JB&JS OPEN ACCESS

In Young Patients Undergoing Total Hip Arthroplasty, Is There a Correlation Between Activity Level and Wear of Highly Cross-Linked Polyethylene?

Sergio F. Guarin Perez, MD, Diego J. Restrepo, MD, Sheng-Hsun Lee, MD, Michael B. Stuart, MD, Robert T. Trousdale, MD, Daniel J. Berry, MD, and Rafael J. Sierra, MD

Investigation performed at the Mayo Clinic, Rochester, Minnesota

Background: Total hip arthroplasty (THA) effectively restores mobility, reduces pain, and enhances the quality of life of patients of all ages. Despite its benefits, concerns regarding the long-term effects of high-impact activities and sports on implant longevity require further study. This study investigated the effect of activity level on long-term radiographic wear of highly cross-linked polyethylene (HXLPE) in young patients undergoing THA.

Methods: Between 1999 and 2008, 785 patients (909 hips) aged ≤50 underwent primary THA using first-generation HXLPE liners from 4 different vendors with either metal or ceramic heads. Functional activity and participation questionnaires, including the Hip Injury and Osteoarthritis Outcome Score (HOOS Jr), University of California Los Angeles (UCLA) activity scale, and High-Activity Arthroplasty Score (HAAS), were surveyed in 2018 to 2019. The response rate was 44%. Radiographic linear wear rates were measured using the ROMAN software in patients who had completed questionnaires and had radiographs taken at least 10 years apart, leaving a final cohort of 249 patients (284 hips). Multivariate analyses were performed to determine the relationship between HXLPE wear rates and activity scores.

Results: At the time of the survey, approximately 10% of the patients performed high-impact activities not-recommended by consensus guidelines. The HXLPE linear wear rate was 0.036 mm/year (SD: 0.026). Patients with higher activity levels, as measured on the continuous UCLA/HAAS activity scale, did not exhibit increased wear (β = -0.0009; p = 0.31). Stair climbing was correlated with increased wear rates (β = 0.0066; p = 0.004), whereas walking (β = 0.0005; p = 0.66) and running (β = 0.0017; p = 0.30) were not significantly correlated. Patients performing nonrecommended activities did not show increased wear rates compared with those performing recommended activities (β = 0.0063; p = 0.19).

Conclusions: Linear wear rates of first-generation HXLPE were not related to functional activity or participation in high-impact activities. Future research should include longitudinal assessments of activity levels and data on other potential complications related to high-impact sports to provide robust evidence regarding recommended activity level postoperatively.

Level of Evidence: Level III, Retrospective Comparative Study. See Instructions for Authors for a complete description of levels of evidence.

Introduction

Total hip arthroplasty (THA) alleviates pain, improves function, and enhances the overall quality of life in patients across all age groups[1]. Concerns remain regarding high-impact activities on implant durability, especially in young patients. Although there have been some changes in individual surgeon recommendations regarding activity levels after THA, including increased tolerance for low-impact activities such as swimming, cycling, and walking, many surgeons continue to restrict some of the high-impact activities postoperatively[2].

Advancements in implant technology, particularly with highly cross-linked polyethylene (HXLPE) liners, have reduced wear concerns[3]. Several clinical studies reported minimal

Dr Daniel J. Berry was funded by grants from the National Institutes of Health (R01AR73147, R01HL147155), NIAMS (P30AR76312). The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

Disclosure: The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (http://links.lww.com/JBJSOA/A821).

JBJS Open Access • 2025:e24.00242. openaccess.jbjs.org 2

radiographic wear and no periprosthetic lysis with these liners after the first decade of use[4,5]. However, other studies have suggested that the risk of XLPE wear may increase after the first decade, underscoring the potential impact of activity on THA survivorship[6]. Simultaneously, there has been an associated increase in femoral head diameter, as larger heads reduce the risk of dislocation and improve joint stability, thereby accommodating an increase in desired patient activities[7]. As femoral head diameter increases, so does volumetric wear of conventional polyethylene[8]. It is important to understand the impact of differing levels of activities and sports on contemporary THA outcomes, to advise patients who may want to resume their preoperative activity levels after THA. This study aimed to report, at a minimum of 10 years, postoperative activity levels in patients aged ≤50 at primary THA and correlate activity levels with first-generation HXLPE radiographic linear wear rates.

Methods

The study included consecutive patients aged ≤50 who underwent primary THA between 1999 and 2008. IRB approval and written consent were obtained from all patients per Health Insurance and Portability Accountability Act requirements. Patients included in the study were ≤50 years old at primary THA using first-generation HXLPE liners from 4 vendors: DePuy Synthes (Raynham, Massachusetts), Smith & Nephew (Memphis, Tennessee), Stryker (Kalamazoo, Michigan), and Zimmer Biomet (Warsaw, Indiana). These first-generation liners were produced using irradiation followed by thermal treatments such as annealing or remelting to enhance durability[9]. Information regarding liner types, radiation doses, and postradiation processing can be found in the supplementary material.

There were 1,100 THAs performed in 946 patients by 23 surgeons during the study period. Patients were excluded if they received a noncrosslinked PE bearing, had postoperative complications (infection, instability, fracture, revision THA not attributable to XLPE wear, or wear-related osteolysis), or were deceased at the time of the survey. Our primary inclusion criteria required patients to respond to functional activity questionnaires. Follow-up letters or emails were sent to nonresponders, and those who did not respond were contacted through telephone. Ultimately, 349 patients (403 hips) completed the survey, with a response rate of 44%. A final cohort of 249 patients (284 hips) who had radiographs taken 10 or more years after the index THA was included in the wear analyses, representing 31.7% of the initial cohort (Fig. 1). The mean age at surgery was 43.4 years (SD: 6.45), average BMI was 30 kg/m^2 (SD: 6.93), and 55.6% were female (Table I). The average time from surgery to survey administration was 14.8 years (SD: 2.5), and the mean interval between initial postoperative and final radiographs was 16.1 years (SD: 3.71). Of the femoral heads,

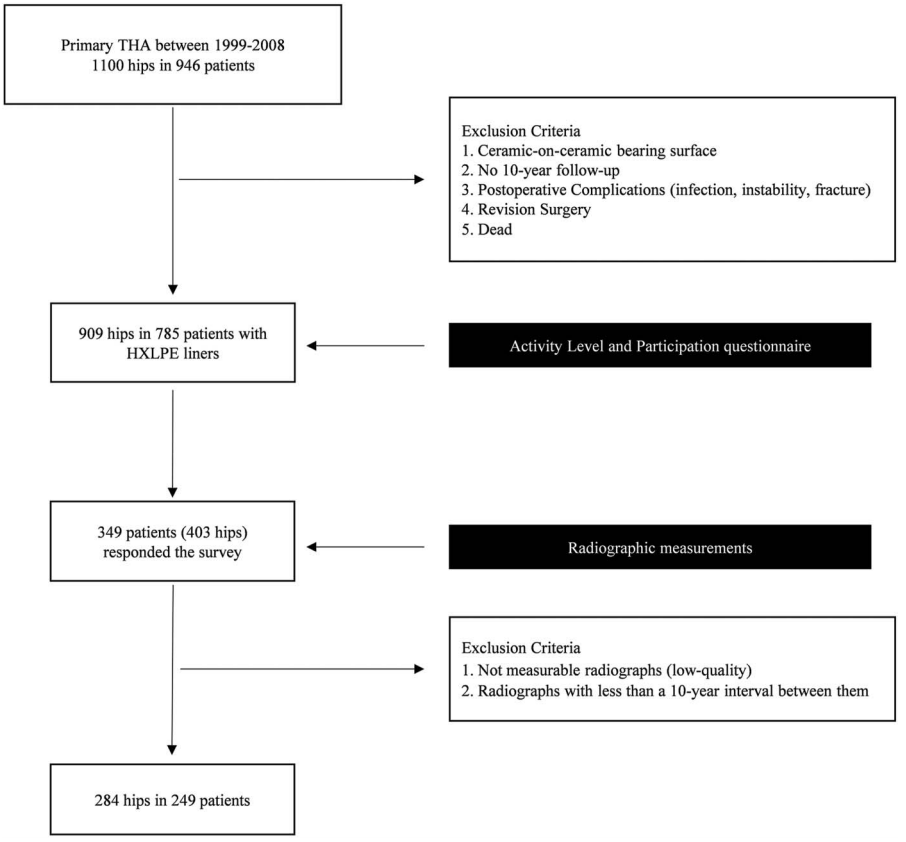

Fig. 1

Flow diagram illustrating the inclusion process of the final cohort.

TABLE I Demographic Characteristics of Final Study Population

	Overall N = 284 Hips (249 Patients)
Age at surgery (years)	
Mean (SD)	43.4 (6.45)
Median (min, max)	45.0 (15, 50)
BMI (kg/m^2)	
Mean (SD)	30.0 (6.93)
Median (min, max)	29.1 (16.2, 63.1)
Gender (%)	
Female	158 (55.6)
Male	126 (44.4)
Femoral head size (%)	
≤28	174 (61.3)
>28	110 (38.7)

270 (95%) were metal, while 14 (5%) were composed of ceramic or oxidized zirconium, with diameters of 28 mm in 167 cases (59%), 32 mm in 76 (27%), 36 mm in 31 (11%), 22 mm in 7 (2%), and 40 mm in 3 (1%).

Validated activity-level questionnaires were sent to assess participation in various activities. The questionnaire included the Hip Disability and Osteoarthritis Outcome Score (HOOS Jr), High-Activity Arthroplasty Score (HAAS), and the University of California Los Angeles (UCLA) activity scale[10-12]. In addition, patients were asked about their participation in 30 activities identified as allowed, allowed with experience, not allowed, or undecided based on consensus guidelines from the Hip Society and American Academy of Hip and Knee Surgeons (AAHKS) members (Supplementary Material)[13]. For research purposes, a nonvalidated approach was used to analyze specific activity components. This included a combination of HAAS and UCLA scores and the subdivision of HAAS into individual activities. The resulting customized scale ranged from 1 to 11 (Supplementary Material). The questionnaire measured the current activity level at that specific time point, including the intensity of participation per activity: never, sometimes (<1/week), and regularly (≥1/week).

The primary outcome measure was the linear wear rate of HXLPE liners assessed using the validated Roentgen Monographic Analysis Tool (ROMAN) software, which has been shown to provide accurate measurements of polyethylene wear in THA[14,15]. The majority (95%) of radiographs were performed in the same radiological department to ensure consistency. Remote radiographs from virtual follow-ups were used only when department images were unavailable. Multiple markers were placed around the acetabular component and femoral head, and all measurements were calibrated based on the known femoral head diameter. The angle and distance between the cup and femoral head centers were calculated, as shown in Fig. 2[16,17]. This process was repeated for the most recent radiographs. The difference between the 2 measurements was

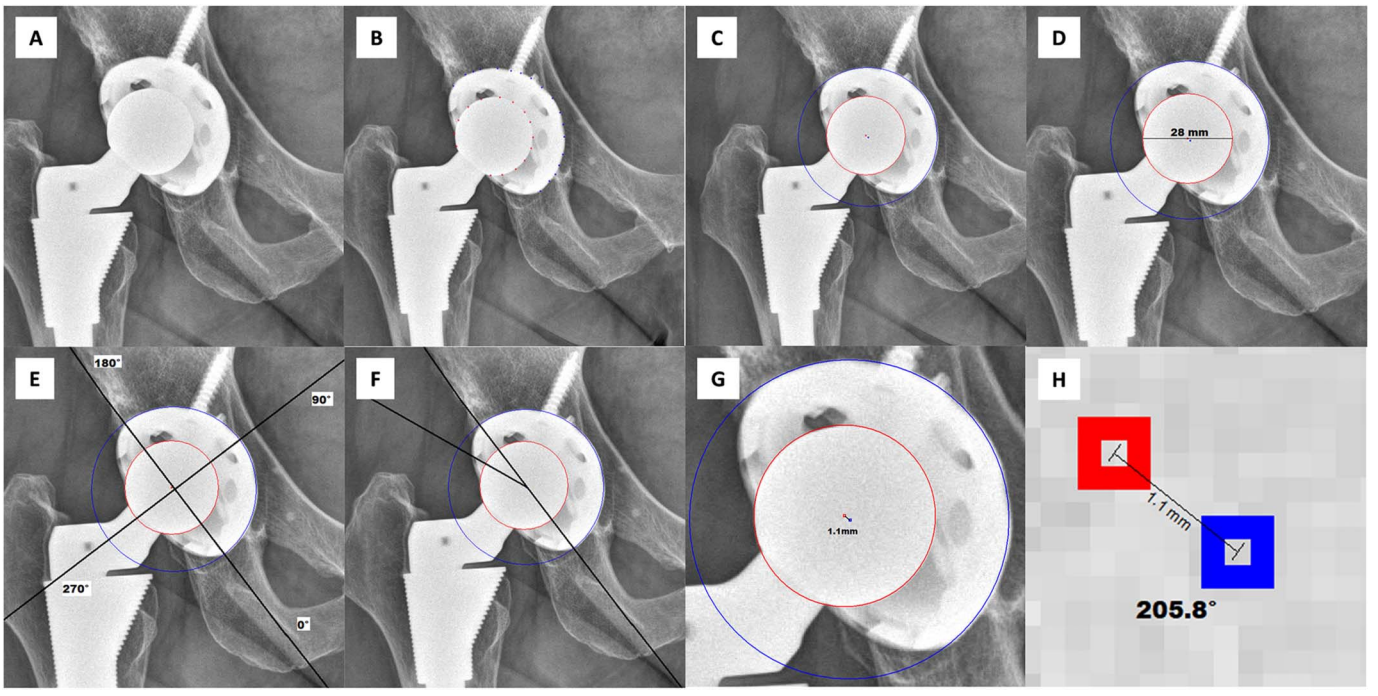

Fig. 2

Process of vector measurements using the ROMAN software. **Fig. 2-A** Hip x-ray. **Fig. 2-B** Landmarks around the acetabular cup (blue) and femoral head (red). **Fig. 2-C** Circumference of the cup and femoral head. **Fig. 2-D** Calibration of measurements based on femoral head size (28 mm in this case). **Fig. 2-E** Standardized coordinates. **Fig. 2-F** Direction of the vector from acetabular cup center to femoral head center. **Fig. 2-G** Distance between the centers of the 2 circumferences. **Fig. 2-H** Zoom at 1995% of the distance and angle value of the vector.

recorded as linear wear[6]. To mitigate measurement bias, measurements were performed by 3 authors (S.F.G.P., M.B.S., and S.H.L.). Interrater and intrarater reliabilities were assessed using the Intraclass Correlation Coefficient (ICC). Each observer measured the linear wear on the same 60 radiographs for interrater reliability with a 2-week interval to evaluate intrarater reliability and reduce recall bias. To handle detection limits, each radiograph was zoomed to 1995%, and the contrast was adjusted to better identify the circumference of the femoral head and acetabular component, ensuring optimal calibration.

Radiographic results were divided into proximal/distal and medial/lateral dimensions to provide a clear representation of linear wear. Each coordinate set reflects wear movement along these axes, with positive values indicating movement in 1 direction and negative values indicating movement in the opposite direction. Positive values along the proximal axis indicate movement toward the body, whereas negative values denote movement away. Similarly, positive values along the lateral axis indicate movement away from the body's midline, while negative values indicate movement toward it[6].

BlueSky Statistics Version 10.3.1, R package version 8.81, and R statistical software version 4.3.2 were used to analyze wear rate results across demographic and categorical variables. Multivariate analyses were employed to evaluate the influence of walking, running, stair climbing, activity level, and activity participation on linear wear rates. Adjustments were made in the models to account for potential confounding factors and to examine subgroups. Potential confounding factors, including age at surgery, BMI, sex, and femoral head size, were identified a priori based on clinical relevance and included in the analyses of wear rates. The threshold for statistical significance was set at $p < 0.05$. To determine whether there was a threshold effect where certain activities could lead to increased wear, each score was evaluated as a dichotomous variable. Comparisons were made between higher and lower levels of activity: HAAS walking (0–4 vs 5), HAAS running (<3 vs ≥3), HAAS stair climbing (0–2 vs 3), and HAAS/UCLA activity level (<7 vs ≥7).

Results

Based on the consensus guidelines of the Hip Society and AAHKS, 61.1% of the cohort performed only recommended physical activities, 26.7% performed activities recommended only with experience, 2.5% performed physical activities considered "undecided", and 9.7% performed activities considered not-recommended. (Fig. 3).

Survey results showed the following: The HOOS Jr. score (0-100) had a mean of 90.93 (SD: 12.57) and a median of 100 (range: 39.9-100). For the HAAS scores, walking (0-5) had an average value of 3.58 (SD,1.64) and a median of 4, running (0-4) had 1.20 (SD: 1.03) and 1, stair climbing (0-3) had 1.90 (SD: 0.77) and 2, and the overall activity level (1-11) showed 5.25 (SD: 1.96) and 6, respectively. Table II includes results from the initial respondents to allow comparison with the final cohort.

The linear wear rate in the final cohort was 0.036 mm/year (SD: 0.026). Divided by 2 dimensions, the average proximal linear wear was 0.0122 mm/year (SD: 0.032), and the average lateral linear wear was 0.0188 mm/year (SD: 0.023) (Table III). The ICC interobserver reliability between the 3 observers was 0.94 (95% CI, 0.91-0.96), and the ICC intraobserver reliabilities were 0.9 (95% CI, 0.84-0.94), 0.94 (95% CI, 0.9-0.96), and 0.97 (95% CI, 0.94-0.98), respectively. According to consensus guidelines, nonrecommended activities were not associated with increased wear compared with recommended activities ($\beta = 0.0063$; 95% CI, −0.0032 to 0.0158; $p = 0.19$) (Table IV). Furthermore, the continuous UCLA/HAAS activity level score (1-11) in this cohort was not correlated with increased HXLPE wear rate ($\beta = -0.0009$, 95% CI −0.0027 to 0.0009, $p = 0.31$). Comparable results were obtained for proximal wear rate ($\beta = -0.0015$, 95% CI, −0.0037 to

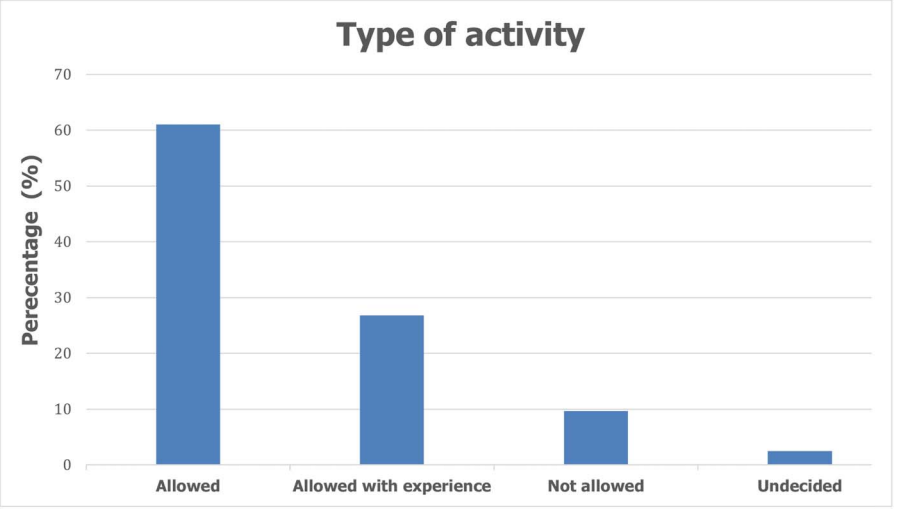

Fig. 3

Proportion of individuals engaging in allowed, allowed with experience, undecided, and not allowed physical activities. Participation in 30 activities based on consensus guidelines from the Hip Society and the AAHKS members. AAHKS = American Academy of Hip and Knee Surgeons.

JBJS Open Access • 2025:e24.00242.

TABLE II Survey Activity Scores: Initial Respondents vs. Final Cohort

	Overall N = 349 Patients (403 Hips)	Overall N = 249 Patients (284 Hips)
Time surgery to survey (years)		
Mean (SD)	14.6 (2.6)	14.8 (2.5)
HOOS JR (0-100)		
Median (min, max)	100 (39.9,100)	100 (39.9,100)
HAAS walking (0-5)		
Median (min, max)	5 (0, 5)	4 (0, 5)
HAAS running (0-4)		
Median (min, max)	2 (0, 4)	1 (0, 4)
HAAS stair climbing (0-3)		
Median (min, max)	2 (0, 3)	2 (0, 3)
Modified activity level (1-11)*		
Median (min, max)	3 (1, 11)	6 (1, 11)

HAAS = High-Activity Arthroplasty Score, HOOS = Hip Injury and Osteoarthritis Outcome Score, and UCLA = University of California Los Angeles. *HAAS and UCLA activity level.

0.0007, p = 0.17) and lateral wear rate (β = -0.0007, 95% CI, −0.0022 to 0.0009, p = 0.40) (Table V).

According to the HAAS score measured as continuous variables, walking (0-5) and running (0-4) were not correlated with wear rate (β = 0.0005, 95% CI, −0.0016 to 0.0025, p = 0.66) and (β = 0.0017, 95% CI, −0.0015 to −0.0050, p = 0.30), respectively. Interestingly, and surprisingly, stair climbing (0-3) showed a significant association (β = 0.0066, 95% CI, 0.0021-0.0111, p = 0.004) with increased linear wear, indicating that each unit increase in stair climbing score was associated with a 0.0066 mm/year increase in linear wear (Table IV). Dichotomous results for the same variables presented in Tables IV and V can be found in the supplementary material. There was no difference in wear rates, whether the variables were evaluated in a continuous or dichotomous manner.

TABLE III Radiographic Wear Rate Results

	Overall N = 284 hips (249 patients)
Time between radiographs (years)	
Mean (SD)	16.1 (3.71)
Linear wear rate (mm/year)	
Mean (SD)	0.036 (0.026)
Proximal wear rate (mm/year)	
Mean (SD)	0.0122 (0.0324)
Lateral wear rate (mm/year)	
Mean (SD)	0.0188 (0.0232)

TABLE IV Correlation Between Continuous UCLA/HAAS Scores (Walking, Stair Climbing, Running) and Hip Society/AAHKS Guidelines (Allowed, Nonallowed Activities) with Radiographic Linear Wear Rate

Independent Variables	Coefficient	2.50%	97.50%	p
Walking (0-5)	0.0005	−0.0016	0.0025	0.66
Running (0-4)	0.0017	−0.0015	−0.0050	0.30
Stair climbing (0-3)	0.0066	0.0021	0.0111	0.004*
Nonallowed vs allowed	0.0063	−0.0032	0.0158	0.19

AAHKS = American Academy of Hip and Knee Surgeons, HAAS = High-Activity Arthroplasty Score, and UCLA = University of California Los Angeles. Linear regressions were adjusted for age at surgery (continuous variable), sex (categorical variables: male, female), BMI (continuous variable), and femoral head (categorical variables: ≤28, >28). 2.5%: lower limit, 95% CI. 97.5%: upper limit, 95% CI. *Statistically significant.

Discussion

For years, surgeons concerned about implant loosening, polyethylene wear and associated risk of complications, have recommended restricting postoperative high-impact activities and some high-repetition activities. This study did not demonstrate a correlation between increased activity levels at an average of 15 years after primary THA and increased linear wear rates of HXLPE. Specifically, walking, running, and participating in "not-recommended" activities did not correlate with increased linear wear.

The average linear wear rate of 0.036 mm/year (SD: 0.026) observed in this study aligns with findings from other populations and series. Harada et al. reported a constant wear rate of 0.005 mm/year after sports participation following THA in a Japanese population[18]. Babovic et al. and Rames et al. documented a negligible level of HXLPE wear, less than 0.02 mm/year, in patients younger than 50 undergoing THA with 10 years of follow-up[19,20]. Pallante et al. demonstrated that patients below 20 had an exceptionally low wear rate (0.01 mm/year) for XLPE at 8 years post-THA[21]. This study adds to the evidence that the wear rate of HXLPE is low and does not seem to be strongly correlated with increased activity.

TABLE V Correlation Between Continuous UCLA/HAAS Activity Level (1-11) and Radiographic Wear Rates

Wear Rate	Coefficient	2.5%	97.5%	p
Linear wear rate	−0.0009	−0.0027	0.0009	0.31
Proximal wear rate	−0.0015	−0.0037	0.0007	0.17
Lateral wear rate	−0.0007	−0.0022	0.0009	0.40

HAAS = High-Activity Arthroplasty Score, and UCLA = University of California Los Angeles. Linear regressions were adjusted for age at surgery (continuous variable), sex (categorical variables: male, female), BMI (continuous variable), and femoral head (categorical variables: ≤28, >28). 2.5%: lower limit, 95% CI. 97.5%: upper limit, 95% CI.

Other studies have investigated the performance of HXLPE under high-demand conditions. Guy et al. showed that ceramic-on-HXLPE in high-demand patients with UCLA ≥8 exhibited lower wear and osteolysis rates with a minimum of 5-year follow-up compared with ceramic-on-conventional polyethylene[22]. In addition, previous studies have shown that wear-related implant failures ranked third after periprosthetic fractures and dislocations among expert opinions for risks associated with high-impact activities[23]. These findings highlight the resilience of HXLPE in high-demand patients, further supporting its reliability in active populations.

This study reports that close to 10% of THA patients were performing high-impact activities that expert panels had previously not recommended[13]. In a systematic review, Sowers et al. reported that post-THA patients demonstrated a trend toward lower-impact sports. The authors also reported that the best prognostic indicator of return to sports was previous experience in that sport, and the main reason patients did not return to high-impact sports was surgeon recommendation[2]. Surgeons at our institution typically advised against high-impact activities during the study period, likely leading patients to limit such activities postoperatively and reducing the number of patients performing high-impact activities.

The UCLA/HAAS activity level score was not correlated with the increased HXLPE wear rate in this population-adjusted regression ($\beta = -0.0009$, $p = 0.31$). Arshi et al. recently reported that patients undergoing THA not only improved their sports/physical activity participation by 86.8% compared with 1 year preoperatively, but also their weekly time spent ($p < 0.05$) and exertion level increased postoperatively ($p < 0.001$)[24]. Crawford et al. found that a higher activity level (UCLA ≥6) after primary THA did not adversely affect survivorship at short-term to mid-term follow-up with modern implants, as compared with a lower activity group ($p < 0.001$) and concluded that higher postoperative activity levels were associated with decreased aseptic loosening[25]. This study provides additional evidence that increased wear is not strongly associated with increased activity; however, implant survivorship was not assessed as those patients who underwent revision surgery for reasons not attributable to wear-related issues were excluded from the survey.

Walking and running were not correlated with HXLPE wear rates. However, stair climbing was significantly correlated with increased wear. The specific stair-climbing assessment asked whether the participant could not climb stairs at all, climbed stairs with assistance, climbed stairs without assistance, or climbed 2 stairs at a time. The analyses suggested that climbing 2 stairs simultaneously was associated with increased linear wear. The clinical significance of this finding requires further investigation and should be interpreted with caution.

Previous biomechanical studies have shown that hip joint loads are higher during running than stair climbing[26,27]. Therefore, it may seem counterintuitive that climbing 2 stairs simultaneously was associated with increased wear, but not running, particularly since studies evaluating wear rates participating in these specific activities are limited. Further research is needed to determine whether climbing 2 stairs at a time has a meaningful impact on implant longevity before restricting it after THA.

This study had some limitations. First, only a select group of patients from our original cohort was included in the wear analysis as nonresponders or those without radiographs taken 10 years apart were excluded. In addition, the higher percentage of female patients in the final cohort was due to more women having follow-up and responding to the questionnaire at 10 years; this demographic characteristic should be considered when interpreting the findings. Moreover, although HAAS and UCLA activity scores are validated tools, our specific approach of combining them and further subdividing HAAS into individual activities has not been formally validated. Similar composite metrics have been used in previous studies, but the sensitivity of this approach in detecting clinically meaningful differences remains uncertain. In addition, the cutoff values used to categorize activity levels were based on functional distinctions rather than established validation, which may affect sensitivity in detecting wear differences. Future research should focus on validating this methodology to strengthen its reliability in wear analyses. In addition, it was difficult to outline ceramic heads on radiographs, making wear measurement challenging, especially in older, low-quality radiographs, which led to the exclusion of more hips from the study. Furthermore, the activity level was assessed at only 1 time point, and patients may have had different activity levels at other times. Also, our survey captured the highest level of function for certain activities but did not assess frequency, making it unclear whether reported activity levels reflect occasional or consistent participation, which may bias correlations with wear. Moreover, wear in THA is volumetric, but in this study, it was only measured linearly. Finally, deleterious effects other than polyethylene wear, such as impingement or adverse events such as dislocation, implant loosening, or periprosthetic fractures, which may occur with high-activity levels, were not accounted for in this study.

In conclusion, high-activity patients aged ≤50 years who underwent primary THA with first-generation HXLPE liners experienced minimal linear wear and absence of osteolysis evaluated at a minimum of 10 years postoperatively. Running, walking, high-impact activities, and higher HAAS/UCLA activity levels were not correlated with increased HXLPE wear rates. These findings support the durability of HXLPE in young, active patients and highlight the need to revisit activity recommendations following THA. Although our results did not show a correlation between activity level and wear, they should be interpreted within the intrinsic limitations of the study. Nevertheless, our findings provide valuable insights to help surgeons counsel young patients undergoing THA and guide recommendations for postoperative activity levels.

Considering advancements in implant technology, including modern bearings and larger femoral heads, developing updated guidelines with input from organizations such as AAHKS and the Hip Society could help ensure alignment with current clinical practice and patient needs. Future research should include longitudinal assessments of activity levels and data on other potential complications related to high-impact sports to provide robust evidence regarding whether patients can safely resume high-impact and/or high-repetition weight-bearing activities and sports after THA.

JBJS Open Access • 2025:e24.00242. **openaccess.jbjs.org** 7

Appendix

eA Supporting material provided by the author is posted with the online version of this article as a data supplement at jbjs.org (http://links.lww.com/JBJSOA/A822). This content has not been copyedited or verified. ■

Sergio F. Guarin Perez, MD[1]
Diego J. Restrepo, MD[1]
Sheng-Hsun Lee, MD[1,2]
Michael B. Stuart, MD[1]
Robert T. Trousdale, MD[1]
Daniel J. Berry, MD[1]
Rafael J. Sierra, MD[1]

[1]Department of Orthopedic Surgery, Mayo Clinic, Rochester, Minnesota

[2]Department of Orthopedic Surgery, Chang Gung Memorial Hospital, Linkou, Taiwan

E-mail address for R.J. Sierra: sierra.rafael@mayo.edu

References

1. Konnyu KJ, Pinto D, Cao W, Aaron RK, Panagiotou OA, Bhuma MR, Adam GP, Balk EM, Thoma LM. Rehabilitation for total hip arthroplasty: a systematic review. Am J Phys Med Rehabil. 2023;102(1):11-8.

2. Sowers CB, Carrero AC, Cyrus JW, Ross JA, Golladay GJ, Patel NK. Return to sports after total hip arthroplasty: an umbrella review for consensus guidelines. Am J Sports Med. 2023;51(1):271-8.

3. Yoon BH, Park JW, Lee YK, Koo KH, Chang CB. Long-term wear-related complications of cross-linked versus conventional polyethylene after total hip arthroplasty: a meta-analysis. J Arthroplasty. 2022;37(11):2308-15.e2.

4. Bonutti PM, Mesko JW, Ramakrishnan R. Long-term wear data from a prospective multicenter study of second-generation highly cross-linked polyethylene inserts in total hip arthroplasty. Orthopedics. 2018;41(4):e529-e533.

5. Hopper RH Jr., Ho H, Sritulanondha S, Williams AC, Engh CA Jr. Otto aufranc award: crosslinking reduces THA wear, osteolysis, and revision rates at 15-year followup compared with noncrosslinked polyethylene. Clin Orthop Relat Res. 2018;476(2):279-90.

6. Campbell DG, Callary SA. Highly crosslinked polyethylene liners have negligible wear at 10 Years: a radiostereometric analysis study. Clin Orthop Relat Res. 2022;480(3):485-91.

7. Mazur M, Steelman K, Sayeed Z, Chen C, Darwiche H, Little B. Total hip arthroplasty in the ultrayoung. Arthroplast Today. 2023;23:101181.

8. Cooper HJ, Della Valle CJ. Large diameter femoral heads: is bigger always better? Bone Joint J. 2014;96-b(11 Suppl A):23-6.

9. Parekh A, Sood A, Monsef JB, Hamouda M, Hussain A, Gonzalez M. Second-generation highly cross-linked polyethylene in total hip arthroplasty. JBJS Rev. 2021;9(4):e20:00065.

10. Lyman S, Lee YY, Franklin PD, Li W, Mayman DJ, Padgett DE. Validation of the HOOS, jr: a short-form hip replacement survey. Clin Orthop Relat Res. 2016;474(6):1472-82.

11. Talbot S, Hooper G, Stokes A, Zordan R. Use of a new high-activity arthroplasty score to assess function of young patients with total hip or knee arthroplasty. J Arthroplasty. 2010;25(2):268-73.

12. Zahiri CA, Schmalzried TP, Szuszczewicz ES, Amstutz HC. Assessing activity in joint replacement patients. J Arthroplasty. 1998;13(8):890-5.

13. Klein GR, Levine BR, Hozack WJ, Strauss EJ, D'Antonio JA, Macaulay W, Di Cesare PE. Return to athletic activity after total hip arthroplasty. Consensus guidelines based on a survey of the Hip Society and American Association of Hip and Knee Surgeons. J Arthroplasty. 2007;22(2):171-5.

14. Geerdink CH, Grimm B, Vencken W, Heyligers IC, Tonino AJ. The determination of linear and angular penetration of the femoral head into the acetabular component as an assessment of wear in total hip replacement. J Bone Joint Surg Br. 2008;90-B(7):839-46.

15. Ranawat AS, Tsailis P, Meftah M, Koob TW, Rodriguez JA, Ranawat CS. Minimum 5-year wear analysis of first-generation highly cross-linked polyethylene in patients 65 years and younger. J Arthroplasty. 2012;27(3):354-7.

16. Martell JM, Berdia S. Determination of polyethylene wear in total hip replacements with use of digital radiographs. J Bone Joint Surg Am. 1997;79(11):1635-41.

17. Rahman L, Cobb J, Muirhead-Allwood S. Radiographic methods of wear analysis in total hip arthroplasty. J Am Acad Orthop Surg. 2012;20(12):735-43.

18. Harada S, Hamai S, Shiomoto K, Hara D, Motomura G, Ikemura S, Fujii M, Nakashima Y. Wear analysis of the first-generation cross-linked polyethylene at minimum 10 years follow-up after THA: no significant effect of sports participation. J Artif Organs. 2022;25(2):140-7.

19. Babovic N, Trousdale RT. Total hip arthroplasty using highly cross-linked polyethylene in patients younger than 50 years with minimum 10-year follow-up. J Arthroplasty. 2013;28(5):815-7.

20. Rames RD, Stambough JB, Pashos GE, Maloney WJ, Martell JM, Clohisy JC. Fifteen-year results of total hip arthroplasty with cobalt-chromium femoral heads on highly cross-linked polyethylene in patients 50 Years and less. J Arthroplasty. 2019;34(6):1143-9.

21. Pallante GD, Statz JM, Milbrandt TA, Trousdale RT. Primary total hip arthroplasty in patients 20 Years old and younger. J Bone Joint Surg Am. 2020;102(6):519-25.

22. Guy S, Flecher X, Sharma A, Argenson JN, Ollivier M. Highly crosslinked polyethylene can reduce wear rate in THA for high-demand patients: a matched-paired controlled study. J Arthroplasty. 2021;36(9):3226-32.

23. Keeney JA, Nunley RM, Baca GR, Clohisy JC. Are younger patients undergoing THA appropriately characterized as active?. Clin Orthop Relat Res. 2015;473(3):1083-92.

24. Arshi A, Khan IA, Ciesielka KA, Cozzarelli NF, Fillingham YA. Participation in sports and physical activities after total joint arthroplasty. J Arthroplasty. 2023;38(5):806-14.e5.

25. Crawford DA, Adams JB, Hobbs GR, Morris MJ, Berend KR, Lombardi AV Jr. Does activity level after primary total hip arthroplasty affect aseptic survival? Arthroplast Today. 2021;11:68-72.

26. Bergmann G, Deuretzbacher G, Heller M, Graichen F, Rohlmann A, Strauss J, Duda GN. Hip contact forces and gait patterns from routine activities. J Biomech. 2001;34(7):859-71.

27. Bergmann G, Graichen F, Rohlmann A. Hip joint loading during walking and running, measured in two patients. J Biomech. 1993;26(8):969-90.