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Original Investigation

# Changes in Functional Mobility and Musculoskeletal Pain After Bariatric Surgery in Teens With Severe Obesity

## Teen–Longitudinal Assessment of Bariatric Surgery (LABS) Study

Justin R. Ryder, PhD; Nicholas M. Edwards, MD, MPH; Resmi Gupta, MS, MA; Jane Khoury, PhD; Todd M. Jenkins, PhD; Sharon Bout-Tabaku, MD, MSCE; Marc P. Michalsky, MD; Carroll M. Harmon, MD, PhD; Thomas H. Inge, MD, PhD; Aaron S. Kelly, PhD

**IMPORTANCE** Severe obesity is associated with mobility limitations and higher incidence of multijoint musculoskeletal pain. It is unknown whether substantial weight loss improves these important outcomes in adolescents with severe obesity.

**OBJECTIVE** To examine the association of bariatric surgery with functional mobility and musculoskeletal pain in adolescents with severe obesity up to 2 years after surgery.

**DESIGN, SETTING, AND PARTICIPANTS** The Teen–Longitudinal Assessment of Bariatric Surgery Study is a prospective, multicenter, observational study, which enrolled 242 adolescents ( $\leq 19$  years of age) who were undergoing bariatric surgery from March 2007 through February 2012 at 5 US adolescent bariatric surgery centers. This analysis was conducted in November 2015.

**INTERVENTIONS** Roux-en-Y gastric bypass (n = 161), sleeve gastrectomy (n = 67), or laparoscopic adjustable gastric band (n = 14).

**MAIN OUTCOMES AND MEASURES** Participants completed a 400-m walk test prior to bariatric surgery (n = 206) and at 6 months (n = 195), 12 months (n = 176), and 24 months (n = 149) after surgery. Time to completion, resting heart rate (HR), immediate posttest HR, and HR difference (resting HR minus posttest HR) were measured and musculoskeletal pain concerns, during and after the test, were documented. Data were adjusted for age, sex, race/ethnicity, baseline body mass index (calculated as weight in kilograms divided by height in meters squared), and surgical center (posttest HR and HR difference were further adjusted for changes in time to completion).

**RESULTS** Of the 206 adolescents with severe obesity included in the study, 156 were female (75.7%), the mean (SD) age was 17.1 (1.6) years, and the mean (SD) body mass index was 51.7 (8.5). Compared with baseline, significant improvements were observed at 6 months for the walk test time to completion (mean, 376 seconds; 95% CI, 365-388 to 347 seconds; 95% CI, 340-358;  $P < .01$ ), resting HR (mean, 84 beats per minute [bpm]; 95% CI, 82-86 to 74 bpm; 95% CI, 72-76), posttest HR (mean, 128 bpm; 95% CI, 125-131 to 113 bpm; 95% CI, 110-116), and HR difference (mean, 40 bpm; 95% CI, 36-42 to 34 bpm; 95% CI, 31-37). These changes in time to completion, resting HR, and HR difference persisted at 12 months and 24 months. Posttest HR further improved from 6 months to 12 months (mean, 113 bpm; 95% CI, 110-116 to 108 bpm; 95% CI, 105-111). There were statistically significant reductions in musculoskeletal pain concerns at all points.

**CONCLUSIONS AND RELEVANCE** These data provide evidence that bariatric surgery in adolescents with severe obesity is associated with significant improvement in functional mobility and in the reduction of walking-related musculoskeletal pain up to 2 years after surgery.

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**Author Affiliations:** University of Minnesota Medical School, Minneapolis (Ryder, Kelly); Cincinnati Children's Hospital Medical Center, Cincinnati, Ohio (Edwards, Gupta, Khoury, Jenkins, Inge); Nationwide Children's Hospital, Columbus, Ohio (Bout-Tabaku, Michalsky); Women and Children's Hospital of Buffalo, Buffalo, New York (Harmon).

**Corresponding Author:** Justin R. Ryder, PhD, Department of Pediatrics, University of Minnesota Medical School, 420 Delaware St SE, MMC 715, Minneapolis, MN 55455 (jryder@umn.edu).

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Adolescent severe obesity (body mass index [BMI, calculated as weight in kilograms divided by height in meters squared]  $\geq 1.2$  times the 95th BMI percentile) is characterized by a number of chronic comorbid conditions including functional mobility limitations and musculoskeletal pain.<sup>1-7</sup> In adults, limitations in functional mobility, assessed using walking tests, are associated with lower quality of life,<sup>8</sup> chronic pain,<sup>9</sup> and early mortality.<sup>10,11</sup> Importantly, the degree of adiposity appears to play a pivotal role in exacerbating functional mobility limitations.<sup>12-14</sup> Youth with obesity are not immune to these consequences, often experiencing musculoskeletal pain,<sup>15</sup> which can lead to declines in physical activity patterns and impaired functional mobility.<sup>16,17</sup> Improving and preserving functional mobility while subsequently reducing musculoskeletal pain in adolescents with severe obesity might encourage more physical activity, thereby improving many important long-term health outcomes.

Lifestyle modification interventions in youth with severe obesity who have incorporated physical activity have shown significant improvements in cardiovascular fitness<sup>18</sup> and walking distance.<sup>19</sup> However, these structured programs are usually offered for a relatively short period and the long-term challenges of adherence to lifestyle changes for youth with severe obesity are well documented.<sup>20,21</sup> Thus, there is a need to investigate whether alternative treatments offer sustained improvements in functional mobility and musculoskeletal pain outcomes in youth with severe obesity. For adults who have undergone bariatric surgery, significant improvements in standardized walk test time, mobility tasks, and cardiovascular fitness along with reductions in musculoskeletal pain have been documented.<sup>22-26</sup> However, to our knowledge, the extent to which similar benefits accrue after bariatric surgery in adolescents is unknown.

The overall goal of this study was to examine the effect of bariatric surgery on functional mobility and musculoskeletal pain in adolescents enrolled in the Teen-Longitudinal Assessment of Bariatric Surgery (Teen-LABS) Study up to 2 years after surgery. We used a standardized 400-m walk test with assessments of time to test completion, resting heart rate (HR), immediate posttest HR, HR recovery, and walking-related musculoskeletal pain to examine changes over time.

## Methods

### Study Cohort and Measurement Points

Participants from the Teen-LABS Study were included in this analysis conducted in November 2015.<sup>27</sup> The Teen-LABS Study is an ongoing National Institute of Diabetes and Digestive and Kidney Diseases–funded, prospective, longitudinal, multicenter observational study that enrolled consecutive adolescents ( $\leq 19$  years of age) undergoing bariatric surgery at 5 clinical centers. Written parental permission, participant assent ( $< 18$  years old), and consent from older adolescents ( $\geq 18$  years old) were obtained. Data collection points used for this analysis were baseline (preoperative) and 6-month, 12-month, and 24-month postoperative assessments. At each assessment, height was measured on a wall-mounted stadiometer and weight on

### Key Points

**Question** Does bariatric surgery improve functional mobility and reduce musculoskeletal pain in adolescents with severe obesity?

**Findings** Within the context of a longitudinal multicenter study of adolescent bariatric surgery, time to completion of a 400-m walk test, resting heart rate, and heart rate difference were improved compared with baseline and at 6, 12, and 24 months after surgery. There were statistically significant reductions in musculoskeletal pain concerns at all times.

**Meaning** Bariatric surgery is associated with improved functional mobility and reduction in musculoskeletal pain in adolescents with severe obesity up to 2 years after surgery.

an electronic scale (Scale-Tronix 5200, Scale Tronix, or Tanita TBF310) and BMI was calculated.

The protocol and data and safety monitoring plans were approved by the institutional review board at each institution and by a data and safety monitoring board for the study as a whole.

### Assessment of Functional Mobility

Participants completed a 400-m walk test prior to planned bariatric surgery and again at 6 months, 12 months, and 24 months after surgery. Time to completion, resting HR, immediate posttest HR, 2-minute HR recovery (posttest HR minus 2-minute postcompletion HR), and HR difference (resting HR minus immediate posttest HR) were measured. Heart rate was measured by a Polar HR monitor (Polar Electro Inc), while completion time was measured by stopwatch. We have previously reported the accuracy and validity of physical activity measurement during a 400-m walk test in youth with severe obesity.<sup>28</sup> Musculoskeletal pain concerns were documented during and after the completion of the 400-m walk tests and consisted of knee, hip, calf, foot, and back pain, along with numbness or tingling and leg cramps. Any of these indications during or after the test qualified as a musculoskeletal pain concern and were combined for analysis (composite end point).

### Statistical Analysis

Standard descriptive statistics summarized participant characteristics at baseline. Categorical variables were calculated as frequencies and percentages. A quantile-quantile plot was used to determine whether response variables (time to completion, resting HR, posttest HR, 2-minute HR recovery, and HR difference) were normally distributed. On the basis of the observed plot, log transformations were used to normalize the time-to-completion distribution for subsequent modeling. Linear mixed-effects models were used to determine the changes over time in functional mobility parameters from baseline. Initially, both random intercept and slope were used to fit the data, but random slope was dropped from the final model because it was not statistically significant. The unstructured covariance was used in order for each variance and covariance to be freely estimated. Generalized estimating equations were used to estimate the relative risk associated with musculoskeletal

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pain concerns (with vs without pain) following surgery. An unstructured correlation with robust variance estimators was used for model estimates. All models were adjusted for age, race/ethnicity, sex, baseline BMI, and surgical center. Surgery type was also entered in the initial models but was not statistically significant in any models, and so it was removed from the final models. Data using postsurgery (6-month, 12-month, and 24-month) follow-up visits for immediate posttest HR, 2-minute HR recovery, and HR difference were further adjusted for changes in time to completion. Multiple imputation was used for missing covariates for all models. Data are presented as means with 95% CIs. The estimates presented in the figures represent marginally adjusted means and associated 95% CIs from the models. The statistical significance level was set at  $\alpha = .05$ . Bonferroni adjustment for multiple testing was used for all post hoc comparisons between time points within each hypothesis considered in this study. All analyses were conducted with SAS statistical software version 9.4 (SAS Institute Inc).

### Results

Preoperative demographic, anthropometric, and clinical characteristics of the sample are displayed in the **Table**. Most patients were female ( $n = 156$ , 75.7%) and white ( $n = 149$ , 72.3%). Of the 3 surgical procedures performed, most were Roux-en-Y gastric bypass ( $n = 139$ , 67.5%) followed by vertical sleeve gastrectomy ( $n = 56$ , 27.2%) and laparoscopic adjustable gastric banding ( $n = 11$ , 5.3%). Owing to the relatively small number of patients who received laparoscopic adjustable gastric banding and the well-described differences in BMI outcome compared with Roux-en-Y gastric bypass and vertical sleeve gastrectomy, this group was excluded from the analysis. The BMI percentage change from baseline to 6 months was a decrease of 32.5%; from 6 months to 12 months, an additional decrease of 7.8% (40.3% cumulative BMI percentage reduction); and from 12 months to 24 months, an additional decrease of 0.2% (40.4% cumulative BMI percentage reduction). A total of 109 patients (53%) had measurements for all 4 visits, and 67 (33%) had 3 measurements of 4 visits. A total of 22 (11%) and 8 (4%) completed 2 measurements and 1 measurement, respectively, of all 4 visits.

At baseline, BMI was significantly positively associated ( $P < .05$ ) with posttest HR ( $r = 0.33$ ;  $P < .01$ ), time to completion ( $r = 0.16$ ;  $P = .02$ ), and 2-minute HR recovery ( $r = 0.18$ ;  $P = .01$ ) and was significantly inversely associated with HR difference ( $r = 0.17$ ;  $P = .01$ ) after adjusting for age, sex, and race/ethnicity (eTable in the Supplement). Changes in time to completion and resting HR, adjusted for age, sex, race/ethnicity, baseline BMI, and surgical center at baseline, 6 months, 12 months, and 24 months are displayed in **Figure 1**. At 6 months after surgery, significant improvements were observed in time to completion (mean [SD], 376 [1] seconds; 95% CI, 365-388 to 347 [1] seconds; 95% CI, 340-358;  $P < .01$ ) and resting HR (mean [SD], 84 [1] beats per minute [bpm]; 95% CI, 82-86 to 74 [1] bpm; 95% CI, 72-76;

**Table. Preoperative (Baseline) Demographic, Anthropometric, and Surgical Type for the Teen-LABS Cohort (N = 206)**

Characteristic	No. (%)
Age at operation, mean (SD) [range], y	17.1 (1.6) [13.2-20.3]
BMI, mean (SD) [range]	51.7 (8.5) [33.9-80.4]
Sex	
Male	50 (24.3)
Female	156 (75.7)
Race/ethnicity	
White	149 (72.3)
Black	44 (21.4)
Asian	1 (0.5)
Multiracial/ethnic	12 (5.8)
Surgical type	
RYGB	139 (67.5)
VSG	56 (27.2)
LAGB <sup>a</sup>	11 (5.3)

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); LAGB, laparoscopic adjustable gastric banding; RYGB, Roux-en-Y gastric bypass; VSG, vertical sleeve gastrectomy.

<sup>a</sup> Data were not included in the present analysis.

$P < .01$ ). The changes in time to completion and resting HR persisted at 12 months and 24 months, with no additional statistically significant improvements observed.

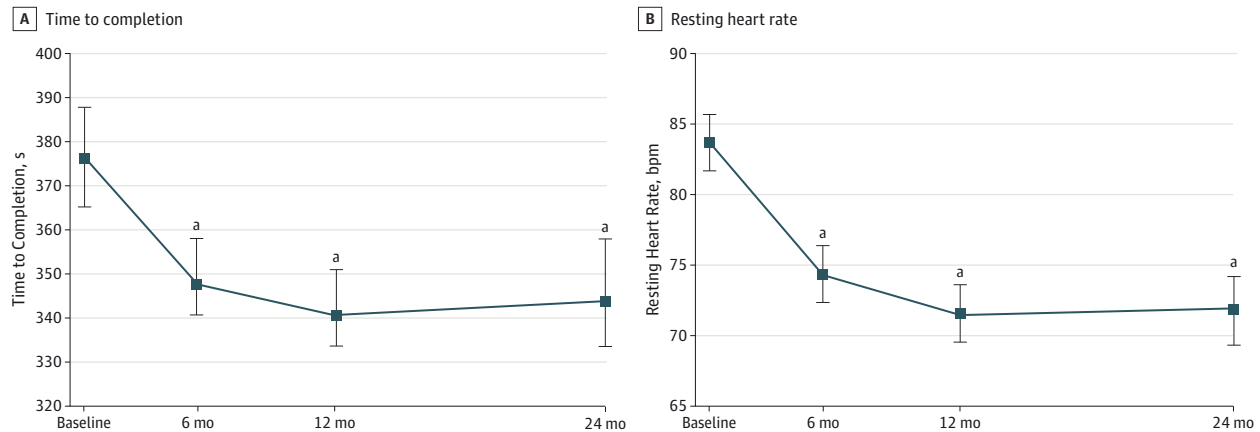
Changes in posttest HR, HR difference, and 2-minute HR recovery, adjusted for age, sex, race/ethnicity, baseline BMI, surgical center, and change in time to completion at baseline, 6 months, 12 months, and 24 months are displayed in **Figure 2**. At 6 months after surgery, significant improvements were observed in posttest HR (mean [SD], 128 [2] bpm; 95% CI, 125-131 to 113 [2] bpm; 95% CI, 110-116;  $P < .01$ ), and HR difference (mean [SD], 40 [2] bpm; 95% CI, 36-42 to 34 [2] bpm; 95% CI, 31-37;  $P < .01$ ). There was a significant improvement in 2-minute HR recovery from baseline to 12 months (mean [SD], -31 [1] bpm; 95% CI -33 to -28 to -25 [1] bpm; 95% CI, -28 to -23;  $P < .01$ ) but no other statistically significant differences were observed between time points. There was no additional statistically significant improvement in HR difference at 12 months and 24 months. Posttest HR further improved from 6 months to 12 months (mean [SD], 113 [2] bpm; 95% CI, 110-116 to 108 [2] bpm; 95% CI, 105-111;  $P = .01$ ) with no additional improvements observed at 24 months.

At 6 months, no association between percentage change in BMI and any measure of functional mobility or musculoskeletal pain was observed. At 12 months ( $\beta = 1.08$ ) and 24 months ( $\beta = 1.01$ ) only, change in time to completion was associated with percentage change in BMI ( $P < .01$ ). Additionally, no consistent associations between changes in systolic blood pressure, diastolic blood pressure, or mean arterial pressure with changes in HR responses were observed.

The cumulative number of participants reporting walking-related musculoskeletal pain concerns is displayed in **Figure 3**. From baseline, the relative risk (RR) of musculoskeletal pain

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Figure 1. Changes in Time to Completion for the 400-m Walk Test and Resting Heart Rate Prior to Testing From Baseline to 6 Months, 12 Months, and 24 Months



Data are adjusted for age, sex, race/ethnicity, baseline body mass index, and surgical center. The error bars represent 95% CIs. bpm indicates beats per minute.

<sup>a</sup>  $P < .01$  from baseline.

concerns after adjusting for age, sex, race/ethnicity, baseline BMI, and surgical center was reduced at 6 months (RR, 0.76; 95% CI, 0.67-0.84), 12 months (RR, 0.62; 95% CI, 0.51-0.71), and 24 months (RR, 0.47; 95% CI, 0.37-0.62) ( $P < .01$  all from baseline).

## Discussion

The findings from this prospective observational study of bariatric surgery in adolescents with severe obesity suggest that meaningful and durable improvements in functional mobility and reductions in musculoskeletal pain occur in the post-surgical setting. Most improvements were observed at 6 months after surgery, which is concurrent with the greatest weight loss achieved. However, the changes at 6 months were not associated with the magnitude of reduction in BMI. Importantly, all measures of functional mobility and musculoskeletal pain, which improved at 6 months, were maintained up to the 2-year follow-up point.

To our knowledge, this is the first study to conduct standardized 400-m walk tests in adolescents with severe obesity prior to and following bariatric surgical intervention (ie, up to 2 years). Our findings are in line with several adult studies, which observed significant improvements in resting HR, posttest HR, exercise capacity, and reductions in musculoskeletal pain after bariatric surgery.<sup>22-26</sup> Direct comparison between adult studies and the present study are challenging because most adult studies used a time-based assessment (6-minute walk test) rather than a distance-based assessment (400-m walk test) as was measured in our study. However, the mean completion time for the walk test among participants in our study was only slightly longer than 6 minutes (6 minutes and 17 seconds) and the distance covered in most adult studies was around 400 m (381-489 m), suggesting that it might be reasonable to make

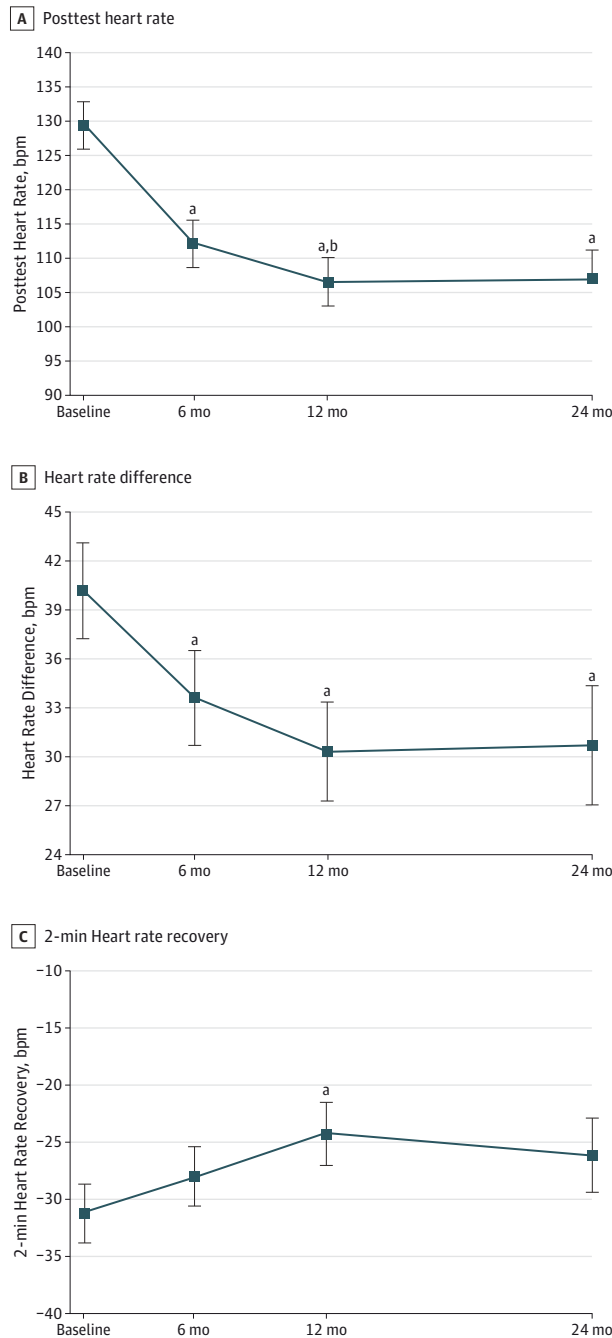
comparisons.<sup>24,26,29</sup> De Souza et al<sup>26</sup> observed improvements in resting HR and immediate posttest HR in adults 7 to 12 months following bariatric surgery along with greater distance achieved. Similarly, Maniscalco and colleagues<sup>29</sup> reported improvements in resting HR, immediate posttest HR, and changes in respiratory function 1 year after bariatric surgery. The magnitude of change in HR response prior to and after testing was comparable between the present study and those reported in adults. Taken together, the body of literature suggests that functional mobility in both adults and adolescents with severe obesity can be improved in a relatively short period following bariatric surgery.

The mechanism(s) responsible for reductions in HR response at rest and after testing are unknown and may not be entirely weight loss dependent. Others have shown that adults 3 months following bariatric surgery exhibited significantly reduced resting HR and, during a 6-minute walk test, had significantly improved HR responses during and immediately following the test as well as demonstrated improved HR recovery.<sup>24</sup> Interestingly, these changes in HR were accompanied by peripheral muscular metaboreflex responses, which are indicative of enhanced muscle profusion. Studies in adults<sup>30,31</sup> and adolescents<sup>32,33</sup> have shown beneficial adaptations in cardiac structure and function following bariatric surgery, which when coupled with improvements in systemic vascular function,<sup>34,35</sup> may play an important role in regulating HR responses during rest and after exercise. Although physiologically plausible, this theory is somewhat speculative, and we observed no association between changes in HR response and changes in blood pressure at any point. However, the mechanism(s) of beneficial adaptation in resting and exercise HR response following bariatric surgery warrants further evaluation.

We also observed meaningful reductions in musculoskeletal pain concerns both during and after the 400-m walk test. The reduction in pain following bariatric surgery

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**Figure 2. Changes in Posttest Heart Rate, Heart Rate Difference, and 2-Minute Heart Rate Recovery From Baseline to 6 Months, 12 Months, and 24 Months**



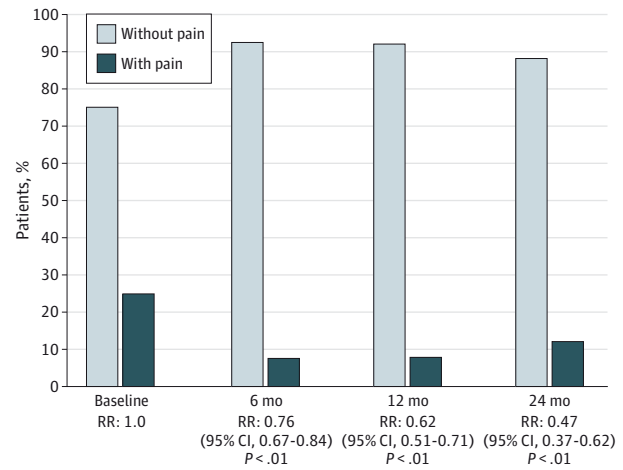
Data are adjusted for age, sex, race/ethnicity, baseline body mass index, surgical center, and change in time to completion. The 2-minute heart rate recovery is calculated by posttest heart rate minus 2-minute postcompletion heart rate. The error bars represent 95% CIs. bpm indicates beats per minute.

<sup>a</sup>  $P < .01$  from baseline.

<sup>b</sup>  $P = .01$  from 6 months.

could translate to increased physical activity patterns in adolescents with severe obesity because joint pain can influence willingness to engage in activity.<sup>36</sup> Correspond-

**Figure 3. Patients With and Without Musculoskeletal Pain Concerns During or After the 400-m Walk Test at Baseline (Preoperative) and 6-Month, 12-Month, and 24-Month Follow-up**



Relative risk (RR) of having musculoskeletal pain concerns from baseline, with 95% CIs listed below. The  $P$  values indicate the difference from baseline.

ingly, increasing physical activity could yield many important improvements in cardiometabolic health without the necessity for further weight loss.<sup>37</sup> Therefore, by reducing musculoskeletal pain, bariatric surgery may make many activities of daily life less burdensome for youth with severe obesity and could contribute to reducing factors that affect long-term health risks.

This study had several strengths including a large sample size, strong longitudinal follow-up, and use of a clinically relevant measure of functional mobility, which was consistently delivered across enrollment sites. Moreover, our adjustments for specific confounding variables (eg, baseline BMI and changes in time to completion), which might influence HR response, aid in the interpretation of the results as differing levels of adiposity and completion time may influence energy demands during movement.<sup>38</sup> Our study was limited by the lack of a nonsurgical control group with which to compare outcomes over time. We were underpowered to determine whether any differences were present in changes in functional mobility or musculoskeletal pain between surgery types (Roux-en-Y gastric bypass vs vertical sleeve gastrectomy), but this comparison is scientifically relevant given the likely differences in mechanisms of metabolic change with these operations. Despite measuring musculoskeletal pain concerns during and after testing, the limited number of concerns, specifically after surgery, limited our ability to determine joint-specific changes. We do not present data on day-to-day variation in musculoskeletal pain,<sup>39</sup> which could have aided in the interpretation of our research findings. Finally, despite being a clinically translatable measure of functional mobility, the 400-m walk test is not a gold-standard measure of physical fitness as compared with a graded exercise test; therefore, these results may or may not be indicative of true changes in cardiorespiratory fitness.

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## Conclusions

Bariatric surgery in adolescents with severe obesity is associated with significant improvement in resting HR, completion time of a standardized 400-m walk test, and immediate posttest HR response; it is also associated with a re-

duction in walking-related musculoskeletal pain concerns at 6 months after surgery. These meaningful improvements were maintained up to 2 years after surgery. Whether these positive changes in functional mobility and musculoskeletal pain persist over the long-term and lead to further improvements in cardiometabolic risk requires evaluation.

## ARTICLE INFORMATION

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**Study concept and design:** Ryder, Edwards, Michalsky, Harmon, Inge, Kelly.

**Acquisition, analysis, or interpretation of data:**

Ryder, Edwards, Gupta, Khoury, Jenkins, Bout-Tabaku, Michalsky, Inge, Kelly.

**Drafting of the manuscript:** Ryder, Gupta, Michalsky, Harmon.

**Critical revision of the manuscript for important intellectual content:** Ryder, Edwards, Gupta, Khoury, Jenkins, Bout-Tabaku, Michalsky, Inge, Kelly.

**Statistical analysis:** Ryder, Gupta, Khoury, Jenkins.

**Obtained funding:** Harmon, Inge.

**Administrative, technical, or material support:** Kelly.

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**Disclaimer:** The content is solely the responsibility of the authors and does not necessarily represent the official views of the NIH.

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