Body height and waist circumference of young Swiss men as assessed by 3D laser-based photonic scans and by manual anthropometric measurements

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Overweight and obesity are considered among the major health concerns worldwide. The body mass index is a frequently used measure for overweight and obesity and is associated with common non-communicable diseases such as diabetes type II, cardiovascular diseases and certain cancers. However, the body mass index does not account for the distribution of body fat and relative fat to muscle mass. 3D laser-based photonic full body scans provide detailed information on various body circumferences, surfaces, and volumes as well as body height and weight (using an integrated scale). In the literature, body scans showed good feasibility, reliability, and validity, while also demonstrating a good correlation with health parameters linked to the metabolic syndrome. However, systematic differences between body scan derived measurements and manual measurements remain an issue. This study aimed to assess these systematic differences for body height, waist circumference, and body mass index using cross-sectional data from a homogenous sample of 52 young Swiss male volunteers. In addition to 3D laser-based photonic full body scans and correlative manual measurements, body fat distribution was assessed through bioelectrical impedance analysis. Overall, an excellent correlation was found between measurements of waist circumference and body mass index, and good correlation between body mass index and total fat mass, as well as between waist circumference and visceral fat mass as assessed by bioelectrical impedance analysis. Volunteers were shorter in height measured by body scan when compared to manual measurements. This systematic difference became smaller when volunteers stood in the scanner in a completely upright position with their feet together. Waist circumference was slightly smaller for manual measurements than for body scan derived values. This systematic difference was larger in overweight volunteers compared to leaner volunteers.

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15 **Short title:** Height and WC: scanner vs manual measure

21 **Abstract**

23 Overweight and obesity are considered among the major health concerns worldwide. The body

24 mass index is a frequently used measure for overweight and obesity and is associated with

25 common non-communicable diseases such as diabetes type II, cardiovascular diseases and

26 certain cancers. However, the body mass index does not account for the distribution of body fat

27 and relative fat to muscle mass. 3D laser-based photonic full body scans provide detailed

28 information on various body circumferences, surfaces, and volumes as well as body height and

29 weight (using an integrated scale). In the literature, body scans showed good feasibility,

30 reliability, and validity, while also demonstrating a good correlation with health parameters

31 linked to the metabolic syndrome. However, systematic differences between body scan derived

32 measurements and manual measurements remain an issue. This study aimed to assess these

33 systematic differences for body height, waist circumference, and body mass index using cross-

34 sectional data from a homogenous sample of 52 young Swiss male volunteers. In addition to 3D

35 laser-based photonic full body scans and correlative manual measurements, body fat distribution

36 was assessed through bioelectrical impedance analysis. Overall, an excellent correlation was

37 found between measurements of waist circumference and body mass index, and good correlation

38 between body mass index and total fat mass, as well as between waist circumference and visceral

39 fat mass as assessed by bioelectrical impedance analysis. Volunteers were shorter in height

40 measured by body scan when compared to manual measurements. This systematic difference

41 became smaller when volunteers stood in the scanner in a completely upright position with their

42 feet together. Waist circumference was slightly smaller for manual measurements than for body

43 scan derived values. This systematic difference was larger in overweight volunteers compared to

44 leaner volunteers.

45

46 **Introduction**

47 Overweight and obesity are major global health concerns, and worldwide more than 1.9 billion

48 adults were overweight in 2016 (WHO 2017). The body mass index (BMI, weight in kilograms

49 divided by squared height in meters) is a frequently used measure for overweight and obesity and

50 is associated with common non-communicable diseases such as diabetes type II, cardiovascular

51 diseases and certain cancers (WHO 2018). However, the BMI does not account for the

52 distribution of body fat and relative fat to muscle mass. Waist circumference (WC) and waist-to-

53 hip ratio are considered to be better than the BMI to predict CVD (Kjaer et al. 2015; WHO

54 2008). However, it is still unclear which measures best correlate with disease risk (Ashwell et al.

55 2012; Kahn and Bullard 2016; Lam et al. 2015). Other techniques used at a population level like

56 Bioimpedance Analysis (BIA) offer and quick and safe measurement of height, weight, BMI,

57 total fat mass, visceral fat mass, and muscle mass, but measures like WC have to be taken

58 classically with a tape and values have to be entered manually in the BIA machine. Furthermore,

59 BIA seems to be less precise in measuring visceral fat mass than other techniques such as the

60 reference standards, computed tomography (CT) and magnetic resonance imaging (MRI)

61 (Murphy et al. 2019). Other circumferences and ratios derived from them are not assessed. Such

62 measurements have therefore their own limitations and new approaches to quantify obesity and

63 categorize the corresponding health risks are therefore necessary.

64

65 3D laser-based photonic full body scans create a detailed surface image of the human body

66 consisting of up to 300 data points per cm^2 within 10-12 seconds. The BS technique provides

67 detailed information on whole body or body-part circumferences, surfaces and volumes as well

68 as body height and weight (using an integrated scale) in a way that is not only fast and non-

69 invasive but also comfortable for scanned individuals. Scan data are increasingly used for the

70 acquisition of clinically relevant anthropometric measurements by comparing 3D scan data with

71 data from classical anthropometry (Bretschneider et al. 2009; Koepke et al. 2017b; Lin et al.

72 2004; Olivares et al. 2007; Wells et al. 2015). Recent studies comparing the body scan technique

73 with classical anthropometry have demonstrated the applicability of the scan technique in an

74 epidemiological context (Jaeschke et al. 2015; Kuehnapfel et al. 2016). In these studies, body

75 scans showed good feasibility, reliability, and validity, and correlations with health parameters

76   linked to the metabolic syndrome were comparable to studies using manual measurement

77   techniques (Jaeschke et al. 2015).

78

79   One issue with body scan studies are systematic differences between body scan derived

80   measurements and manual measurements, which can be considered as the standard. Height

81   derived from scans is slightly less than manually measured height, and different circumferences

82   are either systematically larger or smaller, when derived from scans, as opposed to manual

83   measurement techniques, in various studies (Domina et al. 2008; Jaeschke et al. 2015; Janssen et

84   al. 2002; Koepke et al. 2017b; Wang et al. 2006). Possible factors influencing such differences

85   are variability of posture, the degree of inspiration, and movement of volunteers while standing

86   in the scanner. Also, there are technical differences between different scanner systems in terms

87   of hardware precision, automatic landmark setting, and measurement output of the scanner

88   software (Schwarz-Müller et al. 2018). Regarding different body circumferences such as waist or

89   hip circumference, systematic differences between scans and manual measurements can be

90   explained by a slightly tighter fitting or slightly different positioning of the measurement tape,

91   compared to scan derived circumferences (Koepke et al. 2017b; Wang et al. 2006).

92

93   This study aimed to further assess systematic differences between body scans and manual

94   measurements in height, WC, and BMI, with a goal to further validate scan derived

95   measurements in future population based studies. We also aimed to assess the correlation

96   between BMI, derived from different scanner or manual measurements, and total body fat mass,

97   derived from BIA. Similarly, we aim to assess the correlation between WC, derived from

98   different scanner and manual measurements, and visceral fat mass, derived from BIA.

99

100   **1.   Methods**

101   As part of a larger research project, a cross-sectional study assessing waist circumference, body

102   height and weight, as well as body composition was conducted on 52 Swiss Armed Forces

103   recruits during their basic training. As this is a purely methodological, and not an

104   epidemiological study, we consider a (homogenous) sample size of 52 to be sufficient in order to

105   show systematic differences between measurement techniques. The study took place in

106   Neunkirch in the Canton of Schaffhausen, Switzerland, in August 2017. Study volunteers were

107 all male Swiss Armed Forces recruits aged 19-23 (19 years old: 34.6%, 20 years old: 38.5%, 21

108 years old: 19.2%, 22 years old: 7.7%, mean age: 20.5 years). Volunteers came from different

109 parts of Switzerland and were not selected for socioeconomic status or other demographic

110 variables. This study was conducted with institutional review board approval (BASEC No. 2016-

111 01625), and participation was voluntary. All volunteers were briefed in written form at the

112 beginning of the study and again orally before the examination. All volunteers signed a detailed

113 informed consent form.

114

115 Body scanner derived measurements were acquired using a semi-mobile Body Scanner

116 (VITUSbodyscan, Human Solutions, Kaiserslautern, Germany). This scanner model is equipped

117 with four eye-safe lasers, eight cameras, and acquires up to 300 data points per cm^2 as a 3D point

118 cloud, based on optical triangulation. This type of scanner showed to be reliable and precise in its

119 mesurements (Koepke et al. 2017a). The scanner operating software (Anthroscan, Human

120 Solutions, Kaiserslautern, Germany) calculates more than 150 automatic standard measurements,

121 including height, and a large number of distances and circumferences. The scanner was

122 calibrated according to the manufacturer's instructions at the beginning of the data collection

123 days when body scans and manual measurements were acquired. Volunteers were measured in

124 two positions, once standing straight in an upright position with their feet together (same position

125 as during the manual height measurement with the stadiometer) and another in a standardized

126 position specified by the scanner manufacturer (standing in an upright position, both feet

127 positioned on marks on the scanner platform (spaced approximately 30 cm apart), arms slightly

128 bent in the elbow and held slightly separated from the body, head in accordance to the Frankfurt

129 Horizontal Plane). All volunteers were briefed before each scan regarding exact positioning on

130 the platform. They were asked to hold their breath after exhalation for the scans, which was

131 about 10 seconds per scan. Volunteers wore only form-fitting underpants and a tight-fitting

132 bathing cap. See Supplemental Figures 1a and 1b for the two scan positions.

133

134 For standard WC measurements, a hand-held tape of stretch-resistant quality and automatic

135 retraction was used (seca 201, Seca AG, Reinach, Switzerland). All WC measurements were

136 performed by one of the authors trained in WC measurements (NB) (Koepke et al. 2016; Staub et

137 al. 2018). The tape measurement position was chosen according to WHO guidelines, at midlevel

138   between the lowest palpable point of the rib cage and the highest palpable point of the iliac crest

139   (WHO 2008). The measurement level was marked with a pen in order to make it visible in

140   subsequently performed body scan acquisitions. Due to a tight schedule given by the Swiss

141   Armed Forces, manual WC measurements were only carried out once for each volunteer. Height

142   measurements were carried out with a standard stadiometer (seca 274, Seca AG, Reinach,

143   Switzerland). Volunteers stood straight in an upright position with their feet together, their back

144   and feet against the stadiometer, and head positioned in accordance with the Frankfurt Horizontal

145   Plane.

146

147   To assess body composition, bioelectric impedance analysis (BIA) was utilized, as time

148   constraints and the need for non-invasive methods did not allow for other assessment methods

149   such as dual-energy X-ray absorptiometry (DXA) or magnetic resonance imaging (MRI). We

150   used a medical 8-point body composition analyzer (Seca mBCA 515, Seca AG, Reinach,

151   Switzerland) measuring weight and calculating the amount of whole-body fat mass and visceral

152   fat mass, muscle mass, and intracellular and extracellular water in the body based on bioelectric

153   impedance measurements across a total of four pairs of electrodes placed on both hands and both

154   feet. Whole body and body part composition was calculated based on mathematical algorithms

155   using the integrated software. This software was validated in different settings and with different

156   ethnic groups (Bosy-Westphal et al. 2017; Bosy-Westphal et al. 2013; Day et al. 2018). For BIA,

157   study volunteers stood barefoot on the two pairs of foot-electrodes and placed each hand on one

158   of the two pairs of hand-electrodes.

159

160   A dataset using measurements from all described sources was compiled. Height and WC from

161   manual measurements were included. From body scans, height in a straight position and standard

162   position were included. Furthermore, an automatically calculated WC from the scans and a

163   second WC measurement from the scans that was manually adjusted in the software to the WHO

164   measurement point were included. To obtain this second WC scanner measurement, the

165   measurement line of the software was manually adjusted to match the pen mark of the manual

166   WHO measurement level on the scans (see Supplemental Figure 1c). Additionally, weight (from

167   an incorporated electronic scale, Seca AG, Reinach, Switzerland), relative whole-body fat mass

168   (%), and visceral fat mass (l) from BIA measurements were included. There was one missing

169   body scan in straight position from one study participant. Therefore, for some statistics, N=51

170   was used instead of N=52.

171

172   Volunteers' BMI was calculated from their weight divided by the square of their height in meters

173   in accordance to WHO guidelines (WHO 2018). Volunteers were classified in different BMI

174   subgroups, volunteers with BMI < 18.5 kg/m2 as underweight, volunteers with BMI 18.5 - 24.9

175   kg/m2 as normal weight, volunteers with BMI ≥ 25.0 - 29.9 kg/m2 as overweight, and volunteers

176   with BMI ≥ 30.0 kg/m2 as obese (WHO 2017). In accordance with WHO guidelines, volunteers

177   were categorized for their risk of metabolic complications (RMC) according to their WC. WC <

178   94.0 cm is associated to a low RMC, WC 94.0 – 102.0 cm is associated to an increased RMC,

179   and WC > 102.0 cm is associated to a substantially increased RMC (WHO 2008).

180

181   We included the following WC measurements in the study: the manual WC measurement, the

182   automatic scanner measurement in the standard position, and the adjusted scanner measurement

183   at the WHO measurement point. For height, we included the manually measured height, height

184   measured with the scanner in a straight position (N=51), and height measured with scanner in

185   standard position. We calculated BMI using weight from the internal scale of the BIA and height

186   from the manual measurement as well as using height from the scan in the straight position and

187   the standard position. See Table 1 for an overview of all measurements considered and

188   abbreviations used.

189

190   **Statistical analysis**

191   Descriptive statistics were calculated for all above-listed measures of WC, height, and BMI. The

192   distributions for WC and BMI were not entirely symmetrical (Supplemental Figure 2), and

193   logarithmic transformation did not considerably change their shape. Therefore, non-parametric

194   and parametric methods were applied to analyse the data. Differences between different WC,

195   height, and BMI measures were tested using Wilcoxon signed-rank tests and paired t-tests. To

196   assess the agreement between the different measurements for WC, height, and BMI, and to

197   compare both measurement methods (scanner vs. manual), Lin's correlations coefficients (CCC)

198   (Lin 1989) were used, Pearson's as well as Spearman rank correlations. Kappa coefficients

199   (Altman 1999) were used to assess the classification agreement according to official WHO BMI

200 categories for overweight/obesity as well as increased health risks for WC. Agreements,

201 correlations, and intra- and inter-methods comparisons were visualized using scatterplots and

202 Bland Altman Plots (Bland and Altman 1999). For the Bland Altman plots the batplot package in

203 Stata (Version 14.1) was used, which additionally tests the difference between the methods for

204 trend. To compare effect sizes between methods a linear regression was performed to assess the

205 association between BMI and relative whole-body fat mass, divided into BMI subcategories,

206 separately for the different BMI measures. Similarly, a linear regression was performed to assess

207 the association between WC and visceral fat mass, divided into WC subcategories, separately for

208 the different WC measures.

209

210 **2. Results**

211 Visual evaluation of WC measure scatterplots showed an increasing deviation with larger WCs

212 when manually measured WC was compared to automatic scan WC and to manually adjusted

213 scan WC (Figure 1a and 1c). This increasing deviation is also represented as an increasing

214 difference between the measures with an increasing average of the measures (Figure 1b, 1d). The

215 largest difference (-1.64cm, paired t-test p<0.01) between WC measurements was observed

216 between manual WC (mean 81.65cm, SD = 9.04) and adjusted scan WC (mean 83.29cm, SD =

217 9.95) (Table 2). The smallest and not significant difference (-0.13cm, paired t-test p=0.376) was

218 observed between automatic scan WC (mean 83.15cm, SD =9.73) and adjusted scan WC (mean

219 83.29cm, SD = 9.95). Agreement between automatic scan WC and adjusted scan WC was good

220 (kappa=0.68, agreement = 92.88%) and very good between manual WC and automatic scan WC

221 (k=0.91, agreement =98.08%). Correlation was very high for all WC measurements (CCC >

222 0.96). For all results see Tables 2-5. The results from the non-parametric tests were very similar

223 (Tables 3 and 5).

224

225 For height, visually there was a constant small difference between manually measured height and

226 standard position scan height as well as between standard position scan height and vertical

227 position scan height. This difference was minimal between manual height and vertical scan

228 height (Figure 2a, 2c, and 2e). The smallest height measurements difference (+0.20cm, paired t-

229 test p=0.009) was between manual height (mean 178.69cm, SD = 6.82) and straight scan height

230 (mean 178.18cm, SD=6.55) (Table 2). The largest difference (+0.77cm, paired t-test p<0.001)

231 was between manual height (mean 178.69cm, SD =6.82) and standard scan height (mean

232 177.92cm, SD =6.78) (Table 2). There were significant differences between all compared height

233 measurements (Table 2). The correlation was very high for the manually measured height, and

234 both scanned height measurements (CCC > 0.98). The results from the non-parametric tests were

235 again very similar (Tables 2 and 3).

236

237 For BMI, the inspection of figure 3 revealed a strong association between BMI calculated with

238 manual height and BMI calculated with scan height in a straight posture. The visual association

239 was slightly deviating for manual BMI versus standard scan BMI, and for standard scan BMI

240 versus straight scan BMI, with increasing BMI (Figure 3a, 3c, 3e). All calculated BMI

241 differences were highly significant (Table 2). The smallest difference (-0.06, paired t-test

242 p=0.007) was between manual BMI (mean 23.99, SD =4.01) and straight scan BMI (mean 24.09,

243 SD = 4.06). The largest difference (-0.22, paired t-test p<0.001) was between manual BMI (mean

244 23.99, SD = 4.01) and standard scan BMI (mean 24.20, SD =4.09). The correlation was excellent

245 for all BMI measures (Kappa =1.0, agreement 100%, CCC >0.99). For all results see Tables 2-5.

246

247 There was a strong correlation between the different BMI measures and relative fat mass

248 (Spearman Rho >= 0.86, Table 6, Figure 4a). The WHO subcategories of BMI correlated

249 similarly with relative fat mass in all three BMI measures (Figure 5a). Compared to normal

250 weight volunteers, underweight volunteers measured with classic anthropometry showed -6.6 %

251 (95% CI -13.8 –0.5) less body fat mass. Overweight volunteers showed 11.3 % (CI 95% 8.2 –

252 14.3) more body fat than normal weight volunteers, and obese volunteers showed 20.5 % (CI

253 95% 14.5 – 26.4) more body fat than normal weight volunteers (Figure 5a, upper panel). The

254 results for BMI calculated with scan height in the standard position and in the straight position

255 were very similar. See Figure 5 and supplementary Table 1 for all results.

256

257 There was a strong correlation between the different WC measures and visceral adipose tissue

258 (Spearman Rho >= 0.79, Table 5), but manual WC deviated increasingly from automatic scan

259 WC and adjusted scan WC with increasing WC (Figure 4b). For WC subcategories vs. visceral

260 adipose tissue, the correlation was more different for manual WC than for the other WC

261 measures, when WC was more than 102.0 cm (Figure 5b). Compared to volunteers with WC

262   <94.0 cm (low RMC) volunteers with WC 94.0–102.0 cm (increased RMC) measured with

263   classic anthropometry had 1.94 litre (95% CI 1.53 - 2.34) more visceral fat mass. Volunteers

264   with a WC >102 cm (substantially increased RMC) had 4.57 litre (95% CI 3.7 - 5.44) more

265   visceral fat mass than volunteers with low risk (WC <94.0 cm).

266

267   **3.   Discussion**

268   The presented study evaluated whether the positioning of volunteers in the scanner influenced

269   previously observed differences between height measurements derived from body scans and

270   manually measured height. We confirmed that height was less when measured by the scanner,

271   compared to classical anthropometry. When volunteers stood in the scanner in a completely

272   upright position with their feet together, this difference became smaller. Nevertheless, for height

273   measurements, a small difference remained between the scanner and manual classical

274   anthropometry for the same body position.

275

276   Interestingly, other studies found that height was greater in the scanner than measured with

277   classical anthropometry (Jaeschke et al. 2015; Kuehnapfel et al. 2016). Several factors could

278   explain our findings. In classical anthropometry, the stadiometer behind the volunteers may

279   encourage the volunteers to stand straighter than without the stadiometer in the scanner (Koepke

280   et al. 2017b). Additionally, posture variability in the scanner could also have influenced height;

281   in fact, other studies showed relevant differences due to posture variability (Schwarz-Müller et

282   al. 2018; Tomkinson and Shaw 2013; Wells et al. 2015).

283

284   As expected and similarly to other studies, we found an excellent correlation for WC measured

285   by classical manual anthropometry and scanner derived measurements (Koepke et al. 2017b).

286   However, WC was systematically slightly smaller if measured with manual anthropometry than

287   derived from the scanner. A possible explanation for this difference is that volunteers tend to pull

288   their stomach in for manual measurements (Jaeschke et al. 2015). Other studies showed that arm

289   posture had a significant influence on WC measurements (Lennie et al. 2013; Lu et al. 2010). In

290   our study arm posture was different in the scanner (slightly bend elbows and slightly separated

291   from the body, but not too far away in order not to leave the measuring area) as in manual WC,

292   where volunteers had to hold their arms further away from the trunk due to the measurement

293   procedure. The difference between manual WC and scanner derived measurements was not

294   explainable by a different measuring level, as manual WC deviated more from adjusted scan WC

295   than expected, while there was no significant difference between automatic scan WC and

296   adjusted scan WC. This means that at the population level automatic scan WC is reliable

297   concerning the measuring level and can be equalized to the WHO measuring level.

298

299   Interestingly, manual WC deviated more from scanner measures in obese volunteers compared to

300   lean volunteers. Other studies showed low reliability of manual WC measurements in obese

301   subjects (Kuehnapfel et al. 2016; Verweij et al. 2013). It was more challenging to control tape

302   position when WC was larger and more difficult to identify the WHO measurement level in

303   obese volunteers correctly.

304

305   The scanner derived measures correlated similarly to total fat and visceral fat as the manually

306   derived measures, probably being even superior when it comes to the correlation between waist

307   circumference and visceral fat in strongly obese persons. As just discussed for waist

308   circumference, this might be due to the difficulty in measuring manually the waist circumference

309   in very obese persons. Overall the scanner offers a reliable tool to assess a number of

310   anthropometric measures in a fast and safe way. Furthermore, as Table 4 showed, the difference

311   in categorizations of BMI and WC between scanner and manual measurements was absent or

312   minimal. The scanner can therefore be regarded as an alternative tool to categorize patients into

313   BMI and WC categories, if scans are taken for any reason.

314

315   Several techniques are used to reconstruct body segment volumes, body segment parameter

316   differences, or segment inertial properties, such as 3D body scanners (Norton et al. 2002),

317   infrared scanners (Smith and Bull 2018), magnetic resonance imaging (Cheng et al. 2000) or

318   dual energy x-ray absorptiometry (DEXA) (Durkin and Dowling 2003). The different techniques

319   have their advantages and disadvantages, depending on the specific research target. For

320   epidemiological research on anthropometrical measures, a 3D full body scanner offers a rapid,

321   safe and reliable alternative.

322

323 This study is the first to compare different postures and different measuring levels to assess

324 height and WC with a 3D body scanner. An advantage for the internal validity of this study was

325 the homogenous study group, namely same age, and sex, which reduced physical inter-individual

326 variability apart from BMI. Limitations for the external validity of this study were the small

327 sample size, and the specificity of the sample, particularly regarding sex and age. Due to time

328 constraints, all measurements were only carried out once per volunteer. One trained researcher

329 did all manual WC measurements. Therefore, we could exclude inter-observer bias, but an intra-

330 observer bias cannot be excluded (Koepke et al. 2017b).

331

332 **4.   Conclusion**

333 The body scanner measurement technique seems to be reliable for height and WC and the

334 compared measurement techniques correlated well. However, the small difference in height

335 measurements that also persists after postural correction must be further investigated. Likewise,

336 the observed deviation between manually measured WC and body scan derived values, which

337 systematically increased with increasing BMI of volunteers, must be further investigated.

338 Additionally, extensive studies with volunteers of both sexes, various ages, and different BMIs

339 are required to further evaluate the differences between scanner derived measurements and

340 classic anthropometrics in order to assess the applicability of the scanner technique at a

341 population level.

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344

345 **Acknowledgements**

346

347 The authors are especially thankful to Andreas Stettbacher (Chief Medical Surgeon), Franz Frey,

348 Alexander Faas, Martino Ghilardi, Marco Müller, and Yvanka Jerkovic from the Swiss Armed

349 Forces for their tremendous (logistic) support. We also thank the IEM collaborators Nikola

350 Koepke, Lena Öhrström, Gulfirde Akgül, Anne Lehner and Nakita Frater for helping to collect

351 the data, and Abagail Breidenstein for English editing.

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354 **Figure legends**
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356
357 **Figure 1: Associations between different waist circumference measures.** A), C) and E) show
358 scatter plots of different WC measures (solid line: x=y, dotted line: linear regression). B), D) and
359 F) show Bland Altman plots (the solid line including 95% confidence interval originates from the
360 test for trend using linear regression). There is an increasing deviation between manual
361 measurements and scanner measurements with increasing WC.
362
363
364 **Figure 2: Associations between different height measurements.** A), C) and E) show scatter
365 plots of different height measures (solid line: x=y, dotted line: linear regression). B), D) and F)
366 show Bland-Altman Plots (the solid line including 95% confidence interval originates from the
367 test for trend using linear regression). Panel A) shows the systematic difference between manual
368 height measurement and scanner measurement in the standard scanner position.
369
370
371 **Figure 3: Associations between different BMI measurements.** A), C) and E) show scatter
372 plots of different BMI measures (solid line: x=y, dotted line: linear regression). B), D) and F)
373 show Bland Altman plots (the solid line including 95% confidence interval originates from the
374 test for trend using linear regression).
375
376
377 **Figure 4: Associations between BMI and relative fat mass, and between WC and visceral**
378 **fat mass.** A): Associations between BMI and relative fat mass (%). The different BMI measures
379 are given in different colours and symbols, and linear regression lines. B): Associations between
380 WC and visceral fat mass (l). Different WC measures are given in different colours and symbols,
381 and linear regression lines. The manual measurements are increasingly deviating from the
382 scanner measurements with increasing WC.
383
384
385 **Figure 5: coefficients from regression analysis for categories of BMI vs relative fat mass**
386 **and for categories of WC vs visceral fat mass.** A): coefficients and 95% confidence intervals

387   from regression analyses of BMI categories and relative fat mass (%), for the three different

388   measurements. B): coefficients and 95% confidence intervals from regression analyses of WC

389   categories and visceral fat mass (l), for the three different measurements. The manual WC

390   measurements are increasingly deviating from the scanner measurements with increasing WC.

391

392

393   **Supplemental Figure 1:** A) standardized position specified by the scanner manufacturer:

394   standing in an upright position, both feet positioned on marks on the scanner platform (spaced

395   approximately 30 cm apart), arms slightly bent in the elbow and held slightly separated from the

396   body, head in accordance to the Frankfurt Horizontal Plane. B) standing straight in an upright

397   position with feet together (same position as during the manual height measurement with the

398   stadiometer). C) the measurement line of the software was manually moved to match the pen

399   mark of the manual WHO measurement point on the scans.

400

401

402   **Supplemental Figure 2:** The distributions for WC, height, and BMI were not entirely

403   symmetrical, neither for manual measurements, nor for the two scanner positions.

404

405

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Measurements

1 **Table 1: Measurements**

Used terms	Explanation
Manual WC	WC measured with classic manual anthropometry (tape)
Automatic scan WC	WC measured with the scanner at automatic scanner position
Adjusted scan WC	WC measured with the scanner adjusted at WHO point
Manual height	Height measured with classic manual anthropometry (stadiometer)
Standard scan height	Height measured with the scanner in standard body posture
Straight scan height	Height measured with the scanner in straight body posture
Manual BMI	BMI calculated with height from classic manual anthropometry
Standard scan BMI	BMI calculated with height from the scanner in standard body posture
Straight scan BMI	BMI calculated with height from the scanner in straight body posture

Descriptive statistics for WC, height, and BMI

1 **Table 2: Descriptive statistics for WC, height, and BMI. A) N, mean, standard deviation**

2 **(SD), and median. B) Wilcoxon signed rank test, paired t-test.**

4 **A)**

	N	Mean	SD	Median
WC				
Automatic scan WC	52	83.15	9.73	80.50
Adjusted scan WC	52	83.29	9.95	81.00
Manual WC	52	81.65	9.04	80.00
Height				
Standard scan height	52	177.92	6.78	176.10
Straight scan height	51	178.18	6.55	176.40
Manual height	52	178.69	6.82	177.25
BMI				
Standard scan BMI	52	24.20	4.09	23.81
Straight scan BMI	51	24.09	4.06	23.54
Manual BMI	52	23.99	4.01	23.55

B)	Wilcoxon signed rank test		Paired t-test	
WC	z	p	Delta (cm)	p
Manual WC vs. scan WC	-4.54	<0.001	-1.50	<0.001
Manual WC vs. adjusted scan WC	-4.71	<0.001	-1.64	<0.001
Scan WC vs. adjusted scan WC	-1.06	0.295	-0.13	0.376
Height				
Manual height vs. standard scan height	5.56	<0.001	0.77	<0.001
Manual height vs. straight scan height	2.98	0.003	0.20	0.009
Standard scan height vs. straight scan height	-5.08	<0.001	-0.55	<0.001
BMI				
Manual BMI vs. standard scan BMI	-5.56	<0.001	-0.22	<0.001
Manual BMI vs. straight scan BMI	-3.02	0.003	-0.06	0.007
Standard scan BMI vs. straight scan BMI	5.12	<0.001	0.16	<0.001

Correlations between different measurements of WC, height, and BMI

CCC=Lin's concordance correlation coefficient, R=Pearson's correlation coefficient, C_b=bias correction factor, Rho=Spearman correlational coefficient.

1 **Table 3: Correlations between different measurements of WC, height, and BMI**

2 **(CCC=Lin's concordance correlation coefficient, R=Pearson's correlation coefficient, C_b=bias**

3 correction factor, Rho=Spearman correlation coefficient).

	CCC	R	C_b	Rho
WC				
Manual WC vs. scan WC	0.964	0.979	0.985	0.964
Manual WC vs. adjusted scan WC	0.964	0.983	0.981	0.967
Scan WC vs. adjusted scan WC	0.994	0.995	1.000	0.994
Height				
Manual height vs. standard scan height	0.988	0.995	0.993	0.989
Manual height vs. straight scan height	0.996	0.997	0.999	0.992
Standard scan height vs. straight scan height	0.992	0.996	0.996	0.992
BMI				
Manual BMI vs. standard scan BMI	0.997	0.999	0.998	0.998
Manual BMI vs. straight scan BMI	0.999	0.999	1.000	0.998
Standard scan BMI vs. straight scan BMI	0.998	0.999	0.999	0.998

WHO categories of manual BMI, standard scan BMI, and straight scan BMI. WHO categories of manual WC, standard scan WC, and adjusted scan WC

1 **Table 4: WHO categories of manual BMI, standard scan BMI, and straight scan BMI.**

2 **WHO categories for manual WC, automatic scan WC, and adjusted scan WC**

Manual BMI (kg/m2)	N	Standard scan BMI (kg/m2)	N	Straight scan BMI (kg/m2)	N
< 18,5	2	< 18,5	2	< 18,5	2
18,5 - 24,9	32	18,5 - 24,9	32	18,5 - 24,9	32
25,0 - 29,9	15	25,0 - 29,9	15	25,0 - 29,9	15
>= 30,0	3	>= 30,0	3	>= 30,0	3
Manual WC (cm)		**Automatic scan WC (cm)**		**Adjusted scan WC (cm)**	
<94.0	46	<94.0	46	<94.0	44
94.0 – 101,9	5	94.0 – 101,9	4	94.0 – 101,9	6
>=102.0	1	>=102.0	2	>=102.0	2

Kappa coefficients and % agreement between categories of different measures of WC and BMI

1   **Table 5: Kappa coefficients and % agreement between categories of different measures of**

2   **WC and BMI**

	Kappa	% Agreement
WC		
Manual WC vs. automatic scan WC	0.9081	98.08%
Manual WC vs. adjusted scan WC	0.7593	94.23%
Automatic scan WC vs. adjusted scan WC	0.681	92.31%
BMI		
Manual BMI vs. standard scan BMI	1.000	100%
Manual BMI vs. straight scan BMI	1.000	100%
Standard scan BMI vs. straight scan BMI	1.000	100%

Pearson's (R) and Spearman (Rho) correlation coefficients between measures of BMI and relative fat mass, and between measures of WC and visceral fat mass

1 **Table 6: Pearson's (R) and Spearman (Rho) correlation coefficients between measures of**

2 **A) BMI and relative fat mass, and between measures of B) WC and visceral fat mass**

A) Relative Fat Mass

BMI	R	Rho
Manual BMI	0.884	0.863
Straight scan BMI	0.883	0.861
Standard scan BMI	0.881	0.860

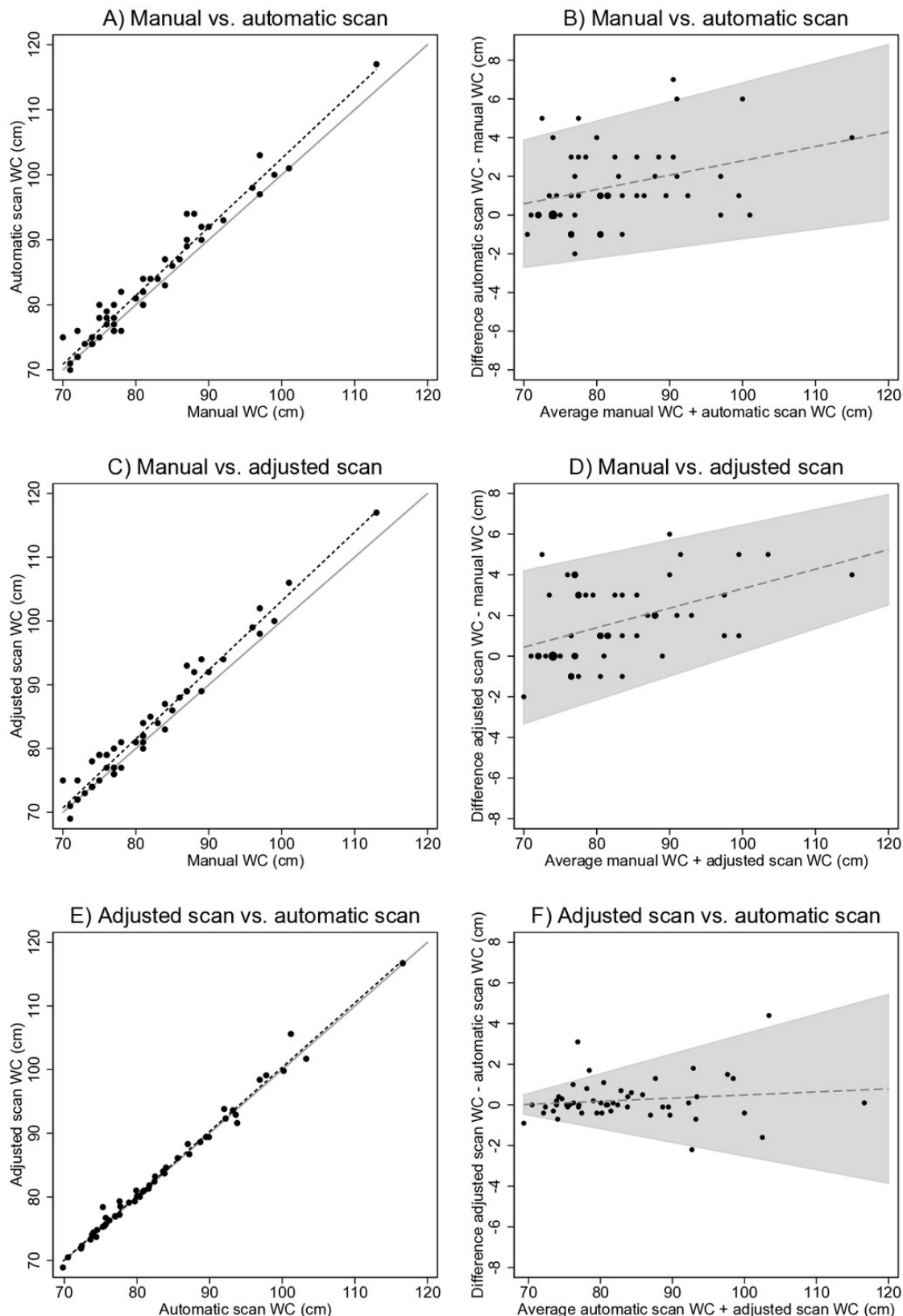
B) Visceral Adipose Tissue

WC	R	Rho
Manual WC	0.919	0.824
Automatic scan WC	0.897	0.790
Adjusted scan WC	0.904	0.808

Figure 1

Associations between different waist circumference measures

A), C) and E) show scatter plots of different WC measures. Lines are from linear regressions. B), D) and F) show Bland Altman plots (the line including 95% confidence interval originates from the test for trend using linear regression). There is an increasing deviation between manual measurements and scanner measurements with increasing WC.

Waist Circumference

A) Manual vs. automatic scan

B) Manual vs. automatic scan

C) Manual vs. adjusted scan

D) Manual vs. adjusted scan

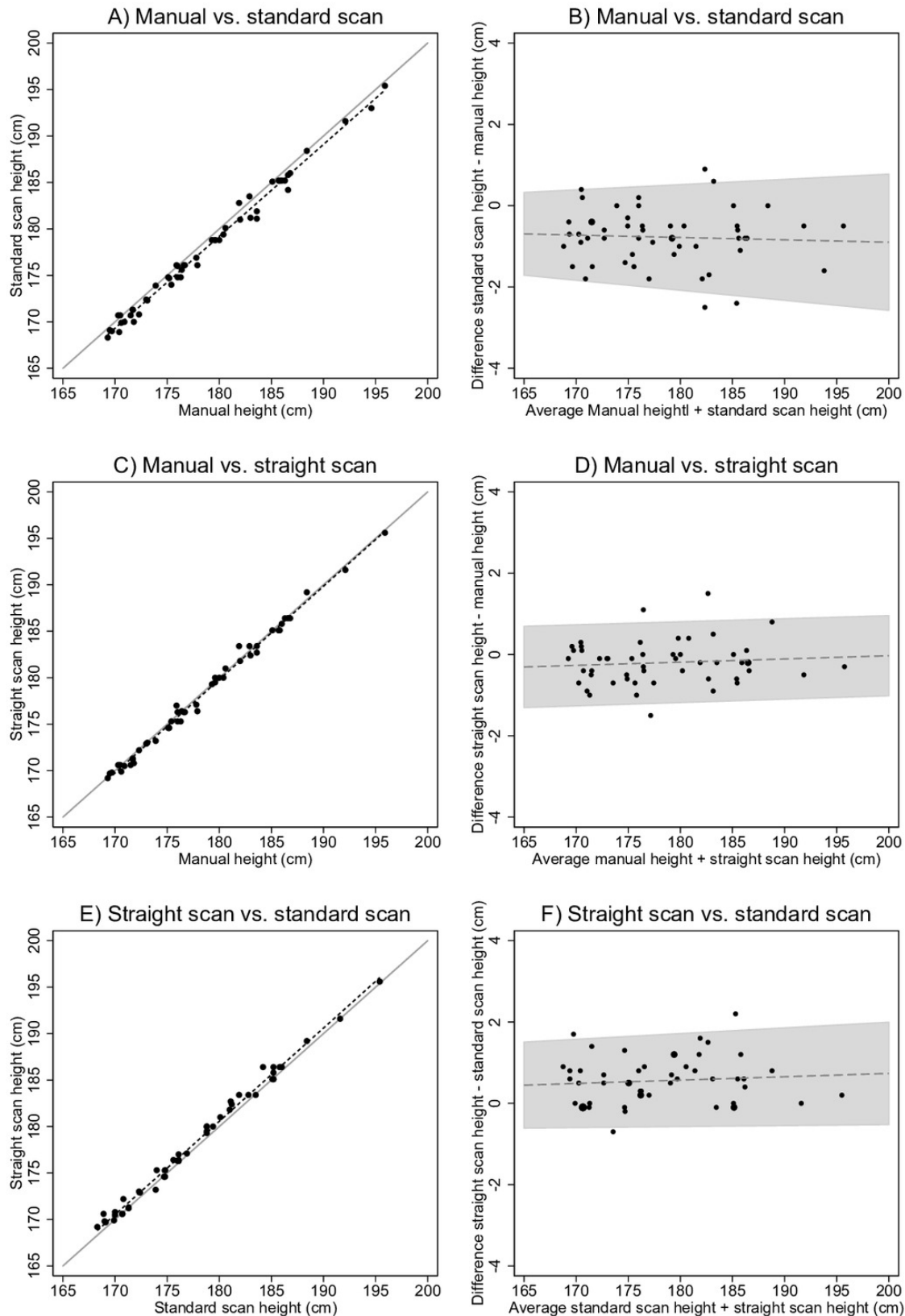
E) Adjusted scan vs. automatic scan

F) Adjusted scan vs. automatic scan

Figure 2

Associations between different height measurements

A), C) and E) show scatter plots of different height measures. Lines are from linear regressions. B), D) and F) show Bland-Altman plots (the line including 95% confidence interval originates from the test for trend using linear regression). Panel A) shows the systematic difference between manual height measurements and scanner measurements in the standard scanner position.

Height

A) Manual vs. standard scan

B) Manual vs. standard scan

C) Manual vs. straight scan

D) Manual vs. straight scan

E) Straight scan vs. standard scan

F) Straight scan vs. standard scan

Figure 3

Associations between different BMI measurements

A), C) and E) show scatter plots of different BMI measures. Lines are from linear regressions.
B), D) and F) show Bland Altman plots (the line including 95% confidence interval originates from the test for trend using linear regressions).

BMI

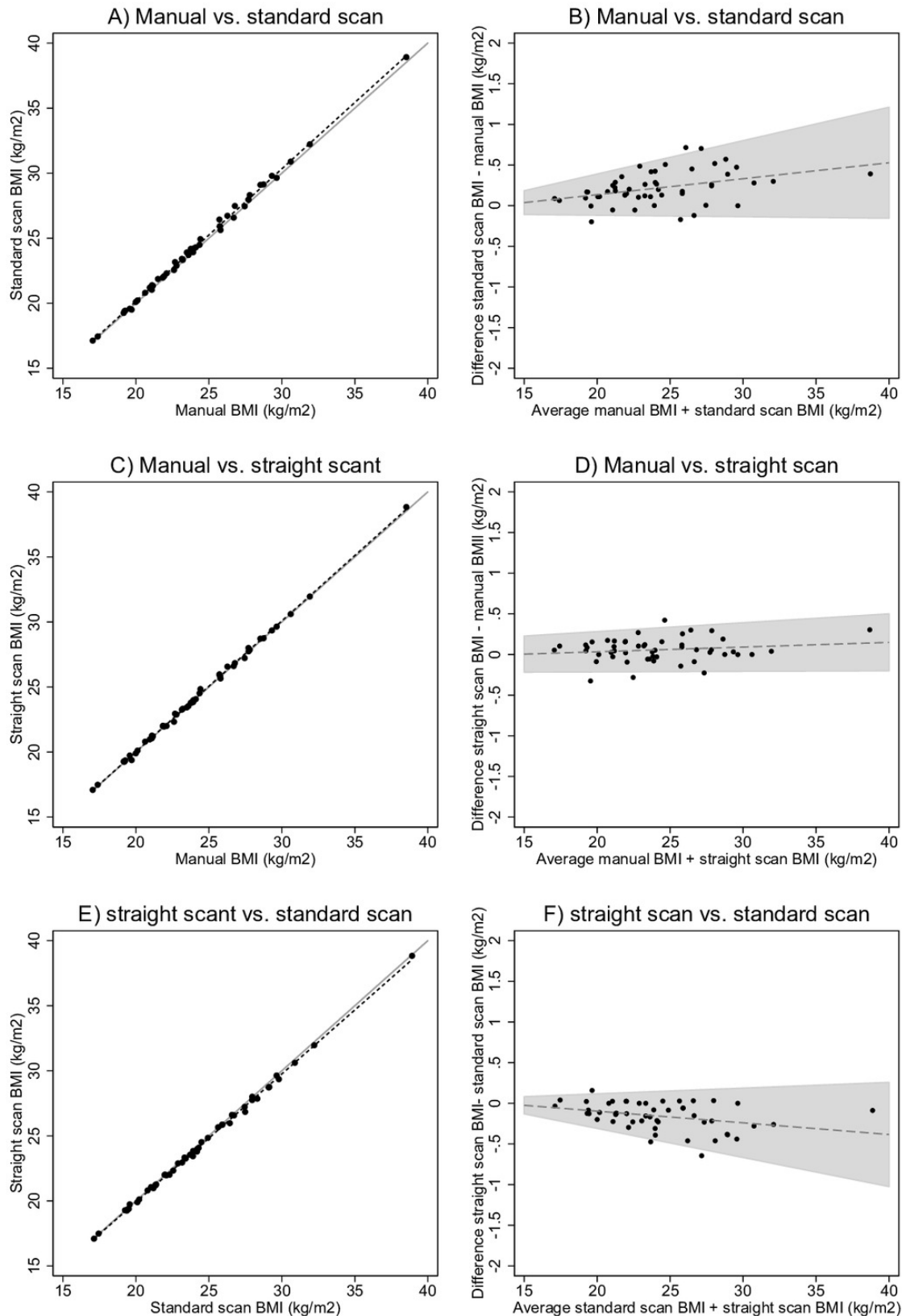



Figure 4

Associations between BMI and relative fat mass, and between WC and visceral fat mass

A: Associations between BMI and relative fat mass (%). The different BMI measures are given in different colours nd symbols. B: Associations between WC and visceral fat mass (l). Different WC measures are given in different colours and symbols. The manual measurements are increasingly deviating from the scanner measurements with increasing WC.

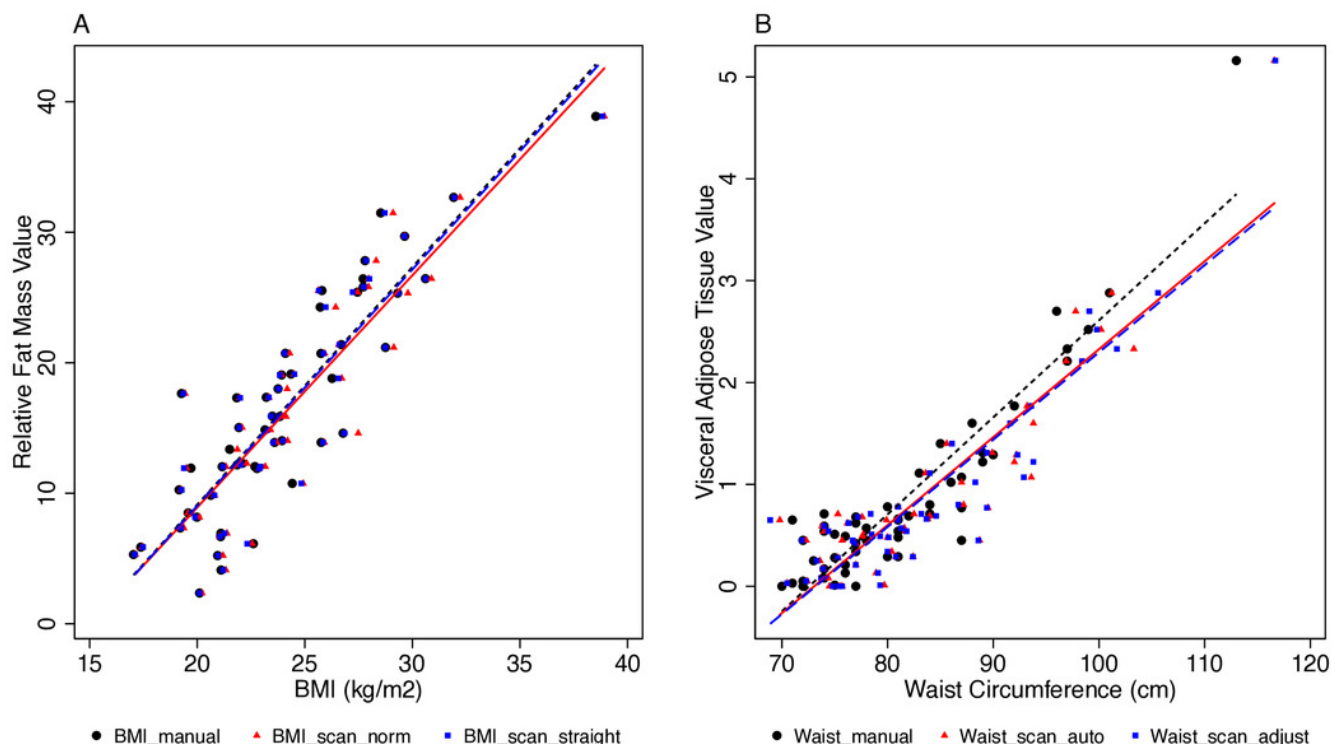



Figure 5

Coefficients from regression analysis for categories of BMI vs relative fat mass and for categories of WC vs visceral fat mass

A: Coefficients and 95% confidence intervals from regression analyses of BMI categories and relative fat mass (%), for the three different measurements. B: Coefficients and 95% confidence intervals from regression analyses of WC categories and visceral fat mass (l), for the three different measurements. The manual WC measuements are increasingly deviating from the scanner measurements with increasing WC.