



Original Research

Sex differences in physical activity engagement after ACL reconstruction



Christopher Kuenze^{a, b, *}, Caroline Lisee^a, Karin A. Pfeiffer^a, Lisa Cadmus-Bertram^c, Eric G. Post^c, Kevin Biese^c, David R. Bell^{c, d}

^a Michigan State University, Department of Kinesiology, 308 W. Circle Drive #105c, East Lansing, MI, 48824, USA

^b Michigan State University, Division of Sports Medicine, College of Osteopathic Medicine, 4660 Hagadorn Rd #420, East Lansing, MI, 48823, USA

^c The University of Wisconsin at Madison, Department of Kinesiology, 2000 Observatory Drive, Madison, WI, 53706-1121, USA

^d The University of Wisconsin at Madison, Department of Orthopedics and Rehabilitation, 1685 Highland Avenue, Madison, School of Medicine and Public Health, WI, 53705-2281, USA

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ABSTRACT

Objectives: To investigate the effects of sex as an effect modifier of objectively measured moderate-to-vigorous physical activity (MVPA) in individuals following ACLR and healthy controls.

Design: Cross-sectional research study.

Setting: University community.

Participants: 59 participants (42.4% male) with a history of ACLR and 55 healthy control participants (40.0% male).

Main outcome measures: Participants were outfitted with an ActiGraph wGT3X-BT accelerometer for a period of 7 days to assess MVPA. Weekly time engaged in MVPA (in bouts ≥ 10 min), % of total time engaged in MVPA, and odds of meeting national physical activity guidelines (MVPA ≥ 150 min/wk) were compared between males and females with a history of ACLR and healthy controls.

Results: There were significant sex X group interactions for weekly MVPA ($p = 0.02$) and % total time in MVPA ($p = 0.01$). The odds of a female ACLR participant meeting national physical activity guidelines were significantly worse ($X^2 = 4.18$, OR = 2.54, CI₉₅ = 1.03–6.27) when compared to participants without ACLR.

Conclusions: Female participants with ACLR were found to be less active than healthy control participants and their odds of meeting national MVPA guidelines were also 2.54 times worse than healthy participants.

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1. Introduction

Anterior cruciate ligament (ACL) rupture is a costly musculoskeletal injury that occurs approximately 250,000 times in the United States annually resulting in over \$3 billion of medical expenditures (Brophy, Wright, & Matava, 2009; Mall et al., 2014). The most common intervention following ACL injury is surgical reconstruction (ACLR) and structured rehabilitation, with the primary goal of treatment being a full return to unrestricted physical activity and sport participation. Despite a concerted primary

prevention effort among sports medicine clinicians, the rate of ACL injury among young female athletes is 4–8 times greater than that of their male counterparts and the rate of ACLR among young females has nearly doubled in the last 10 years (Brophy et al., 2009; Mall et al., 2014). In addition to the disproportionate rate of ACL injury and ACLR between the sexes, the short- and long-term outcomes following ACLR are markedly different. Females are more likely to experience worse knee-related outcomes (Ageberg, Forssblad, Herbertsson, & Roos, 2010), are more likely to experience a 2nd ACL injury (Brophy et al., 2012), and are less likely to return to pre-injury levels of sport following ACLR as compared to males of the same age and pre-injury activity level (Brophy et al., 2012). While young adults with ACLR participate in significantly less moderate-to-vigorous physical activity (MVPA) as compared to healthy matched controls, it is not clear if an individual's sex is a

* Corresponding author. Michigan State University, Department of Kinesiology, 308 W. Circle Drive #105c, East Lansing, MI, 48824, USA.

E-mail address: kuenzech@msu.edu (C. Kuenze).

factor in their determining the likelihood of engagement in healthy levels of MVPA following ACLR (Bell et al., 2017).

The benefits of physical activity are well-documented for adolescents and young adults (Strong et al., 2005); however, many otherwise healthy individuals in this age range do not meet physical activity recommendations (Troiano et al., 2008). As of 2013, only 51% of U.S. adults and 24.8% of adolescents reported meeting current United States Department of Health and Human Services guidelines for physical activity which is a marked decrease over previous decades (Centers for Disease Control and Prevention). Physical inactivity is an independent risk factor for mortality and morbidity (United States Department of Health and Human Services, 2008). Lee et al. estimated that physical inactivity is independently responsible for, on average, 6% of disease burden from coronary heart disease, 7% from type 2 diabetes, 10% from breast cancer, and 10% from colon cancer worldwide (Lee et al., 2012). Additionally, inactivity causes 9% of premature mortality (Lee et al., 2012). The morbidities associated with physical inactivity tend to be associated with the middle-aged and elderly populations. However, longitudinal studies have indicated that physical activity during childhood and early adulthood is a meaningful predictor of physical activity later in the lifespan (Nogueira et al., 2009; Telama et al., 2005). Because of this association, it has been hypothesized that barriers to sport participation and engagement in physical activity that occur early in the lifespan, such as ACLR, may have long term implications for subsequent participation in physical activity (Ardern, Taylor, Feller, Whitehead, & Webster, 2015) and the development of chronic disease (Luc, Gribble, & Pietrosimone, 2014).

Independent of injury status, young males and females participate in different types, volumes, and intensities of physical activity over the course of the teenage and early adult years (Dumith, Gigante, Domingues, & Kohl, 2011). While males and females both experience a decline in physical activity from early (12–13 years old) to late (17–18 years old) adolescence, the decline that girls experience is steeper than that of males (Dumith et al., 2011). In one population-based study, the median level of leisure-time physical activity among girls aged 9–18 years declined by approximately 80% by the age of 18 (Kimm et al., 2002). This is an alarming trend that, when considered along with the significant sex disparity in ACL injury risk during adolescence and early adulthood (Brophy et al., 2009; Mall et al., 2014), begins to highlight a potential risk profile for physical inactivity early in the lifespan that may have significant implications for long term health outcomes. Despite extensive evidence to support the elevated risk of physical inactivity and elevated risk of injury among young females, it is unclear if these factors are related.

Currently, there is little known about the effect of ACLR on long term physical activity participation and even less known about sex-disparities in this critical outcome measure. While physical activity assessment and promotion have been widely adopted in other areas of musculoskeletal health care (Rausch Osthoff et al., 2018), the lack of evidence among individuals with ACLR has limited the ability of clinicians and researchers to adequately address the potential risk of persistent physical inactivity among this population. There is a need to further investigate whether sex and ACL injury status negatively impact engagement in MVPA in order to empower patients and clinicians to individualize rehabilitation and post-clearance medical care to ensure a safe re-integration into healthy levels of physical activity for both males and females with a history of ACLR. Therefore, the purpose of this study was to examine the effects of sex and ACLR status on the volume of MVPA in which an individual engages as well as the likelihood that an individual will meet national guidelines for weekly MVPA. We hypothesized that females with a recent history of ACLR would be

engage in significantly less MVPA on weekly basis and would be less likely to meet national guidelines for MVPA when compared to males with ACLR, healthy males, and healthy females.

2. Methods

This was an observational study in which objective physical activity, self-reported activity level, and patient-reported knee function were measured in males and females with a history of ACLR and healthy control males and females. Participants completed a single study visit during which they provided written informed consent, completed patient-reported outcome measures, and received instruction on the appropriate usage of the physical activity monitor, which they subsequently wore during typical daily activity. This study was approved by the Institutional Review Boards at Michigan State University and the University of Wisconsin - Madison and all participants provided written informed consent prior to study participation.

Fifty-nine participants (25 male/34 female) with a history of primary unilateral or bilateral ACLR and 55 healthy control participants (22 male/33 female) were enrolled in this study (Table 1). All participants were 18–30 years old and free of any other medical condition that may have limited the ability to participate in physical activity. Participants in the ACLR group had undergone their most recent surgery within the past 5 years and had been medically cleared for unrestricted physical activity by a medical professional (physician, physical therapist, or athletic trainer). Participants with MCL injury at the time of ACL injury as well as participants who underwent a meniscal repair or partial meniscectomy at the time of ACLR were included in this study. Participants who experienced significant surgical complication resulting in extended medical care or second surgical procedure and participants who underwent PCL or posterolateral corner reconstruction occurred at the time of surgery were excluded. Healthy control participants were excluded if they had a history of significant lower extremity injury, which resulted in surgery. Patient-reported physical activity level was assessed using the Tegner Activity Scale. In the case of participants with ACLR, pre-injury activity level was assessed and among healthy participants, current activity level was assessed. The Knee Osteoarthritis Outcomes Scale (KOOS) was used to quantify the impact of knee injury on patient-reported function and activities of daily living (Roos & Lohmander, 2003).

During the study visit, participants were outfitted with an ActiGraph wGT3X-BT accelerometer (Sasaki, John, & Freedson, 2011). The ActiGraph wGT3X-BT accelerometer (ActiGraph Corp., Pensacola, FL) has been shown to be both a valid and reliable tool for the objective assessment of moderate-to-vigorous physical activity in young and active populations (Kelly et al., 2013; Sasaki et al., 2011). Participants wore the accelerometer on an elastic belt placed over the right anterior superior iliac spine (ASIS) for a period of 7 days immediately following the study visit. A valid data collection period was considered to be a minimum of 4 days (3 weekdays and 1 weekend day) of wear with no less than 10 h per day (Quante et al., 2015). However, data from all valid days (range = 4–7 days) was included in our analysis. Participants removed the monitor for bathing and sleeping, and recorded their periods of wear and non-wear using a diary. The participants returned the monitor following the wear period at which time the data were assessed for fidelity and consistency with wear guidelines. In the case of insufficient or corrupted data, the participant was asked to re-wear the monitor for the subsequent 7 days.

The ActiGraph monitors collected data in raw acquisition mode after which the data were processed and analyzed using ActiLife software (ActiGraph Corp., Pensacola, FL). Monitor wear time was estimated and validated using recommendations of Choi et al.

Table 1
Demographic and surgical descriptors of the study participants.

	Male Participants		Female Participants		Sex X ACLR Interaction (p)
	Healthy (mean ± SD)	ACLR (mean ± SD)	Healthy (mean ± SD)	ACLR (mean ± SD)	
Number of Participants (#)	22	25	33	34	–
Age (years)	20.4 ± 1.7	20.8 ± 2.6	20.6 ± 1.8	20.1 ± 2.1	0.25
Height (cm)	182.6 ± 5.2	181.8 ± 6.4	169.6 ± 7.9	166.5 ± 7.2	0.41
Weight (kg)	79.7 ± 9.9	81.9 ± 10.9	66.0 ± 10.4	65.0 ± 8.4	0.38
BMI (kg/m ²)	23.9 ± 2.7	24.8 ± 3.0	22.9 ± 3.0	23.5 ± 2.9	0.80
Tegner Activity Level	7.5 [6.0–10.0]	9.0 [7.0–10.0]	7.0 [3.0–10.0]	9.0 [3.0–10.0]	0.01*
KOOS Pain	97.7 ± 4.3	92.0 ± 7.3	99.5 ± 1.6	90.8 ± 11.0	0.29
KOOS Symptoms	95.8 ± 4.9	85.2 ± 12.3	97.2 ± 5.6	83.6 ± 14.9	0.48
KOOS ADL	99.5 ± 1.3	98.6 ± 1.9	100.0 ± 0.0	96.4 ± 7.2	0.09
KOOS Sport and Recreation	96.6 ± 7.8	83.0 ± 15.8	97.3 ± 5.9	82.9 ± 16.3	0.88
KOOS QOL	94.0 ± 15.4	70.3 ± 16.1	99.1 ± 3.2	67.6 ± 23.6	0.23
Graft Source (HSA/BTB/Allo)	–	9 HAS/13 BTB/1 Allo	–	16 HAS/18 BTB	–
Months Since Surgery	–	25.9 ± 15.0	–	32.1 ± 19.5†	–

KOOS = Knee Osteoarthritis Outcome Scale, ADL = activities of daily living, QOL = quality of life, HAS = hamstring autograft, BTB = patellar tendon autograft, months since surgery reflects the number of months since most recent ACLR, * indicates a significant sex by ACLR status interaction, † indicates no significant difference ($p = 0.19$) between men and women.

(Choi, Liu, Matthews, & Buchowski, 2011). The count and frequency of tri-axial accelerations were utilized to discriminate between periods of wear and non-wear. This enabled the study team to assess whether or not the participant had been compliant with the previously established standards (4 days of 10 h) for a successful wear period. When participants returned to the lab following their monitoring period, the data was evaluated and if insufficient wear time was noted, the monitor was given back to the participant and they were asked to continue the wear period in order to ensure a usable dataset. Freedson Adult VM3 cut points were then used to categorize physical activity as light, moderate, vigorous, or very vigorous based on the number of activity counts that occurred per minute during periods of wear time (Sasaki et al., 2011). Based on these cutpoints the percentage of total active time spent in each activity intensity category was calculated to allow for comparison of relative intensity between sexes and ACLR group.

MVPA was also assessed using time spent in MVPA performed in bouts of ≥ 10 min over the course of a 7 day period (Freedson, Melanson, & Sirard, 1998). This was done to facilitate comparison with the federal Physical Activity Guidelines for Americans, which prescribe 150 min of moderate-intensity activity or 75 min/wk of vigorous-intensity activity (or the equivalent combination of the two), performed in bouts of at least 10 min in duration (United States Department of Health and Human Services, 2008). We also calculated the percentage of total monitor wear time during which the participant was engaged in MVPA. This approach to assessment minimizes any variation in monitor wear time that may occur between participants.

Participant demographics, KOOS subscale scores, MVPA characteristics, and activity intensity characteristics were compared between groups using separate 2 (group: healthy, ACLR) X 2 (sex: male, female) analyses of covariance. In all cases, total monitor wear time (minutes) and Tegner activity level were utilized as covariates due to the potential for variation in total wear time and pre-injury level of activity between participants. Distributional characteristics for weekly time spent in bouts of MVPA (skewness = 0.82, kurtosis = 0.09) were evaluated prior to our analyses and supported our use of parametric statistics in this analysis. Distribution of graft source (BTB, HAS) was compared between the male ACLR and female ACLR groups using a Fischer's exact test, while number of months since surgery was compared between the same groups using an independent samples *t*-test. The distributions of participants within each group who met or did not meet national physical activity guidelines were characterized using

frequencies and proportions (%). Lastly, chi-square statistics (X^2) and associated odds ratios (OR) with 95% CIs were calculated to assess the odds that a participant with an ACLR would meet physical activity guidelines when compared to healthy control participants. Using this approach, we compared the total sample, females only, and males only to the control group as a whole. The sample size estimation was based on an attempted 2:1 enrollment of healthy participants compared to men or women with ACLR. Data from a small pilot study that indicated that roughly 66% as many individuals with ACLR would meet physical activity guidelines when compared to healthy controls. Based on these assumptions, we estimated needing roughly 60 healthy participants, 30 men with ACLR, and 30 women with ACLR to achieve execute our planned analysis (Faul, Erdfelder, Lang, & Buchner, 2007). Statistical significance was established a priori as $\alpha \leq 0.05$ and all analyses were performed in SPSS statistical software (v24; IBM Corp.).

3. Results

There were no significant sex X group interactions for demographic variables or KOOS subscale scores (Table 1). There were significant sex X group interactions for weekly time engaged in MVPA ($p = 0.02$) and % total time in MVPA ($p = 0.01$; Table 2). Overall, female participants participated in a greater volume of weekly MVPA (males = 142 ± 115 min/wk, females = 203 ± 130 min/wk) when compared to male participants regardless of surgical status.

The odds of a participant with ACLR meeting national physical activity guidelines (MVPA ≥ 150 min/wk) were significantly worse ($X^2 = 4.85$, OR = 2.36, CI₉₅ = 1.09–5.08) than healthy participants (Table 3). There was no significant difference in the odds ($X^2 = 2.33$, OR = 2.13, CI₉₅ = 0.80–5.69) of meeting national physical activity guidelines between males with a history of ACLR and healthy control participants. Among female participants with ACLR, the odds of meeting national physical activity guidelines were significantly worse ($X^2 = 4.18$, OR = 2.54, CI₉₅ = 1.03–6.27) when compared to healthy control participants.

4. Discussion

Musculoskeletal injuries, including ACL injury and subsequent reconstruction, are primary factors that limit participation in physical activity. The primary finding of this study supports the hypothesis that young females who have undergone ACLR are less

Table 2

MVPA comparisons based on participant sex and ACLR status.

		Healthy mean \pm SD	ACLR mean \pm SD	Sex X ACLR Interaction (<i>p</i>)
Weekly Time in Bouts of MVPA (min/wk)	Male	134 \pm 118	141 \pm 115	0.02*
	Female	260 \pm 138	153 \pm 107	
% Time in MVPA (%)	Male	9.9 \pm 3.0	10.6 \pm 2.7	0.01*
	Female	11.9 \pm 3.9	9.6 \pm 2.7	

MVPA = moderate-to-vigorous physical activity, Analyses include monitor wear time and pre-injury Tegner score as a covariates, * indicates $p \leq 0.05$.**Table 3**

Distribution of participants meeting physical activity guidelines based on sex and ACLR status.

	Meets Guidelines Total (%)	Does Not Meet Guidelines Total (%)	χ^2 (<i>p</i>)	Odds Ratio 95% CI (LB,UB)
Male ACLR	10 (41.7)	14 (58.3)	2.33 (0.13)	2.13 (0.80, 5.69)
Female ACLR	12 (37.5)	20 (62.5)	4.18 (0.04)	2.54 (1.03, 6.27)
Total ACLR	22 (39.3)	34 (60.7)	4.85 (0.03)	2.36 (1.09, 5.08)
Healthy Control	32 (60.4)	21 (39.6)		

 χ^2 and OR reflect comparison to the healthy control group; a participant meets guidelines if weekly time in bouts of MVPA ≥ 150 min.

likely to meet physical activity guidelines than young males and females without ACLR (Table 3). The odds of a female participant with ACLR engaging in ≥ 150 min of MVPA per week were 2.54 ($CI_{95} = 1.03-6.27$) times worse than healthy female participants, while no significant difference was present between males based on surgical status ($OR = 0.94$, $CI_{95} = 0.30-3.14$). When considered with the existing sex-based disparities in the rate secondary ACL injury (Prodromos, Han, Rogowski, Joyce, & Shi, 2007), rate of return to play (Ardern, Taylor, Feller, & Webster, 2014), and long term risk of joint degeneration (Lohmander, Ostenberg, Englund, & Roos, 2004), these findings are troubling and further highlight the potential need for sex-specific interventional approaches in order to improve both short- and long-term health-related outcomes following ACLR.

Sex has been identified as a predictor of patient-reported physical activity participation among young individuals two years after ACLR using the Marx Activity score (Dunn, Spindler, & Consortium, 2010). However, recent evidence has called into question the validity of several common patient-reported physical activity assessment tools in the young ACLR population as patient-reported activity level does not appear to be significantly related to objectively measured physical activity (Kuenze et al., 2017). In this study, we utilized an objective physical activity measurement approach in order to determine if sex was an effect modifier on physical activity participation within 5 years of ACLR. Female participants with a history of ACLR had 2.54 ($CI_{95} = 1.03-6.27$, Table 3) times lesser odds of meeting physical activity guidelines as compared to healthy control participants. Interestingly, male participants with a history ACLR ($OR = 2.13$, $CI_{95} = 0.80-5.69$) did not significantly differ from healthy control participants. It is important to note that the overall percentages of males (58.3%) and females (62.5%) who did not meet physical activity guidelines were very similar, the confidence interval presented for females was very close to overlapping 0 which would indicate a non-significant finding, and fewer males were included in this analysis. All of these factors may have limited our ability to detect differences in the odds of participation in ≥ 150 min of MVPA per week. Sex disparities have been consistently described in other patient-reported and functional outcomes after ACLR (Ageberg et al., 2010; Ryan et al., 2014) and there is natural reduction in physical activity participation that occurs among females during late adolescence and early adulthood (Kimm et al., 2002). Therefore, it is essential to develop a clearer understanding of the patterns of physical activity participation among males and females with ACLR in order to identify risk factors for significant and persistent reduction in

physical activity following ACLR.

ACL reconstruction has been previously shown to negatively affect participation in demanding sport activity (Ardern et al., 2014) and objectively measured MVPA (Bell et al., 2017). However, current guidelines support weekly participation in at least 150 min per week of MVPA in order to maintain adequate cardiorespiratory fitness and reduce the risk of chronic disease (United States Department of Health and Human Services, 2008). Contrary to the group comparisons for volume or percentage of MVPA, the odds of a participant with ACLR meeting physical activity guidelines were 2.36 ($CI_{95} = 1.09-5.08$) times worse than healthy control participants (Table 3). More simply put, only 39.3% of participants with ACLR were found to participate in a healthy volume of MVPA as compared to 60.4% of healthy control participants (Table 3). However, this is the first study to make direct comparison of objectively measured PA data to current recommendations for the maintenance of cardiorespiratory health. These findings highlight the importance of individual comparison to standardized values when attempting to evaluate participation in physical activity among clinical patients and further identify the potential role that ACLR can play as a risk factor for physical inactivity early in the lifespan. Currently, while discussion of return to sport-specific activity is commonplace during the terminal phases of rehabilitation, broad discussion relating to physical activity engagement appears to be less common in clinical management of patients with ACLR (DiSanti et al., 2018). Clinicians may need to consider providing educational resources regarding the importance of consistent physical activity engagement, the current age-specific guidelines for adequate engagement in physical activity, and user-friendly tools (such as pedometers) that can be used by patients to track physical activity participation after release from formalized clinical care.

Participation in physical activity after musculoskeletal injury is often described without specific consideration of the characteristics, such as total time or intensity of participation, of the activity itself. For example, among individuals with ACLR, categorizations such as return to sport (Ardern et al., 2014; Brophy et al., 2012) or return to pre-injury level of activity (Ardern et al., 2016), or current peak level of activity (Dunn et al., 2010) are among the most common descriptors of physical activity participation. This is despite the fact that dichotomous outcomes and patient-reported physical activity have consistently been shown to be poor indicators of actual physical activity participation characteristics among individuals with ACLR (Bell et al., 2017; Kuenze et al., 2017). In our sample, we observed that participants with ACLR reported

significantly greater current activity level via the Tegner Activity Scale and no between group differences in KOOS ADL and KOOS Sport and Recreation scores, which assess perceived function during different forms of physical activity, despite the clear pattern of reduced objectively measured MVPA when compared to healthy controls. In this study, we attempted to investigate potential sex-based differences in the volume of objectively measured MVPA in which individuals participated (Table 2). Inconsistent with previous investigations in the area of young adult physical activity participation, the females participated in a greater volume of MVPA on average as compared to male participants (male = 142 ± 115 min/wk, female = 201 ± 129 min/wk, $p = 0.01$) and despite a significant interaction between sex and surgical status, males (MVPA = 150 ± 114 min/wk) and females (158 ± 107 min/wk) with ACLR participated in very similar volumes of MVPA. Our female participants were slightly further from surgery and this may have impacted their ability to perform MVPA compared to males.

There are several limitations that should be considered when interpreting the findings of this study. Most importantly, the healthy female participants included in this study were highly physically active which is somewhat inconsistent with previous literature in this area. While this finding was consistent at both data collection sites (Site #1 = 259 ± 108 min/wk, Site #2: 225 ± 177 min/wk; $p = 0.52$), it should be considered when interpreting the between sex comparisons presented in this study. The cross-sectional nature of our study limits our ability to establish whether the physical activity characteristics observed among participants with ACLR were present prior to injury or if they are a result of ACLR and subsequent rehabilitation. Additionally, based on our study design it was not possible to account for several factors that may positively or negatively impact engagement in physical activity including socioeconomic status, self-efficacy, and environmental factors. Lastly, detailed information regarding specific meniscus pathology, meniscal procedures at the time of ACLR, and other lower extremity injury that did not meet our exclusion criteria were not consistently recorded during the data collection process. Based on this oversight, it was not possible to take into account the early immobilization and subsequent prolonged sedentary period that is a hallmark of recovery from ACLR with meniscal repair or persistent effects of other lower extremity injuries when completing our analysis. Subsequent studies should provide additional context with regard to the effect of these key factors on physical activity engagement among individuals with a history of ACLR.

5. Conclusion

ACL reconstruction may initiate or accelerate a course of behavioral change that limits participation in physical activity among young and otherwise healthy individuals. Based on the findings of this study, the negative impact of ACLR on participation in physical activity may be more consistent among young females; however, additional work must be done to evaluate whether this pattern is an extension of normal changes that occur in physical activity patterns during adolescence and early adulthood or if it is a result of ACLR. This study highlights the need to address the importance of consistent physical activity engagement, whether sport-related or not, during the rehabilitation process in order to give patients the tools to assess and improve physical activity habits after the completion of formalized clinical care.

Conflicts of interest

The authors declare no conflicts of interest for this work.

Ethical approval

All research related activities were approved by the Institutional Review Boards at the University of Wisconsin – Madison (Health Sciences IRB #2005-1162) and Michigan State University (Human Research Protection Program #15-971), and all participants provided written informed consent prior to study participation.

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