Mobility-related outcomes for periacetabular osteotomy in persons with acetabular dysplasia: setting the stage for measurement of real-world outcomes

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ABSTRACT

Periacetabular osteotomy (PAO) is a surgery for persons with symptomatic acetabular dysplasia (AD) that increases acetabular coverage of the femoral head for reducing hip pain and improving function. Patient-reported outcomes (PROs) are significantly improved following PAO, yet little is known regarding mobility-related outcomes. This narrative review provides a synthesis of evidence regarding PROs and mobility-related outcomes in persons with AD following PAO. We further identified important future research directions, chiefly the need for measurement of real-world outcomes. We searched PubMed using comprehensive predefined search terms. We included studies that (i) enrolled persons with AD undergoing PAO, (ii) included PROs and/or mobility-related outcomes and (iii) were written in English. We synthesized and summarized study characteristics and findings. Twenty-three studies were included in this review. Commonly evaluated PROs included pain ($n = 14$), hip function ($n = 19$) and quality of life ($n = 9$). Mobility-related outcomes included self-reported physical activity (PA; $n = 11$), walking speed and cadence ($n = 4$), device-measured PA ($n = 2$), and sit-to-stand, four-square-step and timed stair ascent tests ($n = 1$). Persons with AD had significant improvements in PROs following PAO, yet mobility-related outcomes (e.g. walking speed and device-measured PA levels) did not change over 1 year following PAO. Few studies have evaluated mobility-related outcomes following PAO, and these studies were of a low methodological quality. Future research might include experience sampling data collection approaches and body-worn devices as free-living, technology-driven methodologies to evaluate mobility and other outcomes in persons with AD undergoing PAO.

INTRODUCTION

Acetabular dysplasia (AD) is a structural anomaly of the hip joint that involves abnormal morphology of the shape and/or size in the acetabulum. AD often results in inadequate bony coverage of the femoral head and hip joint instability [1]. The development of AD is likely multifactorial, yet female sex, breech birth position and having a family history of AD are important risk factors for developing symptomatic AD [2, 3]. The prevalence of symptomatic AD is 5% in the general population [4–6], mainly affecting young females (83% of symptomatic AD cases) and Caucasians (87% of symptomatic AD cases) [3]. Symptomatic AD leads to significant hip-related pain that is often provoked during specific movements and/or positions, including prolonged sitting or standing, walking, or running [3, 5]. In addition to hip-related pain, functional limitations [7, 8], decreased quality of life and joint instability are further negative consequences of symptomatic AD [3]. Importantly, persons with symptomatic AD have a high probability of developing secondary hip osteoarthritis (OA) at an early age and eventually may require total hip replacement [9, 10].

Periacetabular osteotomy (PAO) is the gold-standard hip preservation surgery used to correct the hip deformity associated with symptomatic AD [11]. Reinhold Ganz first developed and described the surgery in 1983 [12], and it has gained in popularity with the surgery being frequently performed in recent years [13]. The PAO procedure aims to optimally reposition

the acetabulum to improve hip joint mechanics, reduce excessive joint contact pressure and edge loading, improve load distribution of the articular surface, and increase stability of the joints; all of which are thought to be essential for pain reduction, improvement in function and decreasing risk of the subsequent development of hip OA [12]. PAO is recommended for skeletally mature adolescents and young to middle-aged adults with symptomatic AD [12] who report hip-related pain for more than 6 months [14] and have radiographic evidence of AD using specific measures (e.g. center–edge angle; CEA), with no significant degenerative changes on the joint (Tonnis grade 0 or 1) [15, 16]. On the contrary, severe femoral or acetabular cartilage damage [17], hip joint subluxations [12] and/or severe motion restrictions in hip joint [12] are generally considered contraindications for PAO. Various studies have reported promising improvements in patient-reported outcomes (PROs), including hip pain, hip-related function and quality-of-life measures in persons with symptomatic AD after PAO [3, 13, 18]. Nevertheless, the procedure does have a risk of associated post-operative complications, including hematoma, malreduction, infection and neurovascular injury [13, 19, 20]. Based on the current published studies, however, the breadth and strength of evidence for the outcomes and efficacy of PAO remain understudied [13, 19, 20].

The impairments associated with symptomatic AD (hip pain; decreased strength [7, 21]) may create significant physical barriers for active engagement in various sports/recreational activities [3, 22, 23], and these might be important targets of rehabilitation interventions for persons with symptomatic AD. The lack of knowledge regarding mobility-related outcomes following PAO in persons with symptomatic AD may further limit the ability of clinicians and orthopedic surgeons to provide accurate expectations for patients regarding return to pre-disease levels of function following PAO. Herein, we performed a narrative review [24] and broadly summarized patient-reported and mobility-related outcomes in persons with symptomatic AD following PAO. The narrative review is appropriate for this stage of research as we sought a synthesis of the current literature for informing future research. To that end, we then reflect on important next steps in future research to understand free-living and patient-centered outcomes following PAO, primarily the need for real-world measurement, including the use of body-worn devices such as accelerometers and experience sampling data collection approaches.

METHODS
Research question
Narrative reviews aim to broadly synthesize the currently available evidence and identify important future research directions [24, 25]. We performed a narrative review because we expected limited published evidence regarding patient-reported and mobility-related outcomes in persons with symptomatic AD both before and after PAO, which would eliminate the feasibility of systematic or scoping review. This narrative review summarized patient-reported and mobility-reported outcomes before and after PAO in persons with symptomatic AD and provided important future research directions involving both patient-reported and free-living outcomes following PAO.

Search strategy
We developed a comprehensive literature search strategy using several relevant terms. We performed the initial search on 6 March 2021 and re-ran the search on 17 September 2021 in the PubMed database (search completed from database inception). Our search strategy was developed by a librarian with extensive knowledge and experience in creating relevant search terms and literature searching. We performed the searches using the following terms/keywords: 'periacetabular osteotomy', 'hip dysplasia', 'symptomatic acetabular dysplasia', 'acetabular dysplasia', 'patient-reported functional outcomes', 'patient-reported mobility outcomes', 'functional performance' and 'physical activity'. We used these terms in various combinations using Boolean operators ('AND', 'OR' and 'NOT') along with relevant Medical Subjects Headings terms (Supplementary Appendix 1).

Eligibility criteria
We included relevant studies that (i) compared patient-reported and/or mobility-related outcomes before and after PAO in persons with symptomatic AD and (ii) were written in English. Studies were excluded if they lacked post-PAO patient-reported and/or mobility-related outcomes data. Additionally, we excluded review studies (including systematic and scoping reviews), conference proceedings, editorials, clinical commentaries, case studies and animal studies. We defined PROs as any form of data related to pain intensity, function, quality of life or self-reported physical activity (PA). Furthermore, we defined mobility-related outcomes as (i) laboratory-based assessments of function (measures such as the 6-min walk test or sit-to-stand test) and (ii) free-living mobility-related assessments (measures such as steps or PA duration and intensity often based on devices such as accelerometers).

Study risk of bias assessment
Risk of bias assessment is not typically required/recommended for narrative reviews, but we were interested in the quality of the included studies to better understand the current state of the literature and assist in making recommendations for future research. Thus, we assessed the methodological quality of all included studies using the modified Coleman Methodology Score [26]. This quality assessment tool has scores that range from 0 to 100, with a score of 100 indicating low study bias [26]. The modified Coleman Methodology Score evaluates 10 criteria based on the subsections of the Consolidated Standards of Reporting Trials statement for randomized controlled trials [27], but the items are adjusted specific to other study designs.

Synthesis of results
Of the included studies, we performed a consolidation thematic analysis and synthesis of the evidence regarding outcomes in persons with symptomatic AD before and after PAO. We organized and presented our results based on two major outcomes areas: (i) PROs and (ii) mobility-related outcomes (laboratory-based functional performance and real-world measurements).
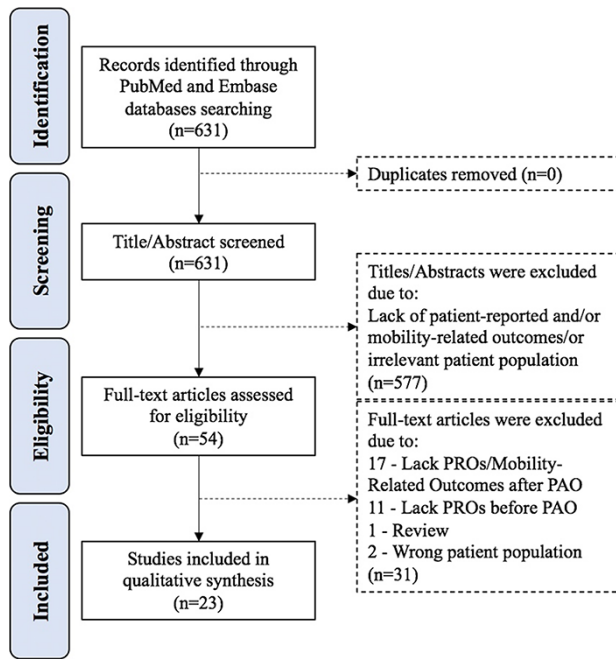
Fig. 1. Database search process and results (The Preferred Reporting Items for Systematic Reviews and Meta-Analysis flowchart).

RESULTS
Search results

The literature search yielded 631 potential studies, and 23 studies met our eligibility criteria (Fig. 1). Studies were excluded ($n = 608$) primarily due to lack of patient-reported and/or mobility-related outcomes or due to the incorrect patient population. Across the included studies ($n = 23$), there was a total sample size of 2355 persons with symptomatic AD who underwent PAO (1778 females). Demographic data for all included studies are provided in Table I.

The average ($\pm$SD) overall modified Coleman score for the included studies was 42.4 ± 10.5 (prospective studies average score = 49.33; retrospective studies average score = 37.9). Of the included studies, the highest score was 59 [28] and the lowest score was 25 [29]. The modified Coleman Methodology Score for all included studies are provided in Table I.

PROs following PAO: summary by measure

PROs are assessment batteries frequently used in research to collect important patient-centered outcomes to establish baseline data and monitor disease activity over time with or without interventions [30]. Individual study results for PROs are summarized in Table I. In reviewing the literature, we observed that PROs were worse before PAO when compared to scores after PAO [3, 7, 22, 23, 28, 31–39]. Before PAO, participants reported higher pain [3, 23, 28, 32, 33, 35, 37–40], worse hip-related function [3, 7, 29, 31–47], lower quality of life [3, 28, 29, 34, 35, 37, 38, 40, 42], worse laboratory-based functional performance (such as walking speed) [32] and a significant reduction in PA levels, both through the use of patient-reported [3, 22, 23, 28, 34, 35, 38, 39, 43, 47, 48] or device-measured [23, 28] PA.

In the studies referenced above, hip-related pain, function and quality of life were measured using common hip-related questionnaires that have been shown to be reliable and valid in individuals with hip pathology, including (i) the modified Harris Hip Score or the standard Harris Hip Score (mHHS/HHS; $n = 15$) [3, 7, 29, 31–33, 35, 36, 38–41, 43, 44, 47], (ii) the Hip Disability and Osteoarthritis Outcomes Score (HOOS; $n = 10$) [3, 29, 32, 35, 37, 38, 40, 42, 43, 46], (iii) the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC; $n = 7$) [33, 35, 38, 39, 44, 46, 47], (iv) the Copenhagen Hip and Groin Outcome Score (HAGOS; $n = 3$) [23, 28, 34], (v) the International Hip Outcome Tool (iHOT-12; $n = 1$) [32], (vi) the Patient-Reported Outcomes Measurement Information System (PROMIS; $n = 1$) [32], (vii) The Short Form 36 Health Survey Questionnaire (SF-36; $n = 2$) [33, 42], (viii) the Numeric Pain Rating scale (NPRS; $n = 1$) [34], (ix) the Visual Analogue Scale (VAS; $n = 1$) [32], and the Non-Arthritic Hip Score (NAHS; $n = 1$) [45].

Patient-reported hip pain intensity following PAO

Of the overall included studies ($n = 23$), 14 studies evaluated pain intensity in persons with symptomatic AD before and after PAO [3, 23, 28, 29, 32, 33, 35, 37–40, 42, 44, 47], using several PROs, included the HOOS ($n = 8$) [3, 32, 35, 37, 38, 40, 42, 48], WOMAC ($n = 6$) [33, 35, 38, 39, 44, 47], HAGOS ($n = 2$) [28, 34], VAS scale ($n = 1$) [32] and NPRS ($n = 1$) [34]. Average scores of pain intensity before and after PAO in persons with symptomatic AD are provided in Table I. Of the 14 studies that evaluated pain intensity in persons with symptomatic AD, 6 studies used prospective study designs monitoring pain changes over 4 months to 2 years following PAO (total combined sample = 857) [3, 28, 32–35]. Eight studies used retrospective study designs reviewing reports that evaluated pain intensity after 2 years [37, 40, 42, 44, 48], 3 years [38], 5 years [39] and 6 years [47] following PAO, respectively (total combined sample = 625). Across studies, there were significant improvements in pain intensity among persons with symptomatic AD up to 6 years following PAO (all studies reported statistically significant improvements; $P < 0.05$; total combined sample = 1482) [3, 23, 28, 29, 32, 33, 35, 37–40, 42, 44, 47].

Patient-reported hip-related function following PAO

Of the overall included studies ($n = 23$), 19 evaluated hip-related function in persons with symptomatic AD before and after PAO [3, 7, 31–45, 47, 48], using several PROs, including the mHHS/HHS ($n = 15$) [3, 7, 29, 31–33, 35, 36, 38–41, 43, 44, 47], HOOS ($n = 7$) [3, 29, 32, 35, 37, 38, 42], WOMAC ($n = 4$) [33, 38, 39, 44], iHOT-12 and the PROMIS (physical function subscale; $n = 1$) [32], HAGOS ($n = 1$) [34], and NAHS (1) [45]. Average scores on hip-related function before and after PAO in persons with symptomatic AD are provided in Table I. Of the 19 studies that evaluated hip-related function in persons with symptomatic AD, 7 studies used prospective study designs monitoring hip function changes before and up to 7 years after PAO (total combined sample = 872) [3, 7, 31–35]. Twelve studies used a retrospective study design reviewing hip function data in persons with symptomatic AD between 6 months and up to 7 years following PAO (sample = 982) [29, 36–45, 47].

Table I. Patient-reported and mobility-related outcomes before and after PAO in persons with symptomatic acetabular dysplasia (n = 23)

Study design	Authors Modified Coleman score (out of 100)	Sample size	Sex distribution	Intervention status	Mean age (years)	Measurement tools	PROs			Mobility scores (functional performance and PA)
							Pain scores	Function scores	Quality-of-life scores	
Prospective (n = 9)	Gahramanov et al. [31]	35	AD Group 31 F 4 M	Pre-and-Post-PAO	33	HHS (out of 100, lower-scores = worse)	—	Pre: 59.7 7-Year Post: 89.4*	—	—
	Coleman Score = 56	35	Healthy controls 30 F 5 M		34	Cadence (steps/min)	—	—	—	AD Group at 7-Year Post-PAO = 111.2 Healthy Group = 115.3
						Walking Speed (m/s)				AD Group at 7-Year Post-PAO = 1.13 Healthy Group = 1.18
	Scott et al. [32]	22	20 F 2 M	Pre-and-Post-PAO	24.5	VAS (out of 100; higher scores = worse)	Pre = 55.2 6-Month Post = 11.4* 1-Year Post = 19.5*	—	—	—
						PROMIS PF (t-score:100)	—	Pre = 41.3 6-Month Post = 52.3* 1-Year Post = 52.2*	—	—
	Coleman score = 42					HOOS (out of 100; lower scores = worse)	Pre = 47.4 6-Month Post = 85.6* 1-Year Post = 82.3*	—	—	—
						iHOT-12 (out of 100; lower scores = worse)	—	Pre = 31.9 6-Month Post = 80.7* 1-Year Post = 76.2*	—	—

(continued)

Table I. (Continued)

Study design	Authors	Modified Coleman score (out of 100)	Sample size	Sex distribution	Intervention status	Mean age (years)	Measurement tools	PROs			Mobility scores (functional performance and PA)
								Pain scores	Function scores	Quality-of-life scores	
							mHHS (out of 100; lower scores = worse)	–	Pre = 60.6 6-Month Post = 89.1* 1-Year Post = 85.3*	–	–
							Sit-to-stand (5 trials; s)	–	–	–	Pre = 10.2 6-Month Post = 8.3* 1-Year Post = 8.40*
							Walking speed (self-selected pace; m/s)	–	–	–	Pre = 1.2 6-Month Post = 1.3 1-Year Post = 1.3
							Four-Square-Step-Test (s)	–	–	–	Pre = 6.0 6-Month Post = 6.1 1-Year Post = 6.5
							Timed stair ascent test (s)	–	–	–	Pre = 4 6-Month Post = 3.8 1-Year Post = 3.70*
	Sucato et al. [7]		21	AD Group 18 F 3 M	Pre-AND-Post-PAO	16	HHS (out of 100; lower scores = worse)	–	Pre = 65 6-Month Post = 76* 1-Year Post = 74*	–	–
	Coleman score = 44		(Not reported)	Healthy Controls (Not reported)			Walking speed (m/s)	–	–	–	Pre = 1.20 6-Month Post = 1.26 1-Year Post = 1.21* Controls: 1.32

Table 1. (Continued)

Study design	Authors Modified Coleman score (out of 100)	Sample size	Sex distribution	Intervention status	Mean age (years)	Measurement tools	PROs			
							Pain scores	Function scores	Quality-of-life scores	Mobility scores (functional performance and PA)
	Karam et al. [33] Coleman score = 33	33	27 F 6 M	Pre-AND-Post-PAO	28.5	WOMAC (out of 100; lower scores = worse)	Pre = 60 1-year Post = 84*	Pre = 74 1-Year Post = 85*	–	–
						HHS (out of 100; lower scores = worse)		Pre = 76 1-Year Post = 83*	–	–
						SF-36 PCS (out of 100; lower scores = worse)	–	Pre = 38.7 1-Year Post = 47.2*		
						Cadence (step/min)	–	–	–	Pre = 106.9 1-Year Post = 108.7
						Walking speed (cm/s)	–	–	–	Pre = 117.7 1-Year Post = 134.6
	Jacobsen et al. [34] Coleman score = 57	82	71 F 11 M	Pre-and-Post-PAO	30	HAGOS (out of 100; lower scores = worse)	Pre = 50 1-Year Post = 76*	Pre = 55 1-Year Post = 81*	Pre = 29 1-Year Post = 57*	Pre = 23 1-Year Post = 44*
						NPRS (out of 10; lower-worse)	Pre = 3 1-Year Post = 0*	–	–	–
	Sankar et al. [3] Coleman score = 41	320	244 F 76 M	Pre-and-Post-PAO	25.4	HOOS (out of 100; lower scores = worse)	Pre = 56 2-Year Post = 84*	Pre = 46 2-Year Post = 77*	Pre = 35 2-Year Post = 70*	–
						mHHS (out of 100; lower scores = worse)	–	Pre = 61.2 2-Year Post = 85.1*	–	–
						UCLA (out of 10; lower scores = worse)	–	–	–	Pre = 6.8 2-Year Post = 7.2*

Table I. (Continued)

Study design	Authors Modified Coleman score (out of 100)	Sample size	Sex distribution	Intervention status	Mean age (years)	Measurement tools	PROs Pain scores	Function scores	Quality-of-life scores	Mobility scores (functional performance and PA)
	Petrie et al. [35] Coleman score = 58	359	279 F 80 M	Pre-and-Post-PAO	25.1	HOOS (out of 100; lower scores = worse)	Pre = 55 1–2-Year Post = 84*	Pre = 45 1–2-Year Post = 76*	Pre = 35 1–2-Year Post = 70*	–
						WOMAC (out of 100; lower scores = worse)	Pre = 61 1–2-Year Post = 86*	–	–	–
						mHHS (out of 100; lower scores = worse)	–	Pre = 61 1–2-Year Post = 85*	–	–
						UCLA (out of 10; lower scores = worse)	–	–	–	Pre = 6.8 1–2-Year Post = 7.4*
	Sandell Jacobsen et al. [23] Coleman score = 54	77	62 F 15 M	Pre-and-Post-PAO	30	HAGOS (out of 100; lower scores = worse)	–	–	–	Pre: 23 1-Year Post = 45*
						Accelerometer	–	–	–	No significant differences in VLI, LI, MI or HI
	Mechlenburg et al. [28] Coleman score = 59	41	34 F 7 M	Pre-and-Post-PAO	28.8	HAGOS (out of 100; lower scores = worse)	Pre = 58 4 Months = 76 1-Year Post = 78*	–	Pre = 35 4-Month Post = 44 1-Year Post = 55*	Pre = 12 4-Month Post: 38 1-Year Post = 38*
						Accelerometer	–	–	–	4–12-Month Post: No significant differences in VLI, LI, MI or HI
Retrospective (n = 14)	Sakamoto et al. [36] Coleman score = 39	27	27 F	Pre-and-Post-PAO	17	HHS (out of 100; lower scores = worse)	–	Pre = 80 3-Year Post = 95*	–	–

(continued)

Table I. (Continued)

Study design / Authors Modified Coleman score (out of 100)	Sample size	Sex distribution	Intervention status	Mean age (years)	Measurement tools	PROs Pain scores	Function scores	Quality-of-life scores	Mobility scores (functional performance and PA)
Boje et al. [37] Coleman score = 46	321	283 F 38 M	Pre-and-Post-PAO	31	HOOS (out of 100; lower scores = worse)	Pre = 53 2-Year Post = 78*	Pre = 42.8 2-Year Post = 69.5*	Pre = 33 2-Year Post = 59*	–
Bogunovic et al. [38] Coleman score = 32	36	21 F 15 M	Pre-and-Post-PAO	25	HOOS (out of 100; lower scores = worse)	Pre = 61 3-Year Post = 86*	Pre = 48 3-Year Post = 80*	Pre = 38 3-Year Post = 71*	–
					WOMAC (out of 100; lower scores = worse*)	Pre = 67 3-Year Post = 89*	Pre = 73 3-Year Post = 94*	–	–
					HHS	–	Pre = 63 3-Year Post = 87*	–	–
					UCLA (out of 10; lower scores = worse)	–	–	–	Pre = 9.2 3-Year Post = 8.8
Okoroafor et al. [39] Coleman score = 32	58	42 F 16 M	Pre-and-Post-PAO	25.3	WOMAC (out of 100; lower scores = worse)	Pre = 69 5-Year Post = 90*	Pre = 75 5-Year Post = 91*	–	–
					mHHS (out of 100; lower scores = worse)	–	Pre = 67 5-Year Post = 88*	–	–
					UCLA (out of 10; lower scores = worse)	–	–	–	Pre = 9 5-Year Post = 8*
Novais et al. [22] Coleman score = 27	51	47 F 4 M	Pre-and-Post-PAO	27	UCLA (out of 10; lower scores = worse)	–	–	–	Pre = 6 1-Year Post = 7* 2-Year Post = 7.5*

(continued)

Table I. (Continued)

Study design	Authors Modified Coleman score (out of 100)	Sample size	Sex distribution	Intervention status	Mean age (years)	Measurement tools	PROs			Mobility scores (functional performance and PA)
							Pain scores	Function scores	Quality-of-life scores	
	Nassif et al. [41] Coleman score = 49	48	Unreported	Pre-and-Post-PAO	Unreported	mHHS	–	Pre = 63 6.5-Year Post = 84*	–	–
	Novais et al. [40] Coleman score = 35	28	All F	Pre-and-Post-PAO	20	mHHS	–	Pre = 67 2-Year Post = 86*	–	–
						HOOS	Pre = 66 2-Year Post = 86*	Pre = 74 2-Year Post = 90*	Pre = 46 2-Year Post = 70*	–
	McClincy et al. [29] Coleman score = 25	39	37 F 2 M	Pre-and-Post-PAO	26.5	mHHS	–	Pre = 64 2-Year Post = 86*	–	–
						HOOS	Pre = 52 2-Year Post = 78*	Pre = 47 2-Year Post = 76*	Pre = 32 2-Year Post = 66*	–
						UCLA	–	–	–	Pre = 6 2-Year Post = 7*
	Jakobsen et al. [42] Coleman score = 48	142	Unreported	Pre-and-Post-PAO	32	HOOS	Pre = 55* 6-Month Post = 79* 2-Year Post = 79	Pre = 44* 6-Month Post = 69 2-Year Post = 71	Pre = 34* 6-Month Post = 58 2-Year Post = 59	–
						SF-36 PCS (out of 100; lower scores = worse)	–	Pre = 36 6-Month Post = 44 2-Year Post = 45	–	–

(continued)

Table I. (Continued)

Study design	Authors Modified Coleman score (out of 100)	Sample size	Sex distribution	Intervention status	Mean age (years)	Measurement tools	PROs Pain scores	Function scores	Quality-of-life scores	Mobility scores (functional performance and PA)
	Heyworth et al. [43] Coleman score = 31	41	36 F 5 M	Pre-and-Post-PAO	26	mHHS	–	Pre = 70 3-Year Post = 90*	–	–
						HOOS		Pre = 64 3-Year Post = 89*	–	–
						UCLA	–	–	–	Pre = 8 3-Year Post = 8
	Gu et al. [44] Coleman score = 35	44	40 F 4 M	Pre-and-Post-PAO	31	WOMAC	Pre = 4 1.6-Year Post = 0*	Pre = 18 1.6-Year Post = 4*	–	–
						mHHS	–	Pre = 70 1.6-Year Post = 91*	–	–
	Ramírez-Núñez et al. [45] Coleman score = 53	131	102 F 29 M	Pre-and-Post-PAO	32	NAHS	–	Pre = 6.6 7.7-Year Post = 90.7*	–	–
	Muffly et al. [46] Coleman score = 45	332	267 F 65 M	Pre-and-Post-PAO	30	HOOS	–	Pre = 51 2-Year Post = 73*	–	–
						WOMAC		Pre = 64 2-Year Post = 86.5*	–	–
	Edelstein et al. [47] Coleman score = 34	67	62 F 5 M	Pre-and-Post-PAO	29	mHHS	–	Pre = 55 6.5-Year Post = 85*	–	–
						WOMAC (out of 10; higher scores = worse)	Pre = 9.1 6.5-Year Post = 3.2*	–	–	–
						UCLA	–	–	–	Pre = 6.5 6.5-Year Post = 77.5*

VLI = very low intensity; LI = low intensity; MI = moderate intensity; HI = high intensity;
*Significant findings (P < 0.05).

Across studies, functional improvements were evident in persons with symptomatic AD from 1 year and up to 5 years following PAO (all studies reported statistically significant improvements; $P < 0.05$; total combined sample = 1854) [3, 7, 29, 31–45, 47].

Patient-reported quality of life following PAO

Of the overall included studies ($n = 23$), nine studies evaluated quality of life in persons with symptomatic AD before and after PAO [3, 28, 29, 34, 35, 37, 38, 40, 42], using two PROs, included the HOOS ($n = 7$) [3, 29, 35, 37, 38, 40, 42] and HAGOS ($n = 2$) [28, 34]. Average scores on quality-of-life measures before and after PAO in persons with symptomatic AD are provided in Table I. Of the nine studies that evaluated quality of life in persons with symptomatic AD, four studies used prospective study designs monitoring quality-of-life improvements over time before and up to 2 years after PAO (total combined sample = 802) [3, 28, 34, 35]. Five studies used a retrospective study design reviewing quality-of-life data in persons with symptomatic AD up to 3 years following PAO (total combined sample = 566) [29, 37, 38, 40, 42]. Across studies, persons with symptomatic AD showed improvements in self-reported quality-of-life measures from 1 year and up to 3 years following PAO (all studies reported statistically significant improvements; $P < 0.05$; total combined sample = 1378) [3, 28, 29, 34, 35, 37, 38, 40, 42].

Mobility-related outcomes following PAO (laboratory-based functional performance and real-world measurements)

Laboratory-based functional performance outcomes following PAO

Laboratory-based functional measures such as the timed up-and-go test [49], 6-min walk test (6MWT) [50] and 10-m walk test [51] are important clinically relevant mobility measures that could be used to evaluate mobility-related outcomes in persons with symptomatic AD following PAO. Of the included studies ($n = 23$), four prospective studies evaluated walking speed (self-selected pace) and cadence ($n = 2$) during a short distance in persons with symptomatic AD before and up to 7 years following PAO (total combined sample = 111) [7, 31, 32, 33]. Average scores of walking speed and cadence before and after PAO in persons with symptomatic AD are provided in Table I. Of the four studies that evaluated walking speed and cadence ($n = 2$), two studies reported no significant improvements in walking speed and cadence in persons with symptomatic AD 1 year following PAO ($P > 0.05$; total combined sample = 55) [32, 33]. One study found improvements in walking speed in persons with symptomatic AD 1 year following PAO (sample = 21) [7]. Additionally, the final study reported no significant differences ($P > 0.05$) in walking speed and cadence between persons with symptomatic AD 7 years following PAO and healthy controls (sample = 35 per group) [31].

Of the included studies ($n = 23$), only one prospective study evaluated laboratory-based functional tasks including study sit-to-stand, four-square-step and timed stair ascent tests in persons with symptomatic AD before PAO and 6 months and 1 year after PAO ($n = 22$) [32]. Average scores of laboratory-based functional tasks before and after PAO in persons with symptomatic AD are provided in Table I. In this study, persons with symptomatic AD showed significant improvements in the sit-to-stand and timed stair ascent tasks 1 year following PAO ($P < 0.05$) [32]. Collectively, to our knowledge and based on the results of our current narrative review, no further studies have evaluated other laboratory-based functional tasks, such as the 6MWT, in persons with symptomatic AD before and after PAO.

Patient-reported PA levels following PAO

Doubtlessly, PA is associated with a myriad of health benefits and improved quality of life among the general population [52, 53, 54, 55]. In contrast, physical inactivity contributes to the incidence and development of several comorbidities and chronic diseases [56, 57, 58, 59, 60]. Often, PA levels are measured using self-reported scales, such as the International Physical Activity Questionnaire (IPAQ) [61], the HAGOS-PA subscale [62], and the University of California, Los Angeles Activity Score (UCLA) activity score [63]. Additionally, PA monitors (e.g. pedometers or accelerometers) are alternative approaches to quantify PA behavior during free-living. PA monitors are considered valid and reliable tools that aim to provide objective, real-time, continuous PA data in terms of volume, intensity, frequency and/or duration and have been applied across patient populations and healthy individuals [64].

Of the overall included studies ($n = 23$), 11 studies evaluated PA levels in persons with symptomatic AD before and after PAO [3, 22, 23, 28, 29, 34, 35, 38, 39, 43, 47], using 2 PROs, including the UCLA activity score ($n = 8$) [3, 22, 29, 35, 38, 39, 43, 47] and the HAGOS-PA subscale ($n = 3$) [23, 28, 34]. Average scores for patient-reported activity levels before and after PAO in persons with symptomatic AD are provided in Table I. Of the 11 studies that evaluated patient-reported PA levels, 5 studies used a prospective study design measuring PA improvements before and 4 months to 5 years following PAO (all studies showed significant improvements; $P < 0.05$; after PAO; total combined sample = 879) [3, 23, 28, 34, 35]. Furthermore, six studies used a retrospective study design reviewing reports containing patient-reported PA data following PAO (total combined sample = 292) [22, 29, 38, 39, 43, 47]. Based on these patient-reported PA studies, persons with symptomatic AD had improvements in activity levels evaluated from 4 months to 6.5 years following PAO (all studies reported statistically significant improvements; $P < 0.05$; total combined sample = 1172) [3, 22, 23, 28, 29, 34, 35, 38, 39, 43, 47].

Device-measured PA following PAO

Of the overall included studies ($n = 23$), only two studies evaluated PA levels using device-measured approaches in persons with symptomatic AD following PAO (total combined sample = 118) [23, 28]. These two studies used a commercially available tri-axial accelerometer worn on the lateral side of the non-affected limb (placement: mid-thigh). In one study [23], device-measured PA was measured over 7 consecutive days, both before and 1 year after PAO. In the other study [28], device-measured PA was measured over 5 consecutive days, at 4 months and 1 year following PAO (no pre-PAO assessment). Both studies instructed participants (i.e. persons with symptomatic AD) to

wear the accelerometer during the entire day (all waking hours) [23, 28]. Average scores of device-measured PA levels in persons with symptomatic AD before and after PAO from these studies [23, 28] are provided in Table I. Results from these two prospective studies indicated that device-measured PA levels (time spent in sitting, standing, walking and/or running; min/day) 1 year after PAO [23, 28] did not change compared to activity levels before PAO or 4 months after PAO [28] in persons with symptomatic AD.

DISCUSSION
Summary of findings from this review

To the best of our knowledge, this is the first review to synthesize evidence regarding patient-reported and mobility-related outcomes following PAO in persons with symptomatic AD as well as to reflect on future research for capturing real-world effects of PAO in this patient population. The current narrative review included 23 studies (9 prospective [3, 7, 23, 28, 31, 32, 33, 34, 35] and 14 retrospective [22, 29, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47]) that presented patient-reported and mobility-related outcomes in persons with symptomatic AD, both before and after PAO. Postoperatively following PAO, there were consistent improvements in PROs (pain, function, quality of life and self-reported PA). Only one study evaluated laboratory-based functional performance (sit-to-stand, four-square-step and timed stair ascent tests) and reported improvements in these tasks (excluding the four-square-step-test) in persons with symptomatic AD 1 year following PAO [32]. However, none of the included studies evaluated other clinically relevant functional performance or walking measures such as the 6MWT. Lastly, only two studies evaluated device-measured PA levels (i.e. accelerometers) and provided no evidence for significant changes/improvements before to 1 year after PAO (both $P > 0.05$) [23, 28]. Importantly, the overall quality of evidence was low (high risk of bias caused by two main factors; follow-up period and study design) and most of the included studies were retrospective, and these may limit our interpretations regarding PROs and mobility-related outcomes following PAO. Overall, the current narrative review reported very limited evidence regarding mobility-related outcomes using device-based approaches (activity-related devices such as accelerometers or pedometers) during continuous, uncontrolled/real-life settings (i.e. measurement in the wild).

Summary of measures used in the included studies (advantages and disadvantages for real-world ambulation)
Supervised assessment of mobility-related outcomes may lack real-life applicability

Mobility-related assessments are administered in controlled and supervised research settings and involve only walking for relatively short distances or performing physical tasks for a relatively short duration (e.g. 6MWT [50] or timed-up-and-go test [49]). Of the included studies ($n = 23$), only one study evaluated laboratory-based performance measures (e.g. sit-to-stand, four-square-step and timed stair ascent tests) [32] and four studies evaluated walking speed and cadence ($n = 2$) in persons with symptomatic AD before and after PAO [7, 31–33].

Laboratory-based performance assessments pertain to various advantages. First, these measures can be utilized to evaluate a specific and discrete functional-related task (e.g. squat and single leg stand) that is relevant to patients' needs and/or complaints as well as in-person observations and detections for an asymmetry/deficit during tasks completion. Second, laboratory-based measures could be performed during regular patients' clinical visits (e.g. screening purposes) and may provide helpful, preliminary data essential for setting the stage for performance standard or capacity for real-world ambulation captured by either patient-reported or device-measured PA outcomes [65]. These assessments may not reflect real-world mobility-related performance. They still, however, are essential measures that need to be assessed and documented prior to real-world mobility-related outcomes that occur in less predictable and controlled environments.

Often, patient-reported PA questionnaires are easy to administer, performed remotely and required less efforts to complete. However, the completion of these activity questionnaires may be subject to recall bias or inaccuracies [66]. Additionally and based on previous research, the use of patient-reported PA questionnaires may further overestimate PA levels (on average, by 84%) [67]. Activity-related devices (e.g. accelerometers or pedometers) measure mobility-related data that reflect real-world functional activities measured over long time periods, allowing researchers to capture improvements or decline in activity levels as well as behavioral changes to targeted PA-related interventions [68]. Specifically, activity-related devices are able to quantify activity levels with respect to total volume, and duration and intensity of movement periods (i.e. metabolic equivalents; light, moderate, vigorous PA or sedentary time), using acceleration count-based cut-points developed in various studies of adult samples [64, 69].

Gaps in knowledge and future research directions in evaluating PAO outcomes

The current narrative review documents a paucity of evidence regarding the use of device-based approaches that quantify PA levels, as a metric of free-living mobility for persons with symptomatic AD following PAO. The use of activity-related devices may provide greater insights into the real-world effects of PAO on activity and mobility-related function in persons with symptomatic AD. Based on the two studies that evaluated PA levels in persons with symptomatic AD using device-measured approaches [23, 28], application of PA-related devices (accelerometers) has provided precise, individualized data regarding specific category of activity levels, including moderate-to-vigorous PA, in real life. In turn, these data can influence future therapeutic interventions such as designing targeted behavioral or individualized rehabilitative programs. Various options are available to accurately measure PA levels before and after PAO, such as accelerometry-based and global positioning system-based devices. These devices capture daily activity during continuous, real-life situations (i.e. walking, running, laying or sitting) for long time periods (e.g. 1–3 weeks) [70, 71]. Additionally, these devices measure and store acceleration data and convert these data into various, meaningful outcomes such as daily step

counts, sedentary behavior and activity intensity/volume [72]. Application of these activity-related devices may allow for the study of demographic, surgical and rehabilitation-related factors associated with improvement/normalization of PA. Specifically, worse pre-operative mental health [73], severe acetabular morphology (i.e. lower CEA) [35] and male sex [3] have been associated with worse outcomes following PAO, and thus, these could be studied for their effect on device-measured, real-world mobility outcomes. Additionally, rehabilitation-specific clinical measures, such as muscle performance (shown to be decreased in those with symptomatic AD/following PAO) [7, 21] and movement patterns/neuromuscular control during various tasks (squat, jump or walk), could be studied for their potential influence on device-measured PA before and following PAO. In turn, this work could inform targeted rehabilitation and/or behavioral intervention studies and clinical trials focused on maximizing real-world, mobility-related outcomes evaluated with activity monitors.

Beyond the use of PA-related devices, other technology-based data-gathering methods may provide further insights into real-world, daily function and recovery for patients with symptomatic AD following PAO. One such data-gathering method that may have important utility in those following PAO is experience sampling methodology (ESM) [74]. ESM is a technology-driven data-gathering method used to understand the day-to-day experience related to a given construct [74]. In ESM, individuals respond to prompts (typically administered using smartphones) multiple times during their daily life about their experience related to a construct of interest at that point in time [75]. In patients with symptomatic AD following PAO, ESM could be used to evaluate important PROs (like pain or function) multiple times during the day or regularly (e.g. daily or weekly) over a longer period of data collection. Unlike one-time questionnaire completion, ESM does not rely on the patient's ability and/or willingness to recall what they experienced over time and across varying situations. Thus, ESM may avoid inaccuracies and/or biases observed with retrospective self-assessment [66]. Importantly, pain intensity is a key impairment for persons with symptomatic AD and a critical outcome to measure the effectiveness of PAO for these persons [14]. Pain could be assessed prior to PAO as well as at regular intervals following PAO, using ESM and valid and reliable pain-related scales (e.g. NPRS [76], VAS [77] or the HOOS pain subscale [78]). A comprehensive pain evaluation across multiple time points following PAO could provide more specific data regarding daily, real-time recovery and help to target/modify rehabilitation programs and post-operative medical care.

Limitations and considerations regarding this review

There are important limitations of the current review. First, a majority of the included studies ($n = 14$) were of low-quality study design (retrospective). This finding demonstrates the overall lack of strong evidence related to patient-reported and mobility-related outcomes following PAO and should be considered when interpreting findings from this review. Second, for the current review, we expected few published studies that evaluated laboratory-based functional performance as well as mobility-related outcomes in persons with symptomatic AD, both before

and after PAO. As a first step in evaluating these outcomes, we limited our search to one database representing the premier source of medical-related studies (PubMed). Although not likely, limiting the search to one database may have missed other relevant studies of patient-reported and/or mobility-related outcomes following PAO. Lastly, the current state of evidence for both patient-reported and mobility-related outcomes in persons with symptomatic AD before and after PAO prevented us from performing a more thorough quantitative synthesis of our results (i.e. meta-analysis).

CONCLUSIONS

Overall, our current narrative review indicates that persons with symptomatic AD exhibited significant improvements across various PROs (pain, function, quality of life and self-reported PA) following PAO. To date, very few studies have evaluated laboratory-based functional performance and mobility-related outcomes in persons with symptomatic AD after PAO, and these studies were typically of low quality and included relatively small samples. Future work should evaluate mobility-related outcomes in persons with symptomatic AD following PAO using performance tests and free-living outcomes (e.g. activity monitors or ESM) for capturing real-time mobility-related and other important outcomes.

SUPPLEMENTARY DATA

Supplementary data are available at *Journal of Hip Preservation Surgery* online.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest related to this work.

REFERENCES

1. Clohisy JC, Beaule PE, O'Malley A *et al.* AOA symposium. Hip disease in the young adult: current concepts of etiology and surgical treatment. *J Bone Joint Surg Am* 2008; **90**: 2267–81.
2. Clohisy JC, Barrett SE, Gordon JE *et al.* Medial translation of the hip joint center associated with the Bernese periacetabular osteotomy. *Iowa Orthop J* 2004; **24**: 43–8.
3. Sankar WN, Duncan ST, Baca GR *et al.* Descriptive epidemiology of acetabular dysplasia: the Academic Network of Conservational Hip Outcomes Research (ANCHOR) periacetabular osteotomy. *J Am Acad Orthop Surg* 2017; **25**: 150–9.
4. Jacobsen S, Sonne-Holm S, Soballe K *et al.* Hip dysplasia and osteoarthrosis: a survey of 4151 subjects from the osteoarthrosis substudy of the Copenhagen city heart study. *Acta Orthop* 2005; **76**: 149–58.
5. Nunley RM, Prather H, Hunt D *et al.* Clinical presentation of symptomatic acetabular dysplasia in skeletally mature patients. *J Bone Joint Surg Am* 2011; **93**: 17–21.

6. Jacobsen JS, Holmich P, Thorborg K et al. Muscle-tendon-related pain in 100 patients with hip dysplasia: prevalence and associations with self-reported hip disability and muscle strength. *J Hip Preserv Surg* 2018; **5**: 39–46.

7. Sucato DJ, Tulchin K, Shrader MW et al. Gait, hip strength and functional outcomes after a Ganz periacetabular osteotomy for adolescent hip dysplasia. *J Pediatr Orthop* 2010; **30**: 344–50.

8. Pedersen EN, Simonsen EB, Alkjaer T et al. Walking pattern in adults with congenital hip dysplasia: 14 women examined by inverse dynamics. *Acta Orthop Scand* 2004; **75**: 2–9.

9. McWilliams DF, Doherty SA, Jenkins WD et al. Mild acetabular dysplasia and risk of osteoarthritis of the hip: a case-control study. *Ann Rheum Dis* 2010; **69**: 1774–8.

10. Wyles CC, Heidenreich MJ, Jeng J et al. The John Charnley Award: redefining the natural history of osteoarthritis in patients with hip dysplasia and impingement. *Clin Orthop Relat Res* 2017; **475**: 336–50.

11. Troelsen A, Elmengaard B, Soballe K. Medium-term outcome of periacetabular osteotomy and predictors of conversion to total hip replacement. *J Bone Joint Surg Am* 2009; **91**: 2169–79.

12. Ganz R, Klaue K, Vinh TS et al. A new periacetabular osteotomy for the treatment of hip dysplasias. Technique and preliminary results. *Clin Orthop Relat Res* 1988; **232**: 26–36.

13. Clohisy JC, Schutz AL, St John L et al. Periacetabular osteotomy: a systematic literature review. *Clin Orthop Relat Res* 2009; **467**: 2041–52.

14. Yasunaga Y, Yamasaki T, Ochi M. Patient selection criteria for periacetabular osteotomy or rotational acetabular osteotomy. *Clin Orthop Relat Res* 2012; **470**: 3342–54.

15. Clohisy JC, Barrett SE, Gordon JE et al. Periacetabular osteotomy for the treatment of severe acetabular dysplasia. *J Bone Joint Surg Am* 2005; **87**: 254–9.

16. Kralj M, Mavcic B, Antolic V et al. The Bernese periacetabular osteotomy: clinical, radiographic and mechanical 7–15-year follow-up of 26 hips. *Acta Orthop* 2005; **76**: 833–40.

17. Wasko M, Nepple JJ, Clohisy JC et al. Arthroscopic hip joint assessment can impact the indications for PAO surgery. *Iowa Orthop J* 2019; **39**: 149–57.

18. Wasko MK, Yanik EL, Pascual-Garrido C et al. Psychometric properties of patient-reported outcome measures for periacetabular osteotomy. *J Bone Joint Surg Am* 2019; **101**: e21.

19. Zaltz I, Baca G, Kim Y-J et al. Complications associated with the periacetabular osteotomy: a prospective multicenter study. *J Bone Joint Surg Am* 2014; **96**: 1967–74.

20. Ali M, Malviya A. Complications and outcome after periacetabular osteotomy - influence of surgical approach. *Hip Int* 2020; **30**: 4–15.

21. Sorensen H, Skalshoi O, Nielsen DB et al. Hip muscle and joint contact forces before, 6 and 12 months after minimally invasive periacetabular osteotomy. *Hip Int* 2020; **31**: 1120700020925411.

22. Novais EN, Heyworth B, Murray K et al. Physical activity level improves after periacetabular osteotomy for the treatment of symptomatic hip dysplasia. *Clin Orthop Relat Res* 2013; **471**: 981–8.

23. Sandell Jacobsen J, Thorborg K, Holmich P et al. Does the physical activity profile change in patients with hip dysplasia from before to 1 year after periacetabular osteotomy? *Acta Orthop* 2018; **89**: 622–7.

24. Green BN, Johnson CD, Adams A. Writing narrative literature reviews for peer-reviewed journals: secrets of the trade. *J Chiropr Med* 2006; **5**: 101–17.

25. Siddaway AP, Wood AM, Hedges LV. How to do a systematic review: a best practice guide for conducting and reporting narrative reviews, meta-analyses, and meta-syntheses. *Ann Rev Psychol* 2019; **70**: 747–70.

26. Coleman BD, Khan KM, Maffulli N et al. Studies of surgical outcome after patellar tendinopathy: clinical significance of methodological deficiencies and guidelines for future studies. Victorian Institute of Sport Tendon Study Group. *Scand J Med Sci Sports* 2000; **10**: 2–11.

27. Altman DG, Schulz KF, Moher D et al. The revised CONSORT statement for reporting randomized trials: explanation and elaboration. *Ann Intern Med* 2001; **134**: 663–94.

28. Mechlenburg I, Jorgensen PB, Stentz-Olesen K et al. Leg power, pelvic movement and physical activity after periacetabular osteotomy. A prospective cohort study. *Acta Orthop Belg* 2018; **84**: 163–71.

29. McClincy MP, Wylie JD, Kim Y-J et al. Periacetabular osteotomy improves pain and function in patients with lateral center-edge angle between 18° and 25°, but are these hips really borderline dysplastic? *Clin Orthop Relat Res* 2019; **477**: 1145–53.

30. Klose K, Kreimeier S, Tangermann U et al. Patient- and person-reports on healthcare: preferences, outcomes, experiences, and satisfaction – an essay. *Health Econ Rev* 2016; **6**: 18.

31. Gahramanov A, Inanici F, Caglar Ö et al. Functional results in periacetabular osteotomy: is it possible to obtain a normal gait after the surgery? *Hip Int* 2017; **27**: 449–54.

32. Scott EJ, Willey MC, Davison JC et al. Physical performance tests correlate with patient-reported outcomes after periacetabular osteotomy: a prospective study. *J Am Acad Orthop Surg Glob Res Rev* 2021; **5**: 1–10.

33. Karam MD, Gao Y, McKinley T. Assessment of walking pattern pre and post peri-acetabular osteotomy. *Iowa Orthop J* 2011; **31**: 83–9.

34. Jacobsen JS, Soballe K, Thorborg K et al. Patient-reported outcome and muscle–tendon pain after periacetabular osteotomy are related: 1-year follow-up in 82 patients with hip dysplasia. *Acta Orthop* 2019; **90**: 40–5.

35. Petrie JR, Novais EN, An TW et al. What is the impact of periacetabular osteotomy surgery on patient function and activity levels? *J Arthroplasty* 2020; **35**: S113–8.

36. Sakamoto T, Naito M, Nakamura Y. Outcome of peri-acetabular osteotomy for hip dysplasia in teenagers. *Int Orthop* 2015; **39**: 2281–6.

37. Boje J, Caspersen CK, Jakobsen SS et al. Are changes in pain associated with changes in quality of life and hip function 2 years after periacetabular osteotomy? A follow-up study of 321 patients. *J Hip Preserv Surg* 2019; **6**: 69–76.

38. Bogunovic L, Hunt D, Prather H et al. Activity tolerance after periacetabular osteotomy. *Am J Sports Med* 2014; **42**: 1791–5.

39. Okoroafor UC, Pascual-Garrido C, Schwabe MT et al. Activity level maintenance at midterm follow-up among active patients undergoing periacetabular osteotomy. *Am J Sports Med* 2019; **47**: 363546519881421.

40. Novais EN, Thanacharoenpanich S, Seker A et al. Do young female dancers improve symptoms and return to dancing after periacetabular osteotomy for the treatment of symptomatic hip dysplasia? *J Hip Preserv Surg* 2018; **5**: 150–6.

41. Nassif NA, Schoenecker PL, Thorsness R et al. Periacetabular osteotomy and combined femoral head-neck junction osteochondroplasty: a minimum two-year follow-up cohort study. *J Bone Joint Surg Am* 2012; **94**: 1959–66.

42. Jakobsen SR, Mechlenburg I, Søballe K et al. What level of pain reduction can be expected up to two years after periacetabular osteotomy? A prospective cohort study of 146 patients. *J Hip Preserv Surg* 2018; **5**: 274–81.

43. Heyworth BE, Novais EN, Murray K et al. Return to play after periacetabular osteotomy for treatment of acetabular dysplasia in adolescent and young adult athletes. *Am J Sports Med* 2016; **44**: 1573–81.

44. Gu Y-G, Shi Z-W, Yue Y-H et al. Analysis of factors affecting early functional recovery of Bernese periacetabular osteotomy. *Orthop Surg* 2021; **13**: 1818–27.

45. Ramírez-Núñez L, Payo-Ollero J, Comas M et al. Periacetabular osteotomy for hip dysplasia treatment through a mini-invasive technique. Our results at mid-term in 131 cases. *Rev Esp Cir Ortop Traumatol* 2020; **64**: 151–9.

46. Muffly BT, Zacharias AJ, Jochimsen KN et al. Age at the time of surgery is not predictive of early patient-reported outcomes after periacetabular osteotomy. *J Arthroplasty* 2021; **36**: 3388–91.

47. Edelstein AI, Nepple JJ, Abu-Amer W et al. What mid-term patient-reported outcome measure scores, reoperations, and complications are associated with concurrent hip arthroscopy and periacetabular

osteotomy to treat dysplasia with associated intraarticular abnormalities? *Clin Orthop Relat Res* 2021; **479**: 1068–77.

48. McClincy MP, Wylie JD, Kim Y-J. *et al.* Periacetabular osteotomy improves pain and function in patients with lateral center-edge angle between 18° and 25°, but are these hips really borderline dysplastic? *Clin Orthop Relat Res.* 2019; **477**: 1145–53.

49. Browne W, Nair BKR. The timed up and go test. *Med J Aust* 2019; **210**: 13–14.e11.

50. Enright PL. The six-minute walk test. *Respir Care* 2003; **48**: 783–5.

51. Unver B, Kahraman T, Kalkan S *et al.* Test-retest reliability of the 50-foot timed walk and 30-second chair stand test in patients with total hip arthroplasty. *Acta Orthop Belg* 2015; **81**: 435–41.

52. Centers for Disease Control and Prevention. Surgeon general's report on physical activity and health. *JAMA* 1996; **276**: 522.

53. Piercy KL, Troiano RP. Physical activity guidelines for Americans from the US Department of Health and Human Services. *Circ Cardiovasc Qual Outcomes* 2018; **11**: e005263.

54. Pate RR. The report of the US physical activity guidelines advisory committee: important findings for employers. *Am J Health Promot* 2019; **33**: 313–4.

55. Bull FC, Al-Ansari SS, Biddle S *et al.* World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *Br J Sports Med* 2020; **54**: 1451–62.

56. Li J, Siegrist J. Physical activity and risk of cardiovascular disease—a meta-analysis of prospective cohort studies. *Int J Environ Res Public Health* 2012; **9**: 391–407.

57. Sluik D, Buijsse B, Muckelbauer R *et al.* Physical activity and mortality in individuals with diabetes mellitus: a prospective study and meta-analysis. *Arch Intern Med* 2012; **172**: 1285–95.

58. Wilmot EG, Edwardson CL, Achana FA *et al.* Sedentary time in adults and the association with diabetes, cardiovascular disease and death: systematic review and meta-analysis. *Diabetologia* 2012; **55**: 2895–905.

59. Biswas A, Oh PI, Faulkner GE *et al.* Sedentary time and its association with risk for disease incidence, mortality, and hospitalization in adults: a systematic review and meta-analysis. *Ann Intern Med* 2015; **162**: 123–32.

60. Moore SC, Lee I-M, Weiderpass E *et al.* Association of leisure-time physical activity with risk of 26 types of cancer in 1.44 million adults. *JAMA Intern Med* 2016; **176**: 816–25.

61. Craig CL, Marshall AL, Sjostrom M *et al.* International physical activity questionnaire: 12-country reliability and validity. *Med Sci Sports Exerc* 2003; **35**: 1381–95.

62. Thorborg K, Hölmich P, Christensen R *et al.* The Copenhagen Hip and Groin Outcome Score (HAGOS): development and validation according to the COSMIN checklist. *Br J Sports Med* 2011; **45**: 478–91.

63. Amstutz HC, Thomas BJ, Jinnah R *et al.* Treatment of primary osteoarthritis of the hip. A comparison of total joint and surface replacement arthroplasty. *J Bone Joint Surg Am* 1984; **66**: 228–41.

64. Freedson PS, Melanson E, Sirard J. Calibration of the Computer Science and Applications, Inc. Accelerometer. *Med Sci Sports Exerc* 1998; **30**: 777–81.

65. Bean JF, Olveczky DD, Kiely DK *et al.* Performance-based versus patient-reported physical function: what are the underlying predictors? *Phys Ther* 2011; **91**: 1804–11.

66. McPhail S, Haines T. Response shift, recall bias and their effect on measuring change in health-related quality of life amongst older hospital patients. *Health Qual Life Outcomes* 2010; **8**: 65.

67. Lee PH, Macfarlane DJ, Lam TH *et al.* Validity of the International Physical Activity Questionnaire Short Form (IPAQ-SF): a systematic review. *Int J Behav Nutr Phys Act* 2011; **8**: 115.

68. Shin G, Jarrahi MH, Fei Y *et al.* Wearable activity trackers, accuracy, adoption, acceptance and health impact: a systematic literature review. *J Biomed Inform* 2019; **93**: 103153.

69. Matthews CE, Chen KY, Freedson PS *et al.* Amount of time spent in sedentary behaviors in the United States, 2003–2004. *Am J Epidemiol* 2008; **167**: 875–81.

70. Vanhelst J, Mikulovic J, Bui-Xuan G *et al.* Comparison of two ActiGraph accelerometer generations in the assessment of physical activity in free living conditions. *BMC Res Notes* 2012; **5**: 187.

71. Grant PM, Ryan CG, Tigbe WW *et al.* The validation of a novel activity monitor in the measurement of posture and motion during everyday activities. *Br J Sports Med* 2006; **40**: 992–7.

72. Freedson P, Pober D, Janz KF. Calibration of accelerometer output for children. *Med Sci Sports Exerc* 2005; **37**: S523–30.

73. Richard HM, Cerza SP, De La Rocha A *et al.* Preoperative mental health status is a significant predictor of postoperative outcomes in adolescents treated with hip preservation surgery. *J Child Orthop* 2020; **14**: 259–65.

74. Smyth JM, Juth V, Ma J *et al.* A slice of life: ecologically valid methods for research on social relationships and health across the life span. *Soc Personal Psychol Compass* 2017; **11**: e12356.

75. Runyan JD, Steinke EG. Virtues, ecological momentary assessment/intervention and smartphone technology. *Front Psychol* 2015; **6**: 481.

76. Williamson A, Hoggart B. Pain: a review of three commonly used pain rating scales. *J Clin Nurs* 2005; **14**: 798–804.

77. Boonstra AM, Schiphorst Preuper HR, Reneman MF *et al.* Reliability and validity of the visual analogue scale for disability in patients with chronic musculoskeletal pain. *Int J Rehabil Res* 2008; **31**: 165–9.

78. Nilsdotter A, Bremander A. Measures of hip function and symptoms: Harris Hip Score (HHS), Hip Disability and Osteoarthritis Outcome Score (HOOS), Oxford Hip Score (OHS), Lequesne Index of Severity for Osteoarthritis of the Hip (LISOH), and American Academy of Orthopedic Surgeons (AAOS) Hip and Knee Questionnaire. *Arthritis Care Res* 2011; **63**: S200–7.