0.053
	2	height	0.20	- 0.213	0.052
<b>spleen [g]</b>	1	age	0.08	- 0.319	0.065
	2	weight	0.15	0.256	0.063
<b>women (n = 103)</b>			<b>R<sup>2</sup></b>	<b>β-Coeff.</b>	<b>SEE</b>
<b>FM [kg]</b> <sup>1</sup>	1	weight	0.81	0.979	3.872
	2	height	0.88	-0.272	3.133
<b>MM [kg]</b> <sup>2</sup>	1	weight	0.35	0.474	2.338
	2	height	0.49	0.389	2.087
<b>brain [g]</b>	1	age	0.14	-0.376	0.088
<b>heart [g]</b>	1	weight	0.14	0.372	0.056
<b>liver [g]</b>	1	weight	0.36	0.528	0.191
	2	height	0.40	0.230	0.184
<b>kidneys [g]</b>	1	weight	0.24	0.493	0.041
<b>spleen [g]</b>	1	weight	0.18	0.434	0.053
	2	age	0.23	-0.227	0.052

<sup>1</sup> fat mass; <sup>2</sup> muscle mass; independent variables: weight [kg], height [m], age [years]

**Table 3** Comparison of body composition between the study population (n = 208) [mean ± SD (range)] and the *reference man* and *reference woman* from 1975 [mean] considering different body heights

	men (n = 105)			reference man <sup>1</sup>	men – reference man <sup>1</sup>		
	Group 1 < 1.74m	Group 2 1.74 – 1.83m	Group 3 > 1.83m		Group 1 Δ mean [%]	Group 2 Δ mean [%]	Group 3 Δ mean [%]
<b>age</b> [years]	51.6 ± 17.8 (22 - 72)	40.5 ± 14.4 (21 - 70)	40.7 ± 12.5 (18 - 65)	20 - 30			
<b>weight</b> [kg]	77.5 ± 11.7 (63.7 - 98.2)	84.5 ± 12.3 (58.2-116.8)	91.5 ± 12.5 (68.9 - 111.6)	70	+ 10.7	+ 20.7	+ 30.7
<b>height</b> [m]	1.70 ± 0.03 (1.61 - 1.73)	1.79 ± 0.02 (1.75 - 1.83)	1.87 ± 0.04 (1.84 - 1.95)	1.70	± 0.0	+ 5.3	+ 10.0
<b>BMI</b> [kg/m <sup>2</sup> ] <sup>2</sup>	26.6 ± 4.1 (21.9 - 33.8)	26.5 ± 3.6 (19.0 - 34.9)	26.0 ± 3.4 (18.3 - 31.5)	24.2	+ 9.9	+ 9.5	+ 7.4
<b>FM</b> [kg] <sup>3</sup>	17.7 ± 7.6 (5.7 - 33.4)	17.8 ± 8.3 (4.3 - 43.7)	22.4 ± 8.2 (9.3 - 40.9)	13.5	+ 31.1	+ 31.8	+ 65.9
<b>MM</b> [kg] <sup>4</sup>	28.8 ± 2.7 (22.1 - 35.7)	32.7 ± 3.3 (25.9 - 39.6)	33.7 ± 3.5 (23.3 - 38.3)	28	+ 2.8	+ 16.8	+ 20.4
<b>brain</b> [g]	1578 ± 80 (1432 - 1718)	1596 ± 109 (1343-1848)	1652 ± 87 (1492 - 1872)	1400	+ 12.7	+ 14.0	+ 18.0
<b>heart</b> [g]	332 ± 58 (211 - 446)	378 ± 79 (236 - 631)	343 ± 79 (240 - 570)	330	+ 0.6	+ 14.6	+ 4.1
<b>liver</b> [g]	1596 ± 269 (1168-2232)	1698 ± 286 (1048-2412)	1838 ± 280 (1074 - 2466)	1800	- 11.4	- 6.7	+ 2.1
<b>kidneys</b> [g]	316 ± 59 (202 - 417)	334 ± 57 (223 - 451)	319 ± 60 (234 - 488)	310	+ 2.2	+ 7.9	+ 2.9
<b>spleen</b> [g]	234 ± 65 (128 - 334)	239 ± 68 (86 - 347)	256 ± 69 (120 - 346)	180	+ 30.5	+ 32.6	+ 42.3
	women (n = 103)			reference woman <sup>1</sup>	women – reference woman <sup>1</sup>		
	Group 1 < 1.64m	Group 2 1.64 – 1.72m	Group 3 > 1.72m		Group 1 Δ mean [%]	Group 2 Δ mean [%]	Group 3 Δ mean [%]
<b>age</b> [years]	47.3 ± 17.7 (22 - 78)	40.9 ± 14.8 (23 - 69)	35.1 ± 11.9 (23 - 65)	20 - 30			
<b>weight</b> [kg]	66.5 ± 12.2 (44.0 - 90.6)	67.9 ± 11.1 (51.2 - 97.1)	72.9 ± 9.9 (54.1 - 90.9)	58	+ 14.6	+ 17.0	+ 25.7
<b>height</b> [m]	1.60 ± 0.03 (1.48 - 1.63)	1.67 ± 0.02 (1.64 - 1.72)	1.76 ± 0.03 (1.73 - 1.83)	1.60	± 0.0	+ 4.3	+ 10.0
<b>BMI</b> [kg/m <sup>2</sup> ] <sup>2</sup>	25.8 ± 4.4 (16.8 - 34.1)	24.2 ± 3.8 (18.5 - 34.3)	23.6 ± 3.1 (17.3 - 26.7)	22.7	+ 13.7	+ 6.6	+ 1.3
<b>FM</b> [kg] <sup>3</sup>	24.0 ± 8.8 (8.0 - 42.7)	22.3 ± 9.4 (4.2 - 50.8)	23.0 ± 7.2 (8.7 - 33.5)	16	+ 50.0	+ 39.4	+ 43.7
<b>MM</b> [kg] <sup>4</sup>	19.6 ± 2.3 (15.2 - 23.3)	21.1 ± 2.5 (15.4 - 27.6)	23.0 ± 3.4 (15.7 - 29.7)	17	+ 15.3	+ 24.1	+ 35.3
<b>brain</b> [g]	1406 ± 112 (1239-1593)	1424 ± 95 (1239 - 1689)	1453 ± 74 (1333 - 1615)	1200	+ 17.2	+ 18.7	+ 21.1
<b>heart</b> [g]	245 ± 46 (172 - 361)	277 ± 64 (178 - 437)	269 ± 58 (206 - 393)	240	+ 2.3	+ 15.8	+ 12.4

								20
<b>liver [g]</b>	1308 ± 260 (944 - 2165)	1445 ± 232 (986 -2113)	1483 ± 193 (1159 - 1918)	1400	- 7.6	+ 3.2	+ 5.9	
<b>kidneys [g]</b>	247 ± 54 (159 - 366)	253 ± 46 (176 - 352)	264 ± 44 (204 - 347)	275	- 11.4	- 7.7	- 4.8	
<b>spleen [g]</b>	174 ± 44 (84 - 260)	193 ± 63 (82 - 319)	209 ± 58 (116 - 334)	150	+ 16.1	+ 29.1	+ 39.8	

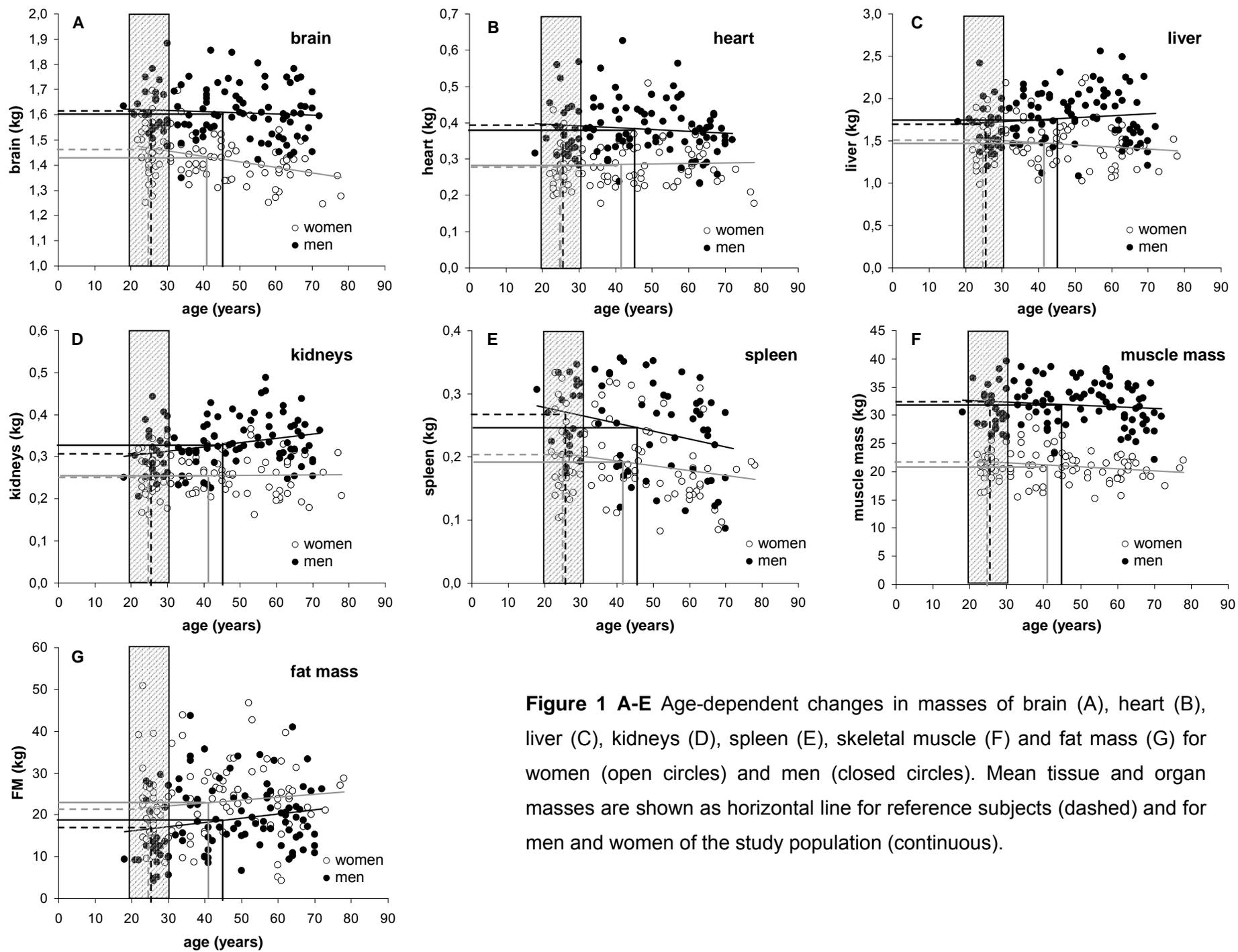
---

<sup>1</sup> Snyder et al., Report of the Task Group on Reference Man, 1975; <sup>2</sup> body mass index; <sup>3</sup> fat mass; <sup>4</sup> muscle mass

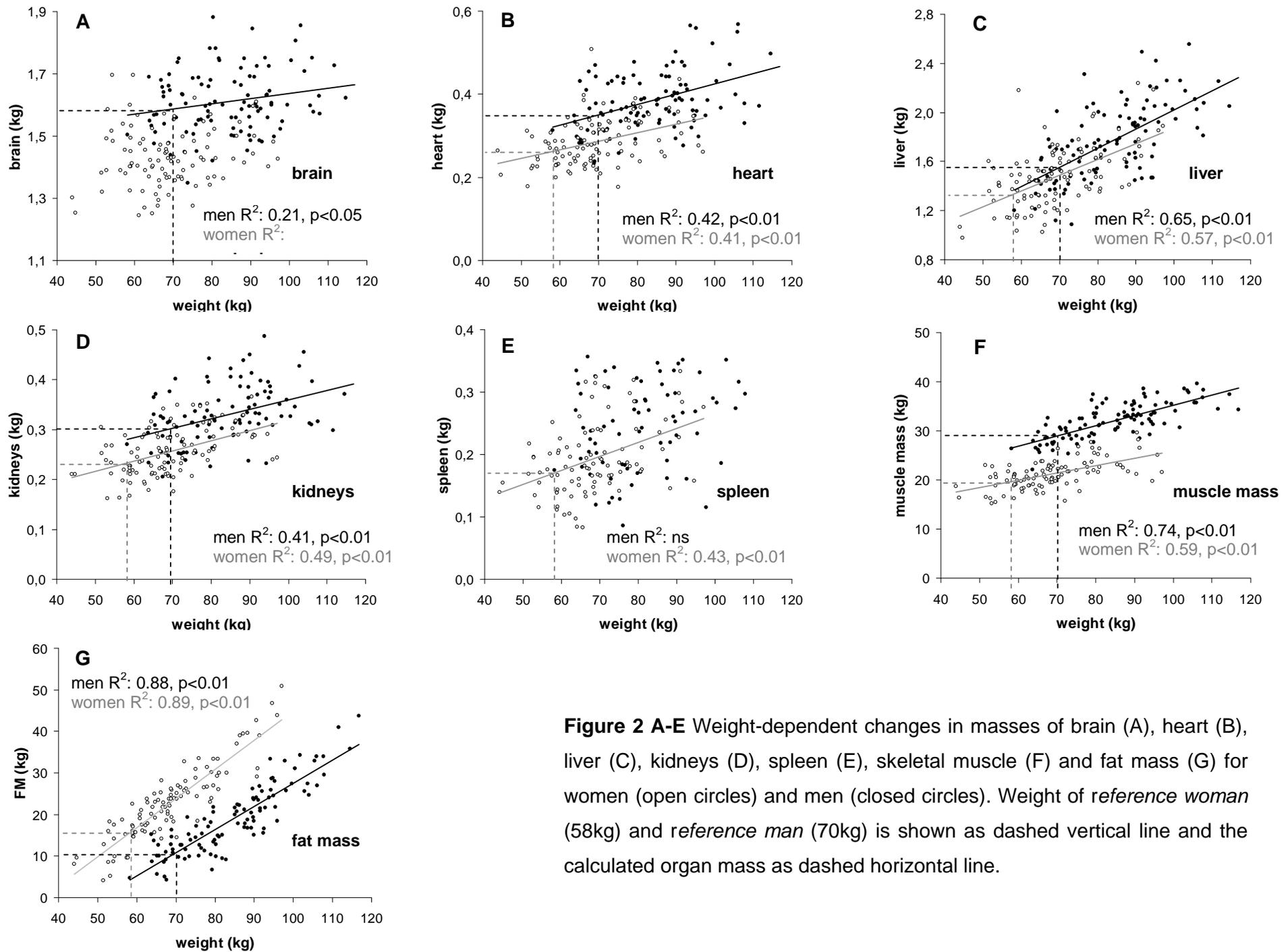
**Table 4** Linear regression equations between body mass and body composition for men and women (n = 208). Deviations between calculated mean values (based on the linear regression equation) and data for *Reference Man* and *Reference Woman*, respectively. Body composition was compared for subjects with identical body weight.

<b>men (n = 105)</b>				
	<b>linear regression equation</b>	<b>man, 70 kg (mean calculated <sup>2</sup>)</b>	<b>reference man <sup>1</sup>, 70 kg (mean)</b>	<b>Δ mean [%]</b>
<b>FM [kg]</b> <sup>3</sup>	0.556 x - 28.11	10.8	13.5	- 20.0
<b>MM [kg]</b> <sup>4</sup>	0.208 x + 14.38	28.9	28	+ 3.2
<b>brain [g]</b>	0.0018 x + 1.45	1576	1400	+ 12.6
<b>heart [g]</b>	0.0018 x + 0.20	326	330	- 1.2
<b>liver [g]</b>	0.0152 x + 0.44	1504	1800	- 16.4
<b>kidneys [g]</b>	0.0019 x + 0.17	303	310	- 2.3
<b>spleen [g]</b>	0.0013 x + 0.138	229	180	+ 27.2
<b>women (n = 103)</b>				
	<b>linear regression equation</b>	<b>woman, 58 kg (mean calculated <sup>2</sup>)</b>	<b>reference woman <sup>1</sup>, 58 kg (mean)</b>	<b>Δ mean [%]</b>
<b>FM [kg]</b> <sup>3</sup>	0.699 x - 25.07	15.5	16	- 3.1
<b>MM [kg]</b> <sup>4</sup>	0.1502 x + 10.86	19.6	17	+ 15.3
<b>brain [g]</b>	0.001 x + 1.36	1418	1200	+ 18.2
<b>heart [g]</b>	0.002 x + 0.13	246	240	+ 2.5
<b>liver [g]</b>	0.0125 x + 0.56	1285	1400	- 8.2
<b>kidneys [g]</b>	0.002 x + 0.11	226	275	- 17.8
<b>spleen [g]</b>	0.0022 x + 0.0391	166	150	+ 10.7

<sup>1</sup> Snyder et al., Report of the Task Group on Reference Man, 1975; <sup>2</sup> mean calculated by linear regression equation; <sup>3</sup> fat mass; <sup>4</sup> muscle mass



**Figure 1 A-E** Age-dependent changes in masses of brain (A), heart (B), liver (C), kidneys (D), spleen (E), skeletal muscle (F) and fat mass (G) for women (open circles) and men (closed circles). Mean tissue and organ masses are shown as horizontal line for reference subjects (dashed) and for men and women of the study population (continuous).



**Figure 2 A-E** Weight-dependent changes in masses of brain (A), heart (B), liver (C), kidneys (D), spleen (E), skeletal muscle (F) and fat mass (G) for women (open circles) and men (closed circles). Weight of *reference woman* (58kg) and *reference man* (70kg) is shown as dashed vertical line and the calculated organ mass as dashed horizontal line.