Dual-Energy X-Ray Absorptiometry Measured Regional Body Composition Least Significant Change: Effect of Region of Interest and Gender in Athletes

Bjoern Buehring,1 Diane Krueger,1 Jessie Libber,1 Bryan Heiderscheit,2,3 Jennifer Sanfilippo,3 Brian Johnson,4 Irina Haller,4 and Neil Binkley*,1

1Osteoporosis Clinical Research Program, University of Wisconsin-Madison, Madison, WI, USA; 2Orthopedics and Rehabilitation, University of Wisconsin-Madison, Madison, WI, USA; 3Intercollegiate Athletics, University of Wisconsin-Madison, Madison, WI, USA; and 4Essentia Institute of Rural Health, Duluth, MN, USA

Abstract

Dual-energy X-ray absorptiometry (DXA) is widely used to evaluate body composition in athletes. Knowledge of measurement precision is essential for monitoring body composition changes over time. This study begins characterizing DXA body composition precision in 60 (30 males and 30 females) Division 1 athletes focusing on gender, regional, and tissue type differences. Two total body scans with repositioning between were performed on the same day. Least significant change (LSC) for the root-mean-square deviation (LSCRMSD) and the percent coefficient of variation (LSC%CV) for total, lean, and fat mass was calculated for 6 regions of interest. The effect of gender, region, tissue type, and mass on the standard deviation (SD) and percent coefficient of variation (%CV) between the 2 scans was evaluated using repeated measures regression analysis. Statistically significant effects of gender, region, tissue type, and mass on SD and %CV were noted. To generalize, a nonlinear positive relationship between LSCRMSD and mass and a nonlinear negative relationship between LSC%CV and mass were observed. In conclusion, DXA body composition LSC varies among genders, regions, tissues, and mass. As such, when evaluating serial body composition in athletes, especially if assessing regional change, knowledge of precision in individuals of similar body size and gender to the population of interest is needed.

Key Words: Body composition; DXA; precision; sports performance.

Introduction

Dual-energy X-ray absorptiometry (DXA) is increasingly being used to measure body composition in various settings (1), including obesity/bariatric surgery (2,3), lipodystrophy assessment in individuals with HIV (4–7), sarcopenia (8–11), and athletic training/performance (12–16). This methodology is rapid, relatively inexpensive, and uses only a small amount of ionizing radiation. Importantly, it allows regional composition measurements, which have primarily received interest for assessing fat distribution (i.e., android/gynoid fat) (17) and appendicular lean mass as part of sarcopenia definition (8,9,11). However, the ability to evaluate regional lean mass carries substantial potential for assessing athletes to evaluate training regimens and also rehabilitation after sports injuries. This ability to evaluate not only total fat and lean mass but also mass in specific regions such as the extremities is a distinct advantage of DXA compared with other measures of body composition, such as bioelectrical impedance or hydrodensitometry (18,19).

In general, a high lean mass-to-fat mass ratio is beneficial for most athletes because high body fat mass leads to less efficient energy utilization (20). However, too little fat mass might negatively impact health as seen in women with female athlete triad (disordered eating, amenorrhea, and low bone mineral density) (21). Despite the potential advantages noted...
previously, only a limited number of studies have used DXA body composition in athletes. Some reports find a high correlation between DXA and other measures of body composition (12,21–24). However, other studies comparing athletes with controls observe differences in body composition, for example, among different Cricketing skill groups and Rugby player positions (14,16). Importantly, serial DXA scans may be used to assess body composition changes over time to monitor training regimens or during the course of a season (13). One can speculate that such serial DXA body composition evaluation in athletes might be most beneficial as it can provide information about not only conditioning status, training regimens, or rehabilitation process but also negative developments that might impact the athletes’ health, such as excessive loss of fat or lean mass.

In serial measurements, however, it is necessary to appreciate and account for method variability to determine if an intervention has altered fat and/or lean mass over time. The International Society for Clinical Densitometry (ISCD) recommends performance of a precision assessment to determine what constitutes a change in the measured parameters with 95% confidence interval (25–27). Importantly, such a precision assessment should be performed “using patients representative of the clinic’s patient population” (26). Because diverse populations with markedly differing body composition may be evaluated depending on the clinical circumstance, it is necessary to understand if variations in body composition, body size, and fat/lean distribution affect reproducibility of these measurements. One obvious example of differences is gender, with males typically being larger with different fat/lean distribution compared with females (28,29). Moreover, although the reproducibility of total body bone, fat, and lean mass has been reported and appears to be excellent in adults with and without disease (6,30–32), there is, to our knowledge, only limited information available regarding the reproducibility of these measurements in athletes (12). Furthermore, only very limited data exist regarding the reproducibility of regional measurements in this population. As elite athletes are very specialized and have widely differing body compositions, we hypothesized that the size and body composition of Division 1 college athletes might be variable enough to warrant separate precision assessments. The goal of this study was to do an initial evaluation of total and regional body composition in Division 1 athletes with focus on gender, tissue, and regional differences.

Methods

Participants

As recommended by the ISCD, precision assessments consisting of 2 total body DXA scans were performed in 60 student athletes (30 females and 30 males) from the University of Wisconsin selected based on the ability to fit within the densitometer scan field. Mean (± standard deviation [SD]) age was 20.6 (±1.3) yr (range, 18.3–23.4 yr) and 19.9 (±1.3) yr (range, 18.1–22.7 yr) for men and women, respectively. These athletes participated in various sports including hockey (17 women and 16 men), basketball (5 women and 4 men), golf (8 women), and wrestling (10 men). This study was determined to be exempt by the University of Wisconsin-Madison Institutional Review Board. All participants provided written consent before undergoing DXA assessment.

DXA Acquisition, Analysis, and Precision Assessment

A GE Healthcare (Madison, WI) Lunar iDXA densitometer was used for all examinations. ISCD-certified technologists performed all scan acquisition and analyses in routine clinical manner following research facility standard operating procedures. All scans were acquired using enCORE software versions 11.0–13.31; version 13.4 was used for analysis. One technologist analyzed all scans using the software autoanalysis feature followed by manual correction of analysis markers when necessary.

Precision assessment was performed in routine clinical manner following ISCD recommendations (26); specifically, each athlete was scanned twice by the same technologist with repositioning between scans. Both scans were conducted at the same scanning session.

DXA Regional Analysis

Total body and regional analyses were performed in routine clinical manner. Six standard regions of interest (ROI) were used for this analysis (Fig. 1). These regions were defined as follows: Total body ROI consisting of the entire body including the head; trunk ROI defined at the upper boundary by the mandible line including the chest, abdomen, and pelvic triangle; the arm ROIs (right and left) were defined by a line bisecting the shoulder joint of the right and left arm; and the leg ROIs (right and left) were defined by a line bisecting the hip joint aligned with the iliac crest and pubis.

Statistical Analyses

The gender differences in age and body mass index (BMI) were evaluated using Student’s t-test. The mean mass, variance and SD between the measurements, and percent coefficient of variation (%CV) were calculated for each subject based on the 2 scans, resulting in 18 observations of each parameter (mean, variance, SD, and %CV) that corresponds to the region (total, trunk, left arm, right arm, left leg, and right leg) and tissue type (total, fat, and lean) combinations. The mean square error (MSE) and least significant difference (LSC) with 95% confidence interval based on both the MSE (least significant change for the root-mean-square deviation [LSC_{RMSD}]) and %CV (least significant change for the percent coefficient of variation [LSC_{%CV}]) were calculated for each region and tissue type for males and females using the ISCD precision calculator available online (http://www.iscd.org/visitors/resources/calc.cfm). The LSC values are a multiple of either the RMSD or root-mean-square %CV; hence, inferences based on the SD or %CV are applicable to the LSC.
values. Wilcoxon rank-sum test was used to evaluate gender differences in variance for total, fat, and lean mass for each region and tissue type. The graphical evaluation of the relationship between mean mass for each region/tissue combination with corresponding mean LSCRMSD and mean LSC\%CV was assessed in JMP (version 10.0; SAS Institute, Cary, NC) using a best-fit model. Repeated measures models with unstructured covariance matrices and Kenward-Roger approximation (33) were used to assess the effect of gender, region, tissue type, and mass on the SD and \%CV. All analyses were done with SAS v9.3 (Cary, NC).

Results

Body Composition

The body composition results are given in Table 1. Males were larger than females (p < 0.01). Specifically, for men, the mean (±SD) BMI was 25.6 (±3.0) kg/m² (range, 21.3–35.7 kg/m²), and for women, it was 23.3 (±2.3) kg/m² (range, 17.7–29.4 kg/m²). The mean total mass for men was 85.2 kg (range, 62.7–123.7 kg), and for women, it was 65.5 kg (range, 52.0–77.1). There was little overlap in total mass between the men and women, in that the heaviest 24 individuals were male. Absolute and percent lean mass measurements were higher in men than in women (p < 0.001) at all ROIs. Fat mass measurements were higher in women (p < 0.05) at all ROIs.

Precision

The LSCRMSD and LSC\%CV values varied between the different regions, tissues, and genders (Table 2). The Wilcoxon rank-sum tests indicated that variance is smaller for females.
than that for males in the fat and lean tissues of the total body ($p < 0.01$) and in the lean tissue of the trunk ($p = 0.03$).

The graphical evaluation of the relationships between the mass and measures of precision, the dependent variables (SD and %CV) were transformed using natural logarithm for estimating the effects of gender, region, and tissue type on SD and %CV in repeated measures regression analyses (Table 3). Subsequently, the estimated effects of the explanatory variables were obtained using reversed transformation of the model parameters. As noted in Table 3, the SD and %CV for female athletes were 81% and 97% compared with males, respectively, with the effect being statistically significant ($p = 0.026$) for SD.

Variability also differed based on ROI. Specifically, variability based on SD for the left arm ROI, right arm ROI, and right leg ROI was less than that for the total body ROI (41%, 45%, and 95%, respectively) and greater than that for the total body ROI in left leg ROI and trunk ROI (110% and 161%). The effect of ROI was statistically significant ($p < 0.001$) for both arms and the trunk. Similar analysis for variability based on %CV revealed that %CV for all regions was greater ($p < 0.001$) compared with that for the total body: 343% (trunk), 519% (right leg ROI), 606% (left leg ROI), 717% (left arm ROI), and 791% (right arm ROI). Additionally, variability of fat and lean mass measurements differed from that of total mass. Specifically, the SD for fat tissue was 70% of that for total ($p < 0.001$), and the SD for lean tissue was 117% of that for total ($p = 0.02$). However, in similar analysis for %CV, both lean and fat tissue %CV values

Table 2

<table>
<thead>
<tr>
<th>Gender</th>
<th>Male</th>
<th>Female</th>
<th>LSC (95% confidence)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RMS SD %CV MSE</td>
<td>RMS SD %CV MSE</td>
<td>LSC$<em>{RMSD}$ LSC$</em>{CV}$ LSC$<em>{RMSD}$ LSC$</em>{CV}$</td>
</tr>
<tr>
<td>Total body ROI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total mass</td>
<td>63 0.07 3958</td>
<td>46 0.07 2121</td>
<td>174 0.2 128 0.2</td>
</tr>
<tr>
<td>Lean mass</td>
<td>208 0.30 43,155</td>
<td>138 0.30 18,938*</td>
<td>575 0.8 381 0.8</td>
</tr>
<tr>
<td>Fat mass</td>
<td>168 1.46 28,186</td>
<td>114 0.64 13,000*</td>
<td>465 4.1 316 1.8</td>
</tr>
<tr>
<td>Trunk ROI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total mass</td>
<td>184 0.46 33,716</td>
<td>142 0.47 20,240</td>
<td>509 1.3 394 1.3</td>
</tr>
<tr>
<td>Lean mass</td>
<td>265 0.80 70,173</td>
<td>170 0.77 28,978*</td>
<td>734 2.2 472 2.1</td>
</tr>
<tr>
<td>Fat mass</td>
<td>149 2.79 22,217</td>
<td>110 1.46 12,086</td>
<td>413 7.7 305 4.0</td>
</tr>
<tr>
<td>Right arm ROI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total mass</td>
<td>45 0.86 2050</td>
<td>47 1.35 2191</td>
<td>125 2.4 130 3.7</td>
</tr>
<tr>
<td>Lean mass</td>
<td>55 1.34 3044</td>
<td>59 2.54 3508</td>
<td>153 3.7 164 7.0</td>
</tr>
<tr>
<td>Fat mass</td>
<td>37 7.09 1361</td>
<td>33 3.85 1105</td>
<td>102 19.6 92 10.7</td>
</tr>
<tr>
<td>Left arm ROI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total mass</td>
<td>69 1.36 4758</td>
<td>45 1.27 2053</td>
<td>191 3.8 126 3.5</td>
</tr>
<tr>
<td>Lean mass</td>
<td>78 1.85 6047</td>
<td>55 2.43 2983</td>
<td>215 5.1 151 6.7</td>
</tr>
<tr>
<td>Fat mass</td>
<td>48 8.00 2313</td>
<td>35 4.34 1195</td>
<td>133 22.2 96 12.0</td>
</tr>
<tr>
<td>Right leg ROI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total mass</td>
<td>137 0.91 18,796</td>
<td>170 1.34 28,768</td>
<td>380 2.5 470 3.7</td>
</tr>
<tr>
<td>Lean mass</td>
<td>131 1.08 17,181</td>
<td>140 1.68 19,723</td>
<td>363 3.0 389 4.7</td>
</tr>
<tr>
<td>Fat mass</td>
<td>47 2.18 2200</td>
<td>56 1.54 3089</td>
<td>130 6.0 154 4.3</td>
</tr>
<tr>
<td>Left leg ROI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total mass</td>
<td>184 1.25 33,778</td>
<td>173 1.39 30,002</td>
<td>509 3.5 480 3.8</td>
</tr>
<tr>
<td>Lean mass</td>
<td>166 1.44 27,612</td>
<td>112 1.41 12,533</td>
<td>460 4.0 310 3.9</td>
</tr>
<tr>
<td>Fat mass</td>
<td>71 3.33 4984</td>
<td>78 2.08 6079</td>
<td>196 9.2 216 5.8</td>
</tr>
</tbody>
</table>

Note: ROI masses, RMS SD, and LSC$_{RMSD}$ values in grams.

Abbr: %CV, percent coefficient of variation; LSC, least significant change; LSC$_{CV}$, least significant change for the root-mean-square percent coefficient of variation; LSC$_{RMSD}$, least significant change for the root-mean-square deviation; MSE, mean square error; RMS SD, root-mean-square error standard deviation; ROI, region of interest.

*p < 0.05 using Wilcoxon rank-sum test to compare variances between genders.
were greater \((p < 0.01)\) compared with \%CV for total tissue: 162\% for lean and 332\% for fat tissue.

To account for different tissue composition and variability in mass between regions, the same models were used with log mean mass instead of region as an explanatory variable (Table 4). The effect of gender was statistically significant in both models \((p = 0.024)\) with both SD and \%CV for females being 80\% of that for males. Variability of lean mass was 124\% of that for total mass \((p = 0.003)\). The natural log of SD increases by 0.22 for every unit increase in the log of the mean mass \((p < 0.001)\), and when converted to the natural scale, the SD is the mean mass raised to the 0.22 power. This suggests that although the SD increases as the mean mass increases, the rate of increase is greater for smaller masses. Conversely, the log of \%CV decreases by 0.78 for every unit increase in the log of the mean mass \((p < 0.001)\). Converted to the natural scale, the estimated \%CV is the mean mass raised to the \(-0.78\) power. This suggests that although the \%CV decreases as the mean mass increases, the rate of decrease is greater for the smaller values of the mass.

**Discussion**

In male and female Division 1 athletes, a group of lean and fit individuals, precision of DXA body composition is excellent for total body and lean mass in all regions assessed in this study. As a clinical generalization, measurement variability was greater in men and differed between lean, fat, and total mass. Moreover, variability generally increases as mass increases, in that measurement sites with larger mass also had higher LSC\_RMSD and lower LSC\_\%CV values in a nonlinear relationship.

Studies evaluating DXA body composition precision are currently quite limited. DXA body composition precision has been reported in nonobese adults \((34)\), young individuals (not athletes) \((17)\), obese populations \((31)\), individuals from the Diabetes Heart Study \((30)\), and individuals with HIV.

![Graph of LSC\_RMSD and \%CV vs. mass](image_url)

**Table 3**

<table>
<thead>
<tr>
<th>Effects</th>
<th>SD</th>
<th>%CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Multiplying factor (95% CI)</td>
<td>(p) Value</td>
</tr>
<tr>
<td>Female</td>
<td>0.81 (0.67—0.97)</td>
<td>0.026</td>
</tr>
<tr>
<td>Male(^a)</td>
<td>Reference</td>
<td>—</td>
</tr>
<tr>
<td>ROI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right arm</td>
<td>0.45 (0.34—0.60)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Left arm</td>
<td>0.41 (0.31—0.53)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Right leg</td>
<td>0.95 (0.71—1.28)</td>
<td>0.751</td>
</tr>
<tr>
<td>Left leg</td>
<td>1.10 (0.85—1.43)</td>
<td>0.446</td>
</tr>
<tr>
<td>Trunk</td>
<td>1.61 (1.35—1.92)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Total(^a)</td>
<td>Reference</td>
<td>—</td>
</tr>
<tr>
<td>Tissue type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fat mass</td>
<td>0.70 (0.60—0.80)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Lean mass</td>
<td>1.17 (1.03—1.34)</td>
<td>0.020</td>
</tr>
<tr>
<td>Total mass(^a)</td>
<td>Reference</td>
<td>—</td>
</tr>
</tbody>
</table>

*Note:* The multiplying factor and the corresponding 95\% CI were estimated from the repeated measures regression models on transformed values (natural logarithm) with SD or \%CV as dependent variables and gender, ROI, and tissue type as explanatory variables.

*Abbr:* CI, confidence interval; \%CV, percent coefficient of variation; ROI, region of interest; SD, standard deviation.

\(^{a}\)Reference category.
Effects of training and food effects on body composition

be fasting and rested before DXA measurement

(36)

body composition change over time in athletic populations

food intake and loss should be considered when monitoring

scans were performed at the same session. However, fluid and

effects do not impact the data reported here, given that these

pact of exercise sessions on body composition; however, such

(36)

with total lean and fat mass values of

found the short-term %CV to be lowest for total mass (0.1%)

Additionally, a recent report of physically active young adults

other methods to assess body composition in athletes

extremity compared with larger region like the total body

when smaller regions have been evaluated, such as a single

mass %CV values of 1.1% and 3.7%, respectively

(31)

studies reported lower %CV studies for fat mass

Although DXA body composition has been compared with

other methods to assess body composition in athletes

only limited data exist on the reproducibility of se-

rial measurements in athletic populations

One study (12) reported the %CV for fat mass to be 2.9%, but

no data for regions or lean mass were reported. A more recent

study that included 31 athletes reported whole-body lean and

fat mass %CV values of 1.1% and 3.7%, respectively

Additionally, a recent report of physically active young adults

found the short-term %CV to be lowest for total mass (0.1%)

with total lean and fat mass values of ~0.5% and ~1.5%

(36). These authors appropriately emphasize the potential im-

pact of exercise sessions on body composition; however, such

effects do not impact the data reported here, given that these

scans were performed at the same session. However, fluid and

food intake and loss should be considered when monitoring

body composition change over time in athletic populations

(36). To this end, it has been suggested that athletic subjects

be fasting and rested before DXA measurement
(35).

Further study of training and food effects on body composition

measurement, ideally leading to standardization of measure-

ment approaches, is needed.

DXA body composition assessment promises to be a valu-

able tool for athletes—it is rapid, relatively uncomplicated,

and has very low radiation exposure. Various sports perform-

ance–related indications could be proposed including com-

paring body composition among different sports, different

positions within team sports, or screening promising young

athletes for lean, fat, and bone mass. However, in our opinion,

most appealing might be the use of DXA body composition

for serial measurement to monitor body composition changes

over time to monitor training programs and/or injury and sub-

sequent rehabilitation. To be able to assess whether a mea-

sured body composition change is larger than the variability

of the assessment itself, a precision analysis must be per-

formed. This can be easily performed using a relatively small

number of individuals with LSCRMSD and LSC%CV being de-

termined using the existing calculators available online

(25–27).

Limitations of this study include the small sample size of

60 participants, use of only a single manufacturer’s densitom-

eter, and study of only young Division 1 athletes from a

limited number of sports. As such, generalization to one par-

icular sport or another densitometer is limited. In addition,

whether similar results are obtained in nonathletic popula-

tions remains to be determined. Importantly, whether the

observed differences in LSCRMSD and LSC%CV are solely re-

duced to ROI mass, or whether other factors also play a role
cannot be determined from this work because of the relatively

small number and heterogeneous sample of these athletes.

Additional studies are necessary to further define whether

there is a gender and/or tissue type effect on precision or

whether the differences observed in this study are simply be-

cause of larger body size of the males in this cohort.

Table 4

Effect of Gender, Tissue Type, and Mean Mass on SD and %CV

<table>
<thead>
<tr>
<th>Effects</th>
<th>SD</th>
<th>p Value</th>
<th>%CV</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Multiplying factor (95% CI)</td>
<td></td>
<td>Multiplying factor (95% CI)</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>0.80 (0.66–0.97)</td>
<td>0.024</td>
<td>0.80 (0.66–0.97)</td>
<td>0.024</td>
</tr>
<tr>
<td>Malea</td>
<td>Reference</td>
<td>—</td>
<td>Reference</td>
<td>—</td>
</tr>
<tr>
<td>Tissue mass</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fat mass</td>
<td>1.07 (0.87–1.33)</td>
<td>0.510</td>
<td>1.07 (0.87–1.33)</td>
<td>0.510</td>
</tr>
<tr>
<td>Lean mass</td>
<td>1.24 (1.08–1.43)</td>
<td>0.003</td>
<td>1.24 (1.08–1.43)</td>
<td>0.003</td>
</tr>
<tr>
<td>Total massa</td>
<td>Reference</td>
<td>—</td>
<td>Reference</td>
<td>—</td>
</tr>
<tr>
<td>Mean mass</td>
<td>c&lt;0.001</td>
<td></td>
<td>e&lt;0.001</td>
<td></td>
</tr>
</tbody>
</table>

| Note: The multiplying factor and the corresponding 95% CI were estimated from the repeated measures regression models on transformed values (natural logarithm) with SD or %CV as dependent variables and gender, tissue type, and mean mass as explanatory variables.
| Abbr: CI, confidence interval; %CV, percent coefficient of variation; SD, standard deviation.
| aReference category.
| bMean mass raised to the power (95% CI) of 0.22 (0.13–0.30).
| cMean mass raised to the power (95% CI) of −0.78 (−0.87 to −0.70).
In conclusion, in this group of Division 1 athletes, fat and lean mass SD and %CV and the corresponding LSCRMSTD and LSC%CV values differed by gender, ROI, tissue type, and mass. Based on analyses of the SD, males have greater variability than females and lean mass has greater variability than fat and total mass, perhaps because of their larger body size. Descriptively, a strong nonlinear positive relationship between LSCRMSTD and mass and a negative relationship between LSC%CV and mass were observed. Thus, to over simplify, variability increases as mass increases and the rate of increase is greater for smaller masses. When using serial total body DXA to evaluate regional fat and lean mass changes in athletes, determination of the LSC values for the body ROIs is essential. Moreover, performance of precision assessment in individuals similar in body size and composition is necessary.

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