Which Functional Assessments Predict Long-term Wear After Total Hip Arthroplasty?

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Abstract

Background There is a paucity of literature concerning functional assessment at long-term followup of THAs in general and in young patients specifically. Functional data may be useful in determining differences in the performance of various implants and surgical techniques in THA. **Questions/purposes** The purposes of this study were to evaluate a group of young patients who were still active 10 years after THA to determine (1) which functional tests and (2) which patient-reported outcome assessments

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predicted long-term THA function, as measured by acetabular UHMWPE wear, and (3) whether medical comorbidities influenced patient performance on activity tests and patient outcome questionnaires.

Methods Fifty patients (58 hips) 50 years and younger at the time of THA were followed clinically and radiographically for a minimum of 10 years. All patients wore step activity monitors for up to 21 days, performed 6-minute walk (6-MW) tests, and every patient had minimum 10-year radiographs and sequential radiographs evaluated for wear using edge detection techniques. Mean age and BMI at surgery were 39 years and 29 kg/m², respectively.

Results Patients who walked more as determined by step activity monitor (average daily steps) had more linear acetabular UHMWPE wear per year and more volumetric wear per year. The 6-MW, University of California Los Angeles (UCLA), and Tegner Lysholm scores did not correlate with acetabular wear. Mean 6-MW distance was 335 m and pedometer data averaged 1.56 million steps per year. Average UCLA and Tegner Lysholm scores were 6 and 3, respectively. Mean linear wear rate was 0.266 mm/year; mean volumetric wear rate was 82.6 mm³/year. The number of comorbid medical conditions had a detrimental effect on our activity parameters and outcomes questionnaires, but the relationships were not statistically significant.

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Conclusions Of functional tools measured, only pedometer data correlated with THA polyethylene wear. Obtaining pedometer data should be considered when trying to distinguish differences in various hip arthroplasty designs and techniques over the long term.

Level of evidence Level IV, diagnostic study. See Guidelines for Authors for a complete description of levels of evidence.

Introduction

Charnley [5] stated it best, “The challenge comes when patients between 45 and 50 years of age are to be considered for the operation, because then every advance in technical detail must be used if there is to be reasonable chance of 20 and more years of trouble free activity.” Only a few studies have evaluated the long-term (> 10 years) durability of uncemented THAs in patients younger than 50 years [4, 7, 20]. Unfortunately, these studies focus only on the radiographic and clinical survivorship of the implant and fail to assess the activity performance of the patients. The activity level of patients, however, provides objective data regarding how well the arthroplasty is functioning long-term [10, 23].

The purpose of the current study was to evaluate a group of young, active patients who were still actively functioning 10 years after their THA by objectively measuring activity level using step activity monitors (SAMs) (Fig. 1), 6-minute walk tests (6-MW), and University of California Los Angeles (UCLA) and Tegner Lysholm activity scores. We used wear as the gold standard surrogate for use and studied the relationship between activity level and UHMWPE wear. We sought to answer two main questions, in the setting of a relatively young, active population: (1) Which functional tests and (2) which patient-reported outcome assessments predicted long-term hip function (acetabular liner wear)? We also asked (3) whether medical comorbidities influenced patient performance on activity tests and patient outcome questionnaires.

Patients and Methods

Fifty patients (58 hips) 50 years and younger at the time of THA were followed clinically and radiographically for a minimum of 10 years. All patients wore SAMs for up to 21 days, performed 6-minute walk (6-MW) tests, and completed SF-36, WOMACTM, UCLA, and Tegner Lysholm questionnaires.

This cohort was a subset of the living patients in a long-term study (minimum 10-year followup) of cementless THAs in patients younger than 50 years [30]. Of the 73 patients (82 hips) who were still living at 10-year followup in that study (original cohort 100 patients, 115 hips),

Fig. 1 The StepWatchTM Step Activity Monitor is worn around the ankle.

we excluded 23 because they refused 6-MW or pedometer evaluation, did not have adequate radiographic followup for wear measurement, or were one of the few patients (three) with cross-linked polyethylene. The surgery was performed between June 1994 and December 1999. All THAs performed in patients 50 years and younger at that time received the same cementless components. No cemented components were used.

The Prodigy[®] (DePuy Orthopaedics, Inc, Warsaw, IN, USA) femoral component was used in all cases, with 22-mm and 26-mm modular femoral heads. The Prodigy[®] femoral components were mated with 27 Harris-Galante ITM (HG I) acetabular components with gamma in air-sterilized polyethylene (Zimmer, Warsaw, IN, USA) or with 31 Duraloc[®] Sector acetabular components with gas plasma-sterilized polyethylene (DePuy Orthopaedics, Inc). The HG I components were used in the first 27 cases, and the Duraloc[®] Sector components were used in the last 31 cases. Gamma in air-sterilized acetabular liners were mated to the HG I components and gas plasma-sterilized polyethylene was used in the Duraloc[®] cases.

The average age of the patients at the time of index surgery was 39 years (range, 18–50 years). Thirty-six were men and 14 were women. The mean preoperative BMI was 29 kg/m² (range, 18–42 kg/m²). Preoperative evaluation included clinical examination and the use of a standard terminology questionnaire for reporting clinical and radiographic results [15]. All surgeries were performed by the senior author (JJC). The posterolateral approach was used in all cases. The postoperative protocol consisted of having the patients weightbearing with crutches for 6 weeks and progress to full weightbearing as tolerated.

Patients were seen for followup every 2 years and sooner if symptoms warranted. The most recent followup

was at 10 years after the index operation. We evaluated patients in person or interviewed them by telephone and completed standard SF-36 [32], WOMACTM [2], Harris hip [14], and UCLA [33] and Tegner Lysholm [31] activity-level questionnaires.

The UCLA activity-level rating is a 10-point rating ranging from wholly inactive and dependent on others (Level 1) to regular participation in impact sports such as jogging or tennis (Level 10) [1]. The score is based on participation in the highest rated activity regardless of the frequency or intensity of participation. Previous studies have addressed application of the score to an arthroplasty population [10, 18, 21, 26, 33]. The Tegner Lysholm activity scale is a 10-point rating system of work and sports activities ranging from sick leave or disabled (Level 0) to elite competitive sports (Level 10) [31]. Although it was developed to assess activity in patients with knee ligament injuries, studies have shown its applicability to the arthroplasty population [10, 21].

The average preoperative and latest followup Harris hip scores were 48.1 points (range, 19–81 points) and 82.3 points (range, 20–100 points), respectively. The average preoperative SF-36 physical and mental scores were 26.1 (range, 9–53) and 49.5 (range, 18–67), respectively; the average postoperative scores, at most recent followup, were 46.2 (range, 14.4–78.7) and 54.2 (range, 19–85.8), respectively. The average WOMACTM scores (using high score = high function) for pain, stiffness, and function were 41.6 (range, 0–95), 40.3 (range, 0–87.5), and 43.4 (range, 2.9–95.6) preoperatively and 86.8 (range, 25–100), 72.3 (range, 0–100), and 78.1 (range, 11.3–100) at latest followup, respectively, using 100 as the best score. The self-reported mean UCLA score for the study group was 6 (range, 2–10) (Fig. 2A). This translates to the following level of activity: regularly participate in moderate activities such as swimming and unlimited housework or shopping. The distribution of UCLA scores between men and women was not significantly different ($p > 0.05$). The self-reported mean Tegner Lysholm score for the study group was 3 points (range, 0–6 points) (Fig. 2B). This translates to the following level of activity: light labor. The distribution of Tegner Lysholm scores between males and females was not significantly different ($p > 0.05$).

Early postoperative and interval followup radiographs included AP projections of the pelvis that included the tip of the femoral prosthesis and lateral projections of the femur that included the hip. Observation measurements were based on the AP radiographs from the early postoperative period and those at latest followup. Minimum 10-year followup radiographs were available for all 50 patients. The minimum radiographic followup was 10 years (average, 12.1 years; range, 10–16 years). Two authors reviewed the radiographs (JJC, RKT) with

Fig. 2A–B The histogram plots are shown for the (A) UCLA and (B) Tegner Lysholm scores.

interpretation reported by consensus. All femoral and acetabular components showed bone ingrowth into the prosthesis on radiographs.

The activity level of all 50 patients (58 hips) was assessed using a StepWatchTM Activity Monitor (StepWatchTM; Orthocare Innovations, Mountlake Terrace, WA, USA) (Fig. 1) [10, 23]. It records the number of strides taken every minute for up to 2 months. Before use, the SAM is programmed to each patient's height and gait characteristics, thus increasing sensitivity. Unlike most pedometers, accuracy is unaffected by soft tissue at the waist so even extremely obese subjects can be monitored accurately [28]. Indoor and outdoor accuracy of the SAM has been shown to be 96% and 99.6%, respectively [3, 6]. Patients were asked to wear the SAM from the time they woke up in the morning until they went to sleep at night for up to 21 days. Output data included steps per day, minutes worn per day, and average steps for days with activity. We then calculated the number of steps per year by multiplying average steps per day by 365.

Additionally, all 50 patients (58 hips) performed a 6-MW. The 6-MW test measures how far a patient can walk at a normal pace for 6 minutes [9]. It is a quick and inexpensive performance-based measure of functional

Table 1. Functional data for influence of comorbidities

Outcome measure	Group (Number of comorbidities)	Score	p value
Average steps per year	None	1.65 million	p = 0.520
	One	1.51 million	
	Two or more	1.51 million	
6-minute walk	None	358 m	p = 0.138
	One	354 m	
	Two or more	308 m	
SF-36 (points)			
Physical	None	50.16	p = 0.133
Physical	One	44.98	
Physical	Two or more	43.73	
Mental	None	55.81	p = 0.225
Mental	One	57.43	
Mental	Two or more	51.58	
Harris hip score (points)	None	87.05	p = 0.049
	One	87.08	
	Two or more	76.35	
WOMAC TM (points)			
Physical function	None	74.99	p = 0.804
Physical function	One	85.16	
Physical function	Two or more	77.29	
Pain	None	82.87	p = 0.699
Pain	One	95.42	
Pain	Two or more	85.77	
Stiffness	None	68.75	p = 0.971
Stiffness	One	83.46	
Stiffness	Two or more	69.83	
UCLA activity score (points)	None	6.05	p = 0.906
	One	6.25	
	Two or more	6.00	
Tegner Lysholm activity score (points)	None	3.20	p = 0.390
	One	3.08	
	Two or more	2.77	

status that can be performed even by severely limited patients [8, 13]. We compared individual performance on the 6-MW test with the predicted distance for each patient using reference formulas incorporating the patient's age, height, and weight. The reference formulas were generated based on a study of selected, healthy, age-matched subjects reported by Enright and Sherrill [9].

We also measured the influence of comorbid medical conditions on the studied clinical and activity outcomes. For the purpose of statistical analysis, patients were divided into groups with no, one, or two or more comorbid conditions. Seventeen patients (20 hips) had no comorbidity, 10 patients (12 hips) had one comorbidity, and 23 patients (26 hips) had two or more comorbidities (Table 1). Eleven

patients (14 hips) had a musculoskeletal comorbid condition and 39 patients (44 hips) did not have such a condition.

All patients in the study had a minimum 10-year radiograph. Radiographs were digitized and comparison of the initial and final postoperative linear head penetration, as determined by the digital edge detection technique described by Shaver et al. [27], was used as a surrogate for wear. We calculated volumetric wear as described by Kabo et al. [16]. All 50 patients (58 hips) had wear analysis performed using minimum 10-year radiographs unless a revision was performed, in which case the wear was based on the radiograph just before the revision surgery. All wear measurements were performed by two authors (RKT, NAB).

We analyzed data by univariate and multivariate linear regressions using STATA (STATA Corporation, College Station, TX, USA). Pearson correlation coefficients were computed to assess the relationship between clinical and radiographic wear variables. We used Wilcoxon rank-sum tests to evaluate differences between categorical variables (such as sex and cup type) and our clinical and radiographic variables. The t-test was used to analyze differences between normally distributed activity data such as 6-MW distances. Finally, we performed ANOVA using SAS (SAS Institute Inc, Cary, NC, USA) and linear regression analysis to evaluate the effects of comorbidities on functional performance.

Results

Patients who walked more as determined by the SAM (average daily steps) showed more linear acetabular UHMWPE wear per year and more volumetric wear per year; results for the 6-MW test did not correlate with polyethylene wear (Fig. 3). The mean steps per year for the study group was 1.56 million (range, 77,000–3.26 million) with most patients walking between 1 million and 2 million steps per year (Fig. 4A). The mean 6-MW distance for the study group was 335 m (range, 15–503 m) (Fig. 4B). The mean linear polyethylene wear rate was 0.266 mm/year (range, 0.034–1.10 mm/year). The mean volumetric polyethylene wear rate was 83.6 mm³/year (range, 9.14–455.15 mm³/year) (Table 2). The steps per year was predictive of linear wear ($p = 0.0005$), volumetric wear ($p = 0.0074$), linear wear per year ($p = 0.0002$), and volumetric wear per year ($p = 0.002$). Mean steps correlated with linear wear ($r = 0.49$) and linear wear per year ($r = 0.48$). The 6-MW was not predictive of linear wear ($p = 0.64$), volumetric wear ($p = 0.76$), linear wear per year ($p = 0.30$), or volumetric wear per year ($p = 0.42$) and showed only low correlation ($r < 0.40$) with any of the wear variables. The distribution of all wear variables between gamma in air-sterilized UHMWPE and gas plasma-sterilized UHMWPE, and

Fig. 3A–C (A) The correlation between linear wear rate and steps per year ($p = 0.0002$) is shown. (B) There was no relationship between linear wear rate and time ($p > 0.05$), or (C) between linear wear rate and 6-minute walk distance ($p = 0.30$).

Fig. 4A–B Histogram plots for (A) the average yearly step activity monitor steps and (B) 6-minute walk distance are shown.

between 22 mm and 26 mm heads, was not significantly different ($p > 0.05$).

None of the patient self-administered outcome measures correlated with THA performance as measured by UHMWPE wear (Fig. 5). The UCLA score was not predictive of linear wear ($p = 0.88$), volumetric wear ($p = 0.55$), linear wear per year ($p = 0.90$), or volumetric wear per year ($p = 0.59$) and showed only low correlation ($r < 0.40$) with the wear variables. The Tegner Lysholm score was not predictive of linear wear ($p = 0.51$), volumetric wear ($p = 0.31$), linear wear per year ($p = 0.37$), or volumetric wear per year ($p = 0.24$) and showed only low correlation ($r < 0.40$) with any of the wear variables.

The number of comorbid medical conditions had a detrimental effect on the Harris hip score ($p = 0.049$), but, with the numbers available, not on the SF-36 composite physical ($p = 0.13$), SF-36 composite mental ($p = 0.23$), WOMACTM pain ($p = 0.70$), WOMACTM stiffness ($p = 0.97$), WOMACTM function ($p = 0.80$), UCLA ($p = 0.91$), Tegner Lysholm ($p = 0.39$), or 6-MW ($p = 0.14$) scores, or average yearly steps as measured by SAM ($p = 0.52$). The presence of a musculoskeletal comorbid medical condition other than arthritis of the hip had a detrimental effect on average yearly steps as measured by SAM ($p = 0.049$) and Tegner Lysholm activity scores

Table 2. Wear results and significant associations with activity data

Wear/activity type	Wear/activity data	p value
Mean wear values/year		
Linear	0.266 mm (0.034–1.10)	
Volumetric	83.6 mm ³ (9.14–455.15)	
Mean activity data		
Steps	1.56 million (0.077–3.26)	
6-minute walk	335 m (15–503)	
UCLA score	6.1 (2–10)	
Tegner Lysholm score	3 (0–6)	
Linear wear in relation to steps		0.0005
6-minute walk		0.6388
UCLA score		0.8826
Tegner Lysholm score		0.5127
Linear wear/year in relation to steps		0.0002
6-minute walk		0.3004
UCLA score		0.8985
Tegner Lysholm score		0.3708
Volumetric wear in relation to steps		0.0074
6-minute walk		0.7642
UCLA score		0.5546
Tegner Lysholm score		0.3149
Volumetric wear/year in relation to steps		0.0024
6-minute walk		0.4241
UCLA score		0.5912
Tegner Lysholm score		0.2351

($p = 0.019$). However, with the numbers available, the presence of such conditions did not have a detrimental effect on the Harris hip score ($p = 0.42$) or the SF-36 composite physical ($p = 0.37$), SF-36 composite mental ($p = 0.52$), WOMACTM pain ($p = 0.88$), WOMACTM stiffness ($p = 0.43$), WOMACTM function ($p = 0.60$), or UCLA ($p = 0.16$) scores.

Discussion

We performed a minimum 10-year followup study on a cohort of patients who underwent a THA at 50 years or younger and who also had minimum 10-year followup performance measurements (SAM and 6-MW), activity scores (SF-36, WOMACTM, UCLA, Tegner Lysholm), and long-term radiographs with assessment of linear and volumetric wear. Our study is one of few to address polyethylene wear in nonhighly cross-linked polyethylene as it relates to activity measures. In terms of wear, all of the UHMWPE acetabular cups were either gamma in air-sterilized or gas plasma-sterilized, therefore, we were able to examine cases with a relatively large amount of wear. Our study showed averages and range of linear and volumetric wear rates similar to those reported in the literature [18, 24, 25]. We also evaluated wear

Fig. 5A–B There was no relationship (A) between linear wear rate and UCLA score ($p = 0.90$) or (B) between linear wear rate and Tegner Lysholm score ($p = 0.37$).

characteristics of patients excluded from our population because they had highly crosslinked polyethylene. The mean linear wear rate in these patients was 0.061 mm/year. This is low compared with our reported rate of 0.266 mm/year. With such low rates it could be difficult to identify patterns between activity and wear. Therefore, our study of functional assessments benefitted from using a polyethylene with increased wear characteristics.

Corroborating Schmalzried et al. [23], we found wear did not correlate with time after implantation [23] (Fig. 3B). We agree with Schmalzried et al. that wear is a function of use, not time. In that study 31 patients (37 hips) were followed for a minimum of 3 years. Mean linear wear rate was 0.14 mm/year (range, 0.03–0.46) and mean cycles per year were 1.9 million (range, 630,000–4.3 million). They found that wear was correlated with use ($p = 0.09$), which was defined as total sliding

distance $\times$ (patient wt/70 kg). Goldsmith et al. also evaluated polyethylene wear versus gait cycles [12]. In their study of 54 patients (mean age, 58 years; mean followup, 13.1 years), the average pedometer cycles per year was 1.4 million (range, 183,000–4.5 million). The mean wear rate, as measured by socket penetration, was 0.14 mm/year (range, 0–0.57). They found no significant correlation between wear and activity level ($r = 0.13$). The only other study that we are aware of that evaluated whether activity measures are predictive of polyethylene wear is that of Sechriest et al. [26]. They studied 34 patients (38 hips) with an average age at surgery of 42 years and minimum 5-year followup. Mean gait cycles per year were 1.2 million (range, 300,000–2.7 million). Mean linear wear rate was 0.16 mm/year (range, 0.02–0.38 mm/year). They found that only femoral head diameter was predictive of linear wear rate ($p = 0.01$), while UCLA score ($p = 0.09$) and gait cycles

per year ($p = 0.99$) were not predictive of wear. Similar to Sechriest et al., we did not find that UCLA score was a predictor of wear. Additionally, we found that other standard functional assessments and patient reported outcome measures, such as 6-MW, Harris hip score, SF-36, and Tegner Lysholm scores, were not predictors of wear. This should engender caution in the orthopaedic community regarding the usefulness of these measurements for accurately grading function in patients who have had THAs, as we have measured it.

This is one of the largest THA followup studies with 6-MW data [17, 19] and the only one that we are aware of that analyzes the relationship of 6-MW data and polyethylene wear. A benefit of the 6-MW is that it is a quick and inexpensive performance-based measure that reflects the capacity to undertake day-to-day activities [9]. It can be performed by elderly, frail, and severely limited patients who cannot be tested using standard (and more expensive) maximal cycle ergometry or treadmill exercise tests [8, 13]. It is self-paced and does not require any special equipment or facilities. Our patients did significantly poorer on the 6-MW test compared with a healthy group of 40- to 80-year-old adults reported by Enright and Sherrill [9]. The average deficit was 198 m (approximately 62% predicted distance). This is not surprising since that study focused on healthy subjects without comorbid medical conditions that could hinder their ability to perform physical activities. When stratifying our patients by the number of comorbidities, we found a nonsignificant trend toward decreased 6-MW distance with an increasing number of comorbidities ($p > .05$) (Table 1). Additionally, when separating patients into those with and without a musculoskeletal comorbidity, the group with a musculoskeletal comorbidity performed worse on the 6-MW.

We found that the number of comorbid medical conditions or the presence of musculoskeletal comorbid conditions influenced functional results and clinical outcome measures. Comorbid medical conditions had a detrimental effect on the Harris hip score ($p = 0.049$) and musculoskeletal comorbid medical conditions other than arthritis of the hip had a detrimental effect on average yearly steps as measured by the SAM ($p = 0.049$) and Tegner Lysholm activity scores ($p = 0.019$). The only other study we are aware of that specifically addressed comorbid medical and musculoskeletal conditions on functional outcome was that of Keener et al. [17] in patients with Charnley THAs. They found the comorbid medical conditions had a detrimental effect on SF-36 composite physical ($p = 0.007$), Harris hip score ($p = 0.004$), WOMACTM physical ($p = 0.015$), WOMACTM pain ($p = 0.02$), and WOMACTM stiffness ($p = 0.007$) scores. They also found that the presence of a musculoskeletal comorbid medical condition other than arthritis of the hip had a detrimental effect on all functional parameters measured except the Noyes activity scale.

Limitations of our study include that this is a subset of a larger living cohort of patients with 23 of 73 patients missing at least one of the data sets studied. Other weaknesses are related to the intraobserver and interobserver variability in evaluating radiographs and that pedometer, patient reported activity level, and 6-MW data were obtained only at final followup. Since activity data are obtained only at final followup it could be argued that the data are skewed toward a period of less activity. We did have one patient who underwent revision surgery within 1 year of wearing a SAM. This patient's average yearly steps were 2.1 million, which was greater than our study average of 1.56 million. Although this is only one case, it shows that the patient was still quite active at minimum 10-year followup. Another limitation is that our grouping of comorbidities did not take into account the severity of such comorbidities. We included only more serious comorbidities, such as symptomatic coronary artery disease, hypertension, diabetes, and chronic obstructive pulmonary disease. However, patients with the same comorbidity could be affected differently because the severity or burden of disease is different. Another limitation of the study is that the correlation coefficients, while supporting a relationship, do leave room for other factors to influence wear. Such factors could include the technical aspects of performing hip arthroplasty. This, however, is mitigated by the fact that the study was performed by a single experienced surgeon using the same technique. Finally, although the nonhighly cross-linked bearing surface studied no longer is used, it was the standard at the time and evaluating its wear characteristics in this population is still informative.

We evaluated the long-term activity through activity measures and patient-reported assessments in a young patient cohort undergoing cementless THAs and compared these parameters with the function of the bearing surface, as estimated by polyethylene wear at 10-year followup. The study showed that the SAM was the only activity measurement tool that correlated with bearing surface wear. The study also showed that medical and musculoskeletal comorbidities correlated with diminished activity. Therefore, future long-term THA outcomes studies should consider prospective evaluation of comorbidities and activity, such as by a SAM, when attempting to evaluate differences in durability of THA designs, materials, and surgical techniques.

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