Cardiorespiratory Fitness, Obesity, and Functional Limitation in Older Adults

Danielle R. Bouchard, K. Ashlee McGuire, Lance Davidson, and Robert Ross

One hundred forty-six abdominally obese adults age 60–80 yr were studied to investigate the interaction between cardiorespiratory fitness (CRF) and obesity on functional limitation. Obesity was determined by fat mass (FM), CRF was determined by a maximal treadmill test, and functional limitation was based on 4 different tasks that are predictive of subsequent disability. Both FM ($r = -.34$, $p \leq .01$) and CRF ($r = .54$, $p \leq .01$) were independently associated with functional limitation in bivariate analysis. After further control for sex, age, and the interaction term (CRF × FM), FM was no longer independently associated with functional limitation ($p = .10$). Analyses were also based on sex-specific tertiles of FM and CRF. The referent group demonstrated significantly lower functional limitation than the low-CRF/low-FM and the low-CRF/high-FM groups (both $p \leq .05$). These results highlight the value of recommending exercise for abdominally obese adults.

Keywords: fat mass, physical activity, physical function

Functional limitation, which refers to restrictions in a person’s performance (e.g., limitation in the ability to transfer from a sitting to standing position; Nagi, 1964), is predictive of disability in older adults (Guralnik, Ferrucci, Simonsick, Salive, & Wallace, 1995). In addition, it is associated with higher frequency and duration of hospitalization (Penninx et al., 2000; Studenski et al., 2003), higher rate of admission to nursing homes (Severson et al., 1994), greater use of hospital services (Mor, Wilcox, Rakowski, & Hiris, 1994), lower quality of life (Campbell, Crews, Moriarty, Zack, & Blackman, 1999), and a greater risk of all-cause mortality (Reuben, Rubenstein, Hirsch, & Hays, 1992). There are several known risk factors for functional limitation, including low cardiorespiratory fitness (CRF) and obesity (Bouchard, Beliaeff, Dionne, & Brochu, 2007; Huang et al., 1998).

It is well established that obesity is associated with increased functional limitation (Bouchard et al., 2007; Davison, Ford, Cogswell, & Dietz, 2002; Sternfeld, Ngo, Satariano, & Tager, 2002; Visser et al., 1998), whereas higher physical activity and CRF are associated with lower functional limitation (Alexander, Dengel, Olson, & Krajewski, 2003; Huang et al., 1998). However, the interaction between these factors needs to be investigated further.
two variables and the independent influence on functional limitation is unclear. Interaction describes a situation where the combined influence of two variables (obesity and CRF) on a dependent variable (functional limitation) is not additive but multiplicative. A clear understanding of the combined effects of CRF and obesity on functional limitation would lead to better identification of high-risk individuals and the development of successful intervention strategies to improve functional status.

Two previous studies reported no interaction between physical activity and obesity (Riebe et al., 2009; Simoes et al., 2006), but Koster et al. (2008) found that the interaction between obesity and physical activity on functional limitation was dependent on sex and the obesity measure used. The discrepancy between studies may be explained in part by the use of indirect or self-report measures to determine physical activity, obesity, and functional limitation (Koster et al., 2008; Riebe et al., 2009; Simoes et al., 2006). This is not a trivial limitation because the use of self-report measurement tools is prone to bias that confounds interpretation (Guralnik & Simonsick, 1993; Myers, Holliday, Harvey, & Hutchinson, 1993).

Thus, the purpose of this study was to clarify whether there is an interaction between CRF and obesity on functional limitation in a sample of sedentary, abdominally obese older adults using objective measures of CRF, obesity, and functional limitation. We hypothesized that both obesity and CRF would be independently associated with functional limitation in abdominally obese older adults. We further hypothesized that for a given CRF in abdominally obese older adults, increasing levels of obesity would be associated with increasing functional limitation, and for a given obesity, increasing levels of CRF would be associated with decreasing functional limitation.

**Methods**

**Participants**

An opportunistic sample of 146 abdominally obese (waist circumference ≥102 cm for men and ≥88 cm for women; Grundy, Brewer, Cleeman, Smith, & Lenfant, 2004), nonsmoking adults 60–80 years old was recruited for an exercise intervention trial published previously (Davidson et al., 2009). Participants were required to be weight stable (±2 kg) for the 6 months before study entry. Potential participants were excluded if they reported any condition that would prevent them from engaging in an exercise program, if they were currently dieting or intended to diet, if they were already engaging in two or more planned exercise sessions per week, or if they were taking any medication to lower glucose levels. The study was approved by the Queen’s University Health Science Research Ethics Board. All participants received medical approval from their personal physicians and gave informed consent before participation.

**Anthropometric and Body-Composition Measures**

Body weight and height were measured with participants dressed in standard T-shirts and shorts. Body-mass index (BMI) was calculated (body weight [kg]/height [m²]). Waist circumference was measured in a standing position using the mean of two measures obtained at the superior edge of the iliac crest (National
Fat mass (FM), skeletal-muscle mass, and visceral fat were measured by magnetic resonance imaging and analyzed using standard procedures (Mitsiopoulos et al., 1998; Ross, Leger, Morris, de Guise, & Guardo, 1992). The ratio of fat to skeletal-muscle mass was also calculated.

Obesity can be estimated using a variety of measures, but the best index varies depending on the study population and the outcome of interest. Two sets of analyses were used to determine which obesity index to use in our investigation. First, with all obesity measures available in this sample (BMI, waist circumference, visceral fat, FM, percentage fat, and ratio of fat to skeletal-muscle mass), correlations adjusted for age and sex were determined. Results indicated that FM was the obesity measure most strongly associated with functional limitation \(r = -0.22, p \leq 0.01\). In fact, no other obesity measures were associated with functional limitation once adjusted for sex and age \(r = -0.02\) to \(-0.08, p > .11\). Second, a stepwise regression with all obesity measures was conducted. FM was the first obesity measure to enter the model. Therefore, FM was used as the indicator of obesity in all analyses.

**CRF**

CRF (measured as oxygen consumption per unit of time [peak VO₂]) was determined using a maximal treadmill test combined with standard open-circuit spirometry techniques (Sensor Medics Corp., Yorba Linda, CA). A modified Balke and Ware treadmill test was used to attain peak VO₂ (Balke & Ware, 1959). Mean speed and slope percentage at maximum effort were, respectively, 5 km/hr (3.2 miles/hr) and 6.9%. Oxygen consumption relative to individual body weight (ml · kg⁻¹ · min⁻¹) was used in all analyses because a weight-bearing exercise (treadmill) was used to measure CRF.

**Classification of CRF and FM Groups**

Tertiles of FM and CRF were created to evaluate functional limitation across groups. Because sex differences in FM and CRF are well documented (Sui et al., 2007), participants were cross-classified into nine sex-specific tertiles (low, medium, and high) and then collapsed across gender (Table 1) based on their sex-adjusted functional limitation.

**Functional Limitation**

Functional limitation was evaluated using four tests designed by Rikli and Jones (2001) that are associated with independent living in older adults. Items consisted of the maximal number of chair stands performed in 30 s (the number of times the subject stood up from a chair without arm support), the 2-min step (the number of steps in place in 2 min), the 8-ft up-and-go (the time needed to get out of a chair, walk 2.4 m, and return to a seated position in the chair), and the seated arm curl (the number of times a hand weight [2.25 kg for women and 3.6 kg for men] could be curled through a full range in 30 s). We chose to evaluate functional limitation using predominantly lower extremity exercise tests because they are strong predictors of subsequent disability (Guralnik, Ferrucci, Simonsick, Salive, & Wallace,
Because the unit of measurement is not equivalent across tests, a composite score was calculated by normalizing each score using the \( z \) scores. An average of the results from the four tests was then computed to derive a mean \( z \) score for each individual, and this functional limitation composite score was used in all further analyses. That score was used to define functional limitation and was multiplied by 100 to facilitate interpretation. A factor analysis was performed to confirm that all functional limitation tests could be used to create an aggregated score. The factor analysis revealed that each of the four tests was highly related (\( r \geq .86 \)) to the factor score.

### Statistical Analysis

Partial correlations adjusted for age and sex were used to examine the associations between FM, CRF, the interaction between CRF and FM (CRF \( \times \) FM) and the functional limitation composite score. A general linear model was used to test for sex interaction terms with CRF, FM, and CRF \( \times \) FM. No interaction terms were significant for sex, so results were collapsed across gender. Because age, sex, and body-fat distribution are known to be associated with functional limitation, three models predicting the functional limitation composite score were analyzed: an unadjusted model, a model adjusted for age and sex, and a model adjusted for age, sex, and waist circumference.

Finally, participants were cross-classified into sex-specific tertiles according to CRF and FM. General linear models were used to identify differences in functional limitation among the nine groups after controlling for age. Dunnet’s post hoc test was used for group comparisons, with low FM/high CRF as the reference group.

Data management and statistical analyses were performed using SAS, version 9.1 (SAS Institute, Inc., Cary, NC).
Results

Descriptive characteristics are shown in Table 2. All characteristics, except age and BMI, were different between men and women ($p \leq .05$). Partial correlations adjusted for age and sex indicated that functional limitation was significantly associated with CRF ($r = .31, p \leq .01$) and FM ($r = -.22, p \leq .01$), whereas there was no significant association with CRF × FM (Table 3).

### Table 2  Participant Characteristics, $M \ (SE)$

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>$68 \pm 5$</td>
</tr>
<tr>
<td>Men, $n \ (%)$</td>
<td>$61 \ (41.8)$</td>
</tr>
<tr>
<td><strong>Body composition</strong></td>
<td></td>
</tr>
<tr>
<td>Weight, kg</td>
<td>$85.50 \pm 12.57$</td>
</tr>
<tr>
<td>Body-mass index, kg/m$^2$</td>
<td>$30.07 \pm 3.07$</td>
</tr>
<tr>
<td>Waist circumference, cm</td>
<td>$107.59 \pm 9.08$</td>
</tr>
<tr>
<td>Fat mass, kg</td>
<td>$34.80 \pm 7.02$</td>
</tr>
<tr>
<td>Fat percentage</td>
<td>$41.59 \pm 9.67$</td>
</tr>
<tr>
<td>Visceral fat, kg</td>
<td>$3.38 \pm 1.40$</td>
</tr>
<tr>
<td>Skeletal-muscle mass, kg</td>
<td>$24.23 \pm 6.23$</td>
</tr>
<tr>
<td>Ratio of fat to skeletal muscle</td>
<td>$1.53 \pm 0.47$</td>
</tr>
<tr>
<td><strong>Cardiorespiratory fitness level</strong></td>
<td></td>
</tr>
<tr>
<td>Absolute VO$_{2peak}$, L/min</td>
<td>$2.10 \pm 0.44$</td>
</tr>
<tr>
<td>Relative VO$_{2peak}$, ml · kg$^{-1} · $min$^{-1}$</td>
<td>$24.48 \pm 5.11$</td>
</tr>
<tr>
<td><strong>Functional limitation</strong></td>
<td></td>
</tr>
<tr>
<td>30-s chair stands, #</td>
<td>$13.63 \pm 3.72$</td>
</tr>
<tr>
<td>30-s arm curls, #</td>
<td>$17.03 \pm 4.22$</td>
</tr>
<tr>
<td>2-min steps test, #</td>
<td>$99.58 \pm 20.59$</td>
</tr>
<tr>
<td>8-ft up-and-go, s</td>
<td>$4.75 \pm 0.90$</td>
</tr>
<tr>
<td>$z$ Score × 100</td>
<td>$-0.02 \pm 50.10$</td>
</tr>
</tbody>
</table>

### Table 3  Association Between Functional Limitation, Cardiorespiratory Fitness (CRF), and Fat Mass (FM)

<table>
<thead>
<tr>
<th></th>
<th>Unadjusted functional limitation</th>
<th>Adjusted functional limitation$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRF</td>
<td>$.54^*$</td>
<td>$.31^*$</td>
</tr>
<tr>
<td>FM</td>
<td>$-.34^*$</td>
<td>$-.22^*$</td>
</tr>
<tr>
<td>CRF × FM</td>
<td>$.26^*$</td>
<td>$.01</td>
</tr>
</tbody>
</table>

$^a$Correlations adjusted for sex and age.

$^p \leq .01.$
In the unadjusted multiple-regression model, CRF ($p < .001$) was a significant predictor of functional limitation, but FM and CRF $\times$ FM were not. However, after adjustment for age and sex, CRF ($p = .009$) and CRF $\times$ FM ($p = .044$) were independently associated with functional limitation but FM was not ($p = .10$; Table 4). Further adjustment for waist circumference did not increase the variance explained by the models.

Further analyses based on tertiles of CRF and FM indicated a significant difference in functional limitation among groups after controlling for age and sex ($p \leq .01$; Figure 1); the referent group demonstrated significantly lower functional limitation than the low-FM/low-CRF group ($p \leq .05$) or the high-FM/low-CRF group ($p \leq .05$).

**Discussion**

The primary finding of this investigation is that CRF but not FM is associated with functional limitation after adjustment for age, sex, and interaction (CRF $\times$ FM). Secondary findings suggest that for a given FM, functional limitation is lower in individuals with high CRF than in those with low CRF. This observation highlights the importance of CRF as an independent predictor of functional limitation in older adults and the value of promoting physical activity to increase physical fitness and muscle strength in this population.

Our findings extend and clarify previous research describing the interaction between self-reported physical activity and obesity on functional limitation. Two studies found no interaction (Riebe et al., 2009; Simoes et al., 2006); however, those studies had several limitations including the use of self-reported physical activity, indirect measures of body composition, and questionnaires to evaluate functional limitation. On the other hand, Koster et al. (2008) reported an interaction in women when percentage body fat and waist circumference were used as the obesity index, not BMI. No interaction was found in men. Methodological differences may in part explain the inconsistencies between our results and those of previous studies. In our study, a composite score of four objective tests of functional limitation was used instead of questionnaires. Objective measurement of functional limitation is recognized as the gold standard because it does not rely on the participant’s perception, it is more sensitive to differences between participants (Hoeymans, Feskens, van den Bos, & Kromhout, 1996), and it is better able to characterize individuals across a broad spectrum of functional limitation (Guralnik et al., 1994). In addition, we acquired measurements of body composition and CRF using criterion measurement tools. Self-reported and indirect measures of physical activity and body composition have been criticized (Fernandez-Real, Vayreda, Casamitjana, Saez, & Ricart, 2001; Prince et al., 2008). Therefore, the methodology used in our study increases the validity of our findings.

Our findings are consistent with previous literature regarding the independent role of CRF on functional limitation (Alexander et al., 2003; Brach, VanSwearingen, FitzGerald, Storti, & Kriska, 2004; Huang et al., 1998). High CRF prevents morbidities such as cardiovascular disease and hypertension that may lead to functional limitation (Franchignoni, Tesio, Martino, & Ricupero, 1998; Sloan, Sawada, Martin, Church, & Blair, 2009). In addition, high CRF is associated with increased
Table 4 Prediction of Functional Limitation From Cardiorespiratory Fitness (CRF) and Fat Mass (FM), Unstandardized β (SE)

<table>
<thead>
<tr>
<th>Model</th>
<th>CRF (ml · kg⁻¹ · min⁻¹)</th>
<th>p</th>
<th>FM (kg)</th>
<th>p</th>
<th>CRF × FM</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1 ($F = 19.7, R^2 = .29$; adjusted $R^2 = .28$)</td>
<td>12.77 (4.14)</td>
<td>≤.001</td>
<td>-5.13 (2.92)</td>
<td>.704</td>
<td>-0.23 (0.12)</td>
<td>.063</td>
</tr>
<tr>
<td>Model 2 ($F = 15.9, R^2 = .37$; adjusted $R^2 = .34$)</td>
<td>10.85 (4.00)</td>
<td>.009</td>
<td>-4.81 (2.80)</td>
<td>.088</td>
<td>-0.26 (0.12)</td>
<td>.044</td>
</tr>
<tr>
<td>Model 3 ($F = 13.3, R^2 = .37$; adjusted $R^2 = .33$)</td>
<td>10.49 (4.04)</td>
<td>.010</td>
<td>-3.25 (2.92)</td>
<td>.148</td>
<td>-0.24 (0.12)</td>
<td>.051</td>
</tr>
</tbody>
</table>

Note. Model 1 is unadjusted; Model 2 is adjusted for sex and age; Model 3 is adjusted for sex, age, and waist circumference.

Figure 1 — Functional limitation according to fat mass (FM) and cardiorespiratory fitness (CRF; tertiles). Data are presented as sex- and age-adjusted means. *Significantly different from the referent group ($p ≤ .05$). Note that a negative $z$ score means presenting more functional limitation than a positive $z$ score.
muscle strength, irrespective of obesity (Flouris, Metsios, & Koutedakis, 2006) and muscle mass (Davidson et al., 2009), which attenuates functional limitation.

Our results do not support the dogma that obesity is associated with increased functional limitation after control for self-reported physical activity (Bouchard et al., 2007; Brach, Simonsick, Kritchevsky, Yaffe, & Newman, 2004; Koster et al., 2008; Lebrun, van der Schouw, de Jong, Grobbee, & Lamberts, 2006). This result does not imply that CRF is more strongly related to functional limitation than physical activity. Similar to previous literature, our results suggest that CRF might be a better surrogate of habitual activity than self-reported physical activity (Church, Earnest, Skinner, & Blair, 2007; Jackson, Sui, Hebert, Church, & Blair, 2009). Thus, it is possible that an objective measure of physical activity (e.g., accelerometry) would be an equal predictor of functional limitation compared with CRF. Furthermore, our finding that body-fat distribution, indicated by waist circumference, is not associated with functional limitation is also in contrast with prior observations suggesting an association between waist circumference and functional limitation (Chen, Bermudez, & Tucker, 2002; Guallar-Castillon et al., 2007; Ramsay, Whincup, Shaper, & Wannamethee, 2006). These differences may be partially explained by the absence of a large variability in FM among our sample. Nevertheless, to our knowledge, no other study considered CRF when assessing the interaction between obesity and functional limitation. Other mechanisms such as muscle strength and power may also contribute to the association observed between physical activity or CRF and functional limitation (Flouris et al., 2006; Lucia et al., 2002).

Previous studies have shown that a decrease in adiposity or an increase in muscle strength or mass after an intervention are associated with improvements in functional limitation (Bouchard, Soucy, Senechal, Dionne, & Brochu, 2008; Davidson et al., 2009; Villareal, Banks, Sinacore, Siener, & Klein, 2006). For example, Davidson et al. reported that older adults who increased skeletal-muscle mass but had no change in obesity or CRF experienced improvements in functional limitation. In addition, older adults who increased CRF and decreased obesity but had no change in skeletal-muscle mass also decreased functional limitation. Thus, older abdominally obese individuals would benefit from regular exercise (aerobic or resistance) to decrease functional limitation.

Limitations of this study include our homogeneous sample of abdominally obese, sedentary older individuals, most of whom were White and without any physical impairment. Therefore, our results may not be generalizable to individuals with different activity levels, those without abdominal obesity, or those of different ethnicity and age. However, the population in our study does represent a high-risk group that is prevalent, so our observations may be applicable to a large population of older adults. Another limitation that must be raised is the fact that muscle strength was not assessed in the current study because an individual’s strength could potentially affect the interaction between FM and CRF.

In summary, our study suggests that CRF but not FM is associated with functional limitation after adjustment for age, sex, and interaction in abdominally obese older adults. This suggests that CRF may have a stronger effect on functional limitation than obesity. This highlights the role of physical activity, which improves CRF and strength, in determining functional limitation and the importance of recommending regular exercise in this high-risk population. However, these findings do not provide insight into the impact of FM and CRF on normal-weight individuals.
Acknowledgment

This research project was funded by research grant MT 13448 from the Canadian Institutes of Health Research (CIHR). Dr. Bouchard is supported by the CIHR, and K.A. McGuire is supported by the Canadian Diabetes Association.

References


