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Review

Effects of total hip arthroplasty for primary hip osteoarthritis on postural balance: A systematic review

Fernando de Lima[a], Daniel A. Fernandes[b,*], Gilberto Melo[c], Carlos R. de M. Roesler[d], Fabrício de S. Neves[e], Francisco Rosa Neto[f]

[a] Baía Sul Hospital, Florianópolis, Santa Catarina, Brazil
[b] Department of Surgery, Federal University of Santa Catarina (UFSC), Florianópolis, Santa Catarina, Brazil
[c] Postgraduate Program in Dentistry, Federal University of Santa Catarina (UFSC), Florianópolis, Santa Catarina, Brazil
[d] Department of Mechanical Engineering, Federal University of Santa Catarina (UFSC), Florianópolis, Santa Catarina, Brazil
[e] Department of Clinical Medicine, Federal University of Santa Catarina (UFSC), Florianópolis, Santa Catarina, Brazil
[f] Centre of Health and Sports Sciences, State University of Santa Catarina, Florianópolis, Santa Catarina, Brazil

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ABSTRACT

Background: Hip osteoarthritis is one of the major causes of disability worldwide, and although total hip arthroplasty is considered effective in the management of this condition, its effects on postural balance remain unclear.
Research Question: What are the effects of total hip arthroplasty for primary hip osteoarthritis on the postural balance compared to preoperative status and/or to healthy controls?.
Method: A systematic review was conducted, and the Embase, Latin American and Caribbean Health Sciences (LILACS), PubMed, Scopus, The Cochrane Library, and Web of Science databases were searched. Randomized and non-randomized studies were considered eligible for inclusion. The risk of bias of included studies was assessed using the Joanna Briggs Institute critical appraisal tools.
Results: Among the 41 potentially eligible studies, 13 studies were included for qualitative synthesis—8 studies had low risk of bias and 5 had moderate risk of bias. Ten studies compared the effects of total hip arthroplasty on the postural balance in healthy controls. Meanwhile, the remaining 3 studies compared such effects to the preoperative status only. Comparable results on the postural balance between the intervention and control groups were observed in 5 studies, whereas 3 studies showed better scores among healthy controls. The other 2 studies reported that postural balance could still be impaired at 6 months to 3 years postoperatively. All 3 studies with no healthy controls reported an improvement in the postural balance compared to the preoperative status.
Conclusions: Major post-surgical improvements were consistently observed compared to preoperative status, although postural balance impairment was still noted compared to healthy controls.
Significance: The results of this study might be a useful guide for clinicians on the extent of the therapeutic effects of hip arthroplasty on postural balance. Furthermore, the standardization of balance assessment tools could strengthen the certainty of cumulative evidence in future studies.

1. Introduction

Hip osteoarthritis (OA) is a chronic disease with a multifactorial etiology, and it is generally characterized by cartilage loss, stiffness, and pain, which might often lead to disability [1]. According to the Global Burden of Disease Study 2010, which aimed to estimate the epidemiological levels of 291 diseases across 187 countries, hip and knee OA was ranked as the 11th highest contributor to global disability [2]. Problems with balance and postural stability are likely to occur in patients with hip OA due to several reasons. Firstly, damage to joint capsule receptors that control posture might occur in an arthritic condition [3]. In addition, since degenerative disorders are usually unilateral in most patients, the position of the pelvis and spine might be affected in individuals with hip OA, resulting in asymmetric loading of the lower limbs [4]. Moreover, individuals with hip OA often present muscular strength loss in the affected limb, which may lead to

* Corresponding author at: Department of Surgery, Federal University of Santa Catarina, University Campus, Mailbox 476 – Trindade, Florianópolis, Santa Catarina, 88040900, Brazil.
E-mail address: danielortopediafernandes@gmail.com (D.A. Fernandes).

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impairments in balance-related outcomes [5].

Balance is a complex function that can be assessed by different tools, which could be divided into 3 domains including functional, physiological, and quantitative assessments (e.g., static or dynamic posturography) [6]. Furthermore, some parameters could be used to precisely evaluate the components of postural function, such as center of mass (COM), center of pressure (COP), and postural stances [7]. Hence, these variables provide a detailed information on the postural balance of healthy individuals and individuals with hip OA.

The current treatment of choice for advanced and disabling hip OA is total hip arthroplasty (THA), which is one of the most effective interventions for hip function restoration, pain reduction, and improvement in the patients' quality of life [8–10]. Notwithstanding the widely accepted benefits of THA, there is a lack of consensus in the literature demonstrating the effects of THA on postural balance, since there are several reports of persistent postural balance impairment compared to healthy individuals [3]. Consequently, the purpose of this systematic review (SR) was to answer the following focused question: "Among adults, what are the effects of total hip arthroplasty on postural balance compared to preoperative status and/or to healthy individuals?"

2. Methods

2.1. Protocol and registration

A review protocol based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Protocols [11] was elaborated and registered in the Prospective Register of Systematic Reviews (PROSPERO) [12] and made publicly available under the registration number CRD42018094106. In addition, the reporting of this study was based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Checklist [13].

2.2. Eligibility criteria

Studies investigating the effects of THA on postural balance were considered. All validated measures to assess balance and all balance components such as functional stability limits, reactive control, control of balance during an active task, and standing balance will be accepted. No publication time and language restrictions were applied.

The following exclusion criteria were applied: 1) Samples that included children and adolescents; 2) Samples that included participants treated with hip arthroplasty for secondary hip OA (e.g., hip dysplasia, rheumatoid arthritis, ankylosing spondylitis, osteonecrosis, infection, and trauma); 3) Samples that included participants with conditions affecting postural balance (e.g., neuromuscular disorders and Parkinson's disease); 4) Studies wherein participants were treated with partial hip and surface replacement arthroplasty or with previous hip surgery; 5) Studies that did not compare balance-related outcomes to preoperative status or to healthy controls; 6) Studies that evaluated participants with knee arthroplasty (if data were not provided separately for hip arthroplasty); 7) Studies in which the primary objective was to evaluate different physiotherapy protocols; 8) Studies that did not evaluate postural balance through validated tools; 9) Studies with less than 1 month of follow-up; 10) Abstracts, reviews, case reports, case series, protocols, personal opinions, letters, posters, and laboratory research; and 11) Full-text not available.

2.3. Information sources

Appropriate truncation and word combinations were elaborated and adapted for each of the following electronic databases: Embase, LILACS, PubMed, Scopus, The Cochrane Library, and Web of Science. In addition, a partial grey literature search was conducted through Google Scholar, Open Grey, and ProQuest. All electronic database searches were performed from the starting coverage date through November 05, 2018. Detailed search strategies are provided in Supplementary File 1.

Furthermore, based on the recommendation by Greenhalgh and Peacock [14], the reference lists of included studies were manually searched to assess potentially relevant references. Reference management and duplicate removal were performed using a software (EndNote X7, Thomson Reuters).

2.4. Study selection

A two-phase selection process was conducted. In phase 1, using an online software (Rayyan, Qatar Computing Research Institute), 2 reviewers (F. L. and D. F.) independently screened the titles and abstracts of identified references to assess potentially eligible studies, and discrepancies were resolved by a consensus discussion. If necessary, a third reviewer was involved (G. M). In phase 2, a full-text reading of the selected studies was performed by the same reviewers; the third reviewer was also involved if disagreements were not solved. Studies were included for qualitative analysis if they met the inclusion criteria.

2.5. Data collection process and data items

Two independent reviewers (F. L. and D. F.) collected pertinent data from included studies; information was then cross-checked to warrant the integrity of the contents. Moreover, the collected data encompassed the following key features: authors, year of publication, country, study design, sample size, study groups, mean age, tools to assess balance, THA characteristics, time of follow-up, main findings, and conclusions.

2.6. Risk of bias in included studies

Risk of bias was assessed by 2 reviewers (F. L. and D. F.) using The Joanna Briggs Institute critical appraisal tools for quasi-experimental studies [15]. A computer software (Review Manager 5.3, The Cochrane Collaboration) was used to generate figures.

2.7. Summary measures

Measures for continuous data such as mean values, mean and standardized mean differences, and its respective standard deviations, which measured the absolute difference between baseline and follow-up evaluations and intervention and control groups, were considered. The statistical significance was set at $\alpha = 5\%$.

2.8. Synthesis of results

A qualitative analysis of the results based on balance improvement following THA was performed. A statistical pooling of data using a meta-analysis was planned if studies were considered sufficiently homogeneous.

2.9. Risk of bias across studies

Heterogeneity across studies was evaluated by comparing the variability in participants' characteristics (e.g., age), intervention characteristics (e.g., surgical approaches and type of hip prosthesis), and study methods (e.g., balance assessment tools, presence of healthy controls, and appropriate follow-up time).

2.10. Additional analyses

The overall quality of evidence was assessed using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) criteria [16]. A summary of findings table was generated using an online software (GRADEpro GDT; the GRADE Working Group).

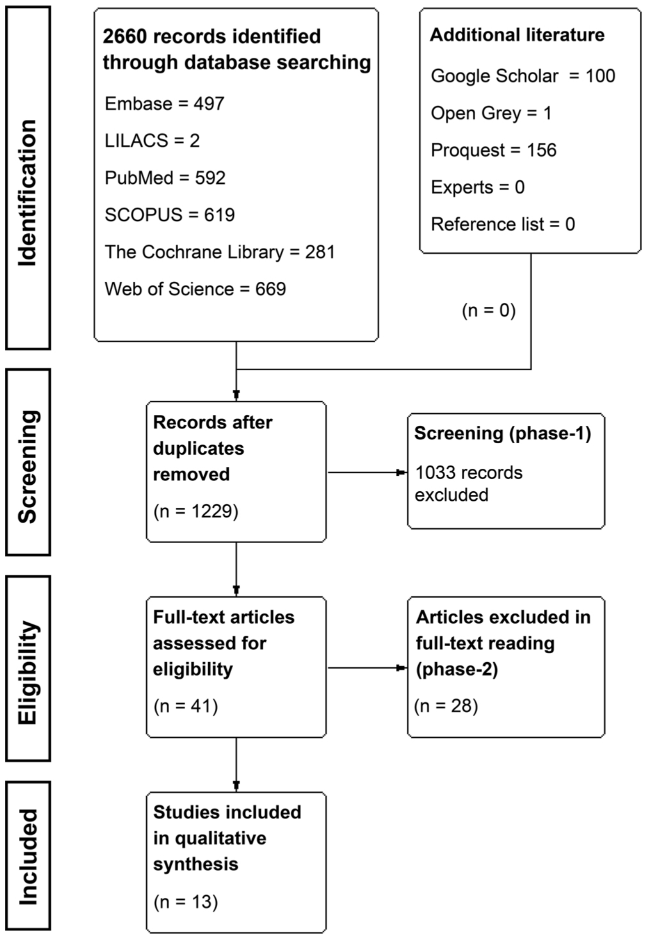

Fig. 1. Flow diagram of literature search and selection criteria (adapted from Preferred Reporting Items for Systematic Reviews and Meta-Analysis and generated using the software Review Manager 5.3, The Cochrane Collaboration).

3. Results

Based on the main electronic database search, a total of 1229 studies were identified after duplicates were removed. No studies from the grey literature were included because identified references were already in the other databases. The reviewers examined the titles and abstracts of identified references; among them, 41 studies were considered eligible for inclusion. Thereafter, a full-text reading was performed and 13 studies met the inclusion criteria [17–29]. Further information on the reasons for exclusion after full-text reading is presented in Supplementary File 2. The complete process of identification, inclusion, and exclusion of studies is provided in Fig. 1.

From the included articles, 10 were non-randomized studies with healthy control groups [17,19–26,28], 2 were before–after studies (no healthy controls) [18,27], and 1 was a randomized study (no healthy controls) [29]. A total of 648 participants were enrolled in the study, and approximately half of them were women. The included studies were published between 1989 [29] and 2018 [26] and conducted in Canada [25], Hungary [19], India [24], Italy [17], Japan [20], Poland [26], Sweden [27,29], Switzerland [23], the United States of America [21,22,28], and Taiwan [18]. The minimum follow-up duration was 4 months [17,22], and the maximum follow-up duration was 5 years [21] postoperatively. Table 1 summarizes the descriptive characteristics of the included studies.

3.1. Risk of bias within studies

About 8 studies have a low risk of bias [17,19,20,22,23,25–27] while 5 studies have a moderate risk of bias [18,21,24,28,29]. Most frequent concerns regarding bias were related to: 1) measurements of outcomes pre- and post-interventions, 2) participants included in comparisons receiving similar treatment/care other than the intervention of interest, and 3) absence of healthy controls. Further information with regards to bias assessment is shown in Fig. 2.

3.2. Results of individual studies

The effects of THA on postural control was assessed by Calò et al. [17], which reported that normal postural control was observed in THA participants at 4 months after surgery compared to healthy controls. Similarly, Holnapy et al. [19] proposed that in the first 6 months after surgery, both lateral and posterior exposures continuously improved the dynamic balance of THA participants compared to the healthy controls.

Variables related to the center of gravity (COG), such as velocity and displacement, were assessed by Kanzaki et al. [20]. It was proposed that COG displacement was reduced at 6 months following THA, suggesting postural balance improvement. On the other hand, Lugade et al. [22] reported that, although the balance control (measured by COM/pressure inclination angles) improved at 4 months following THA, THA individuals did not reach the control level. Moreover, functional deficits were observed in the study by Nantel et al. [25], which suggested that THA individuals presented lower COP displacement amplitudes than the healthy controls at 6 months postoperatively.

Larkin et al. [21] evaluated the proprioception scores in participants who underwent THA between 1 and 5 years prior to study measurements. Both standard femoral head and large femoral head groups performed similarly with the healthy controls in a double-limb testing, suggesting that THA individuals presented no proprioception deficits. Similar results were observed by Majewsky et al. [23] who reported almost normal functional performance at 1 year following THA compared to healthy individuals, as measured by means of stance and gait tasks.

Equilibrium scores were assessed by Nallegowda et al. [24] through sensory organization and limits of stability tests. Although the control group performed better than the THA individuals in all variables of the dynamic tests, no proprioceptive deficits were observed. However, Pop et al. [26] reported that impaired static balance can possibly occur among THA individuals between 24 and 36 months postoperatively. Similarly, although no differences were observed by Sliwinski et al. [28] between the THA and control groups on the dynamic stability with single limb support, differences in the pattern dynamic stability with double limb support were found between groups.

Comparison of THA individuals and healthy controls was not performed in 3 studies, and thus, a descriptive analysis was conducted comparing the preoperative status [18,27,29]. Chang et al. [18] observed that the Berg balance test scores significantly decreased at 2 weeks postoperatively and gradually improved, reaching the highest score at 6 months. Based on the postural sway on quiet bilateral standing, Rasch et al. [27] evaluated the individuals before THA with up to 2 years of follow-up and reported that postural sway following THA was reduced, suggesting improvements in postural stability. The study of Wykman et al. [29] investigated the postural stability of cemented and non-cemented THA groups. It was observed that improvements in postural stability were similar in both groups at 1 year follow-up, although inconsistent findings at 6 months were observed.

3.3. Synthesis of results

Clinical and methodological heterogeneity across studies were considered high because of different exposure methods in THA and differences in postoperative supportive care. In addition, no standardized balance assessment tool was found, and therefore, effect measures were not directly comparable. Hence, statistical pooling of data using a

Table 1
Summary of descriptive characteristics of included articles (n = 13).

STUDY	POPULATION				INTERVENTION CHARACTERISTICS		MAIN FINDINGS	CONCLUSION
Author (Year); Country *Study design*	Sample (n/ women)	Groups (n/women)	Mean age (± SD) in years	Tools to assess balance	THA characteristics	Time of follow-up	Mean values (MV), mean differences (MD), standard deviation (SD), relative or absolute frequencies, or other pertinent findings	
Calò et al. (2009); Italy *Non-randomized study*	43 (23 F)	**Healthy controls** 20 (10 F) **THA** 23 (13 F)	**Healthy controls** 62.27 ± 13.9 **THA** 62.27 ± 13.9	Dynamic posturography was performed by using a device namely the Equi-Test Dynamic Posturography System by NeuroCom (Int. Inc., Clackamas, Oregon, USA).	THA surgery with lateral approach incision for uncemented prosthesis. Standard 4 weeks standard rehabilitation protocol.	4 months after THA	**1. Equilibrium score (p > 0.05)** ***Healthy controls*** 78.16 ± 3.53 ***THA*** 75.54 ± 8.11 **2. Somatosensorial (p > 0.05)** ***Healthy controls*** 97.78 ± 4.65 ***THA*** 97.16 ± 4.44 **3. Visual (p > 0.05)** ***Healthy controls*** 90.39 ± 5.77 ***THA*** 87.81 ± 9.04 **4. Vestibular (p > 0.05)** ***Healthy controls*** 73.94 ± 10.20 ***THA*** 70.86 ± 9.94 **5. Preferential (p > 0.05)** ***Healthy controls*** 96.46 ± 6.03 ***THA*** 95.48 ± 6.27	Data confirm a normal postural control and symmetrical responses in THA patients compared to healthy controls.
Chang et al. (2015); Taiwan *Before-after study*	23 (13 F)	**THA** 23	**THA** 60 ± 9.9	To measure postural stability, participants were instructed to stand barefoot with 4 foot placements as shoulder width stance, feet side-by-side stance, tandem stance with affected limb in the front, and tandem stance with non-affected limb in the front on a 0.5 m long pressure measurement mat (RSscan International Co., Belgium) and were instructed to stand as still as possible with both arms at their sides and eyes staring at a target 5 m away in front of them.	All THAs were performed by an experienced orthopaedic surgeon. All the THAs are minimally invasive but with slight variation in the number and location of incisions.	T0) Presurgery T1) 2 w T2) 6 w T3) 3 mo T4) 6 mo T5) 1 y	**Berg balance test T0)** 44.6 ± 7.3 **T1)** 36.4 ± 12.9 **T2)** 41.4 ± 7.9 **T3)** 47.7 ± 4.7 **T4)** 53.2 ± 1.9 **T5)** 52.5 ± 3.3 p < 0.01	Berg balance test decreased significantly (p < 0.05) at 2 weeks and improved gradually, reaching the highest score of 53.2 ± 1.9 at 6 months.
Holnapy et al. (2013); Hungary *Non-randomized study*	117 (58 F)	**Healthy controls** 45 (22 F) **THA (direct-lateral exposure)** 25 (13 F) **THA (antero-lateral exposure)** 22 (11 F) **THA (posterior exposure)** 25 (12 F)	**Healthy controls** 60.9 ± 3.2 (M) 60.4 ± 4.1 (F) **THA (DL exposure)** 60.4 ± 2.4 (M) 59.9 ± 3.4 (F) **THA (AL exposure)** 61.3 ± 3.4 (M) 62.1 ± 2.4 (F) **THA (posterior exposure)** 61.2 ± 2.9 (M) 60.8 ± 3.0 (F)	The dynamic balancing ability was characterized by ultrasound- based provocation tests. Unidirectional sudden perturbation was modelled by a PosturoMed (Haider-Bioswing GmbH, Weiden, Germany) therapeutic device.	Patients were operated on by 1) traditional direct-lateral (DL) exposure with the joint capsule removed; 2) antero-lateral (AL) exposure, also with the joint capsule extirpated; and 3) posterior exposure with the joint capsule preserved. Rehabilitation of all patients was supervases on the basis of a previously	T0) Presurgery T1) 6 w T2) 12 w T3) 6 mo	**Double-leg stance** ***Healthy controls*** 4.65 ± 0.33 (M) 4.99 ± 0.29 (F) ***THA DL exposure*** T0) 3.40 ± 0.55 (M) T3) 4.47 ± 0.27 (M) p < 0.05 (vs controls) T0) 3.49 ± 0.50 (F) T3) 4.79 ± 0.31 (F) p < 0.05 (vs controls) ***THA AL exposure*** T0) 3.45 ± 0.52 (M) T3) 4.49 ± 0.25 (M) p < 0.05 (vs controls) T0) 3.53 ± 0.48	Dynamic balancing ability of patients operated on with DL and AL exposure continuously improved during the first 6 months of the postoperative period. The dynamic balancing ability improved more quickly with a posterior exposure if either of the other two approaches was used.

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Table 1 (*continued*)

STUDY	POPULATION				INTERVENTION CHARACTERISTICS		MAIN FINDINGS	CONCLUSION
Author (Year); Country *Study design*	Sample (n/ women)	Groups (n/women)	Mean age (± SD) in years	Tools to assess balance	THA characteristics	Time of follow-up	Mean values (MV), mean differences (MD), standard deviation (SD), relative or absolute frequencies, or other pertinent findings	
					arranged protocol by the same physiotherapist until the 12th week postoperatively.		(F) T3) 4.81 ± 0.30 (F) $p < 0.05$ (vs controls) ***THA Posterior exposure*** T0) 3.44 ± 0.41 (M) T3) 4.73 ± 0.25 (M) $p < 0.05$ (vs controls) T0) 3.58 ± 0.39 (F) T3) 4.97 ± 0.27 (F) $p < 0.05$ (vs controls)	
Kanzaki et al. (2008); Japan *Non-randomized study*	20 (9 F)	**Healthy controls** 11 F **THA** 9 F	**Healthy controls** 46.3 ± 12.4 **THA** 48.9 ± 8.24	For each trial, the 3-dimensional COG velocity, displacement, and COG displacement volume were measured by double integrations of each component in the total ground reaction forces.	The surgeries in all cases were performed by the anterolateral approach (Dall's approach) with non-cemented prostheses. All patients received their prescribed 4-week rehabilitation program.	T1) 4 w T2) 6 mo	**Displacement width of COG** ***Healthy controls*** Lateral (cm): 3.26 ± 0.67 cm Fore-aft (cm): 3.26 ± 0.67 cm Vertical (cm): 3.26 ± 0.67 cm Displacement volume (cm^3): 29.6 ± 11.2 ***THA (T1) vs controls*** Lateral (cm): 3.48 ± 1.11 (NS) Fore-aft (cm): 2.67 ± 0.46 ($p < 0.05$) Vertical (cm): 4.36 ± 1.06 (NS) Displacement volume (cm^3): 43.8 ± 29.1 (NS) ***THA (T2) vs controls*** Lateral (cm): 2.51 ± 0.55 ($p < 0.05$) Fore-aft (cm): 2.14 ± 0.32 (NS) Vertical (cm): 3.61 ± 0.79 (NS) Displacement volume (cm^3): 20.0 ± 8.01 ($p < 0.05$)	The COG displacement width during one gait cycle and the work were particularly reduced as the gait velocity increased at postoperative 6 months.
Larkin et al. (2014); USA *Non-randomized study*	75 (35 F)	**Healthy controls** 25 (10 F) **THA (standard femoral head)** 25 (13 F) **THA (large femoral head)** 25 (12 F)	**Healthy controls** 48.7 ± 6.6 **THA (standard femoral head)** 53.6 ± 5.0 **THA (large femoral head)** 53.3 ± 6.3	Testing was conducted on the PROPRIO 5000 machine (Perry Dynamics, Decatur, IL, USA), a commercially available device that quantifies dynamic postural stability.	Patient recruitment started both in the outpatient clinics and through screening of an institutional total joint registry. To be eligible for the study, patients need to had undergone unilateral primary hip reconstruction between 1 and 5 years prior; A control group was also established that adhered to the same inclusion and exclusion criteria save for the fact that they did not undergo any previous hip reconstructive procedure	Minimum: 1 y Maximum: 5 y	**Double-limb operative side proprioception scores** ***Healthy controls*** 807.0 ± 44.7 ***THA (standard femoral head)*** 802.7 ± 39.9 $p = 0.25$ (vs controls) ***THA (large femoral head)*** 826.3 ± 69.6 $p = 0.94$ (vs controls)	Both groups perform similarly to healthy control subjects in double-limb testing.
Lugade et al. (2008); USA *Non-randomized study*	30 (11 F)	**Healthy controls** 10 (5 F) **THA** 20 (6 F)		Whole-body motion data were collected using an	All patients underwent primary THA using the	T0) Presurgery T1) 6 w T2) 16 w	Patients having THA had improved gait and balance	Although balance control has improved, as measured

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Table 1 (*continued*)

STUDY	POPULATION				INTERVENTION CHARACTERISTICS		MAIN FINDINGS	CONCLUSION
Author (Year); Country *Study design*	Sample (n/ women)	Groups (n/women)	Mean age (± SD) in years	Tools to assess balance	THA characteristics	Time of follow-up	Mean values (MV), mean differences (MD), standard deviation (SD), relative or absolute frequencies, or other pertinent findings	
			Healthy controls 59.9 ± 5.3 **THA** 57.0 ± 5.2	eight-camera motion system (Motion Analysis Corp, Santa Rosa, CA) with a set of 29 reflective markers placed on bony landmarks. Two force plates (Advanced Mechanical Technologies Inc, Watertown, MA) were placed in series at the center of the walkway to collect ground reaction forces and moments.	anterior (12 patients) or lateral (eight patients) surgical approach on the affected limb and received uncemented (17 patients) or cemented (three patients) Zimmer hip implants (Zimmer Inc, Warsaw, IN). Patients then underwent an identical physical therapy regimen with the same physical therapist during the study period.		control by 16 weeks postsurgery. Patients undergoing THA had a smaller (p = 0.0084) medial inclination angle with a greater (p = 0.0247) posterior inclination angle 16 weeks postsurgery when compared with before surgery	by the center of mass-center of pressure inclination angles, patients undergoing THA still have not reached the level of control subjects by 16 weeks postsurgery.
Majewski et al (2005); Switzerlan *Non-randomized study*	24 (NR)	**Healthy controls** 50 (NR), gender-matched **THA** 24 (11 F)	**Healthy controls** NR, age-matched **THA** 67.0 ± 6.2	Control of balance, in the form of trunk pitch (forwards backwards) and roll (side-to-side) movements, was measured during the stance and gait tasks by the two angular velocity sensors (fibreoptic gyroscopes) of the SwayStar balance system (Balance International Innovations GmbH, Iseltwald, Switzerland), which was attached by a belt to the patient so that the sensors were at the L2/3 level.	All patients received the same type of THR, a Morscher press-fit acetabular component (Zimmer, Winterthur, Switzerland) and a cemented MS-30 femoral component (Zimmer) inserted through a transgluteal approach with the patient in the supine position. All operations were performed either by or under the supervision of an experienced surgeon with regional anaesthesia being used in most cases. After surgery all patients were mobilised fully weight-bearing with crutches on the first post-operative day.	T0) Presurgery T1) 4 mo T2) 1 y	1) Balance while walking over low barriers and while getting up from a stool improved significantly after surgery and approached the values of the age-matched control group at four and 12 months. 2) Roll velocities exceeded values of the normal control group at follow-up at 12 months. 3) The roll angular amplitudes remained larger than those of the control group for the barriers task.	Almost normal functional performance at 12 months suggested that surgery successfully restored joint mobility and control in these patients.
Nallegowda et al. (2003); India *Non-randomized study*	60 (10 F)	**Healthy controls** 30 (5 F) **THA** 30 (5 F)	**Healthy controls** NR, age-matched **THA** 40.9 (NR)	A Smart Balance Master (version 7, Neurocom Inter- national, Clackamas, OR) was used for evaluation of sensory organization tests (SOT), limits of stability, rhythmic weight shift, and weight bearing.	Both unilateral, bilateral, cemented, and noncemented cases were included in the study. All the patients in the study had undergone surgery with posterolateral approach incision. Unilateral THR constituted a major part, with 26 cases. There were 16 noncemented cases, eight hybrid cases, and one case of bilateral revision arthroplasty. In the hybrid cases, noncemented	The mean duration from the date of surgery to the date of assessment was 271 days.	**Sensory organization test (equilibrium scores)** ***Healthy controls*** SOT-1: 91.65 ± 5.40 SOT-2: 91.71 ± 2.47 SOT-3: 91.35 ± 3.65 SOT-4: 80.52 ± 11.38 SOT-5: 64.08 ± 10.40 SOT-6: 61.11 ± 8.05 ***THA*** SOT-1: 93.03 ± 2.72 (NS) SOT-2: 91.65 ± 2.01 (NS) SOT-3: 87.06 ± 6.54 (p = 0.01) SOT-4: 79.21 ± 8.54 (NS) SOT-5: 60.37 ± 13.33 (NS) SOT-6: 54.12 ± 17.83 (p = 0.04) **Limits of stability**	Compared with the healthy age- and sex matched controls, patients with total hip replacement did not have any proprioceptive deficit In this dynamic test, the control group performed better than THA in all variables.

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Table 1 (*continued*)

STUDY	POPULATION				INTERVENTION CHARACTERISTICS		MAIN FINDINGS	CONCLUSION
Author (Year); Country *Study design*	Sample (n/ women)	Groups (n/women)	Mean age (± SD) in years	Tools to assess balance	THA characteristics	Time of follow-up	Mean values (MV), mean differences (MD), standard deviation (SD), relative or absolute frequencies, or other pertinent findings	
					acetabulum and cemented stem were used for replacement of the hip joint.		test ***Healthy controls*** RT (sec): 0.90 ± 0.28 MV (deg/sec): 3.98 ± 1.22 DC (%): 87.77 ± 3.16 MXE (%):98.51 ± 3.68 EPE (%): 88.28 ± 7.61 ***THA*** RT (sec): 1.11 ± 0.25 (p = 0.004) MV (deg/sec): 2.50 ± 0.71 (p = 0.001) DC (%): 78.31 ± 9.47 (p = 0.001) MXE (%): 82.81 ± 9.50 (p = 0.001) EPE (%): 65.49 ± 11.35 (p = 0.001)	
Nantel et al. (2009); Canada *Non-randomized study*	28 (9 F)	**Healthy controls** 14 (6 F) **THA (large femoral head)** 14 (3 F)	**Healthy controls** 44.5 ± 8.7 **THA (large femoral head)** 50.8 ± 5.8	For the dual-leg stance task, ground reaction forces and moments were collected with an AMTI forceplate recording at a sampling frequency of 60 Hz. The average COP position in the medial-lateral direction was calculated over the 120 seconds of the trial and expressed from the fore-aft midline of the base of support delimited by reflective markers on heels and toes.	Three experienced surgeons performed the surgeries. In all cases, they used a posterior surgical approach. In the large diameter head THA group, a CLS Spotorno titanium uncemented femoral stema was used with a large diameter modular metal head (Metasul) and a Durom acetabular component. After surgery, all patients underwent a 12-week rehabilitation program including isometric and stretching exercises that targeted the knee and hip flexor-extensor muscle groups as well as the hip adductor-abductor muscles and internal-external rotator muscles.	Short-term follow-up (range, 5-7 mo)	***Controls*** RMS-COP (AP): 5.77 ± 2.37 RMS-COP (ML): 2.56 ± 0.86 RMS-COM (AP): 5.52 ± 2.42 RMS-COM (ML): 2.30 ± 0.87 Abductor muscles strenght (%): 105.0 ± 16.0 ***THA (large femoral head)*** RMS-COP (AP): 5.01 ± 1.16 (NS) RMS-COP (ML): 1.92 ± 0.89 (p = 0.04) RMS-COM (AP): 4.75 ± 1.14 (NS) RMS-COM (ML): 1.77 ± 0.89 (NS) Abductor muscles strenght (%): 88.0 ± 17.0 (p = 0.04)	THA patients did not fully recover abductor muscle strength 6 mo after surgery. This lower abductor muscular strength could be mainly responsible for the lower COP displacement amplitude in the medial-lateral direction compared to the controls.
Pop et al. (2018); Poland *Non-randomized study*	103 (62 F)	**Healthy controls** 48 (31 F) **THA** 55 (31 F)	**Healthy controls** 58.0 ± 6.2 **THA** 56.3 ± 8.7	Static balance assessment, using the stabilometric force platform, was performed once between 24 and 36 months after the THA surgery.	All patients had undergone unilateral THA surgery with a lateral approach and uncemented prosthesis. All the surgical procedures were a minimally invasive (joint capsule saving) approach performed by the same team of orthopedic surgeons in the same clinic (The Holy Family Specialist Hospital, Rudna Mała, Poland) using the same	Mean time since surgery: 29.2 mo Min: 24 mo Max: 36 mo	1) There were statistically significant differences in the COP deviation mean velocity in ML direction between the study and the control groups during the test with eyes opened. 2) Higher values for both of these parameters were present in the study group. 3) More significant differences were observed during the test with eyes closed. 4) All stabilometric parameter	Static balance parameters in the group of THA patients can still be impaired up to 2-3 years after the surgery, compared to the age matched, asymptomatic control group.

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Table 1 (*continued*)

STUDY	POPULATION				INTERVENTION CHARACTERISTICS		MAIN FINDINGS	CONCLUSION
Author (Year); Country *Study design*	Sample (n/women)	Groups (n/women)	Mean age (± SD) in years	Tools to assess balance	THA characteristics	Time of follow-up	Mean values (MV), mean differences (MD), standard deviation (SD), relative or absolute frequencies, or other pertinent findings	
					implant type. The post-surgery rehabilitation program consisted of 4-week standard protocol including progressive strengthening exercise of the hip muscles, progressive range of motion (ROM) exercise, stretching of the hamstrings and hip adductor muscles, progressive weight-bearing walking with crutches, and the educational program focused on the potential postsurgical complications and limitations.		values, excluding the COP path area,were significantly higher in the study group	
Rasch et al. (2010); Sweden *Before-after study*	22 (18 F)	**THA** 22 (18 F)	**THA** 67.0 ± 7.0	A force plate (MuscleLab; Ergotest, Langesund, Norway) connected to the computer and dedicated software was used to analyze lateral and sagittal sway.	Two types of hip prostheses were ised: a cementless porous-coated femur stem (Bi-metric; Biomet Inc., Warsaw, IN) (n = 8) and a cemented polished and tapered femur stem (CPT; Zimmer Inc., Warsaw, IN) (n = 12). A cemented, highly crosslinked polyethylene cup (Muller; Stryker Howmedica Inc., Rutherford, NJ) was used in all patients. All patients completed 10 sessions of weekly group training after operation, and thereafter home exercises were encour- aged. A traditional rehabilitation program using the patient's own body weight as resistance was used.	T0) Presurgery T1) 6 mo T2) 2 y	***THA (T0)*** Sagital sway (OE): 4.5 ± 1.6 Sagital sway (CE): 6.1 ± 2.6 Lateral sway (OE): 3.0 ± 1.6 Lateral sway (CE): 4.1 ± 2.2 ***THA (T1)*** Sagital sway (OE): 3.9 ± 1.2 Sagital sway (CE): 4.6 ± 1.3 Lateral sway (OE): 2.4 ± 0.9 Lateral sway (CE): 2.8 ± 0.9 ***THA (T2)*** Sagital sway (OE): 3.5 ± 0.7 Sagital sway (CE): 4.6 ± 1.3 Lateral sway (OE): 2.0 ± 0.7 Lateral sway (CE): 2.6 ± 1.0 **p-value (one-factor ANOVA)** Sagital sway (OE): p = 0.04 bSagital sway (CE): p < 0.001 Lateral sway (OE): p = 0.04 Lateral sway (CE): p = 0.006	Postural sway on quiet bilateral standing was reduced after THA and the natural interpretation would be that an impaired postural stability due to OA became improved after THA.
Sliwinski et al. (2004); USA *Non-randomized study*	32 (20 F)	**Healthy controls** 16 (11 F) **THA** 16 (9 F)	**Healthy controls** 74 ± 5.7 **THA** 70.9 ± 4.2	The VICON 370 system and workstation software (version 3.0, Oxford Metrics, England) with six infrared cameras was used for 3-dimensional (3D) kinematic data collection while participants walked for 10 trials across a 30-	A convenience sample of 32 volunteers were recruited from the New Jersey and Pennsylva-nia area. The individuals with unilateral THA had a history of osteoarthritis as the cause for the unilateral THA, were a minimum of 2 months	Ten of the THA participants were 2–3 mo post surgery, and one each 5, 6 and 7 mo, and one 2 years post-surgery.	***Controls (SLS dynamic stability [cm])*** Right: 3.52 ± 1.40 Left: 3.17 ± 1.02 ***Controls (DLS dynamic stability [%])*** Right: 47.6 ± 6.7* Left: 55.5 ± 7.3* ***THA (SLS dynamic stability [cm])*** Operated: 3.67 ± 1.14 Non-	While no significant difference was identified during SLS phase for within and between group comparisons, results indicate that there was a difference in the pattern of dynamic stability during

(*continued on next page*)

Table 1 (*continued*)

STUDY	POPULATION				INTERVENTION CHARACTERISTICS		MAIN FINDINGS	CONCLUSION
Author (Year); Country *Study design*	Sample (n/ women)	Groups (n/women)	Mean age (± SD) in years	Tools to assess balance	THA characteristics	Time of follow-up	Mean values (MV), mean differences (MD), standard deviation (SD), relative or absolute frequencies, or other pertinent findings	
				footwalk-way. The camera sampling rate was 120 Hz.	post-surgery, had completed their rehabilitation, and were full weight bearing. Fourteen of the 16 participants had cemented procedures and 2 had non-cemented.		operated: 4.36 ± 1.45 ***THA (DLS dynamic stability [%])*** Operated: 54.2 ± 4.7* Non-operated: 52.3 ± 5.0* *p < 0.01	the DLS phase between the two groups.
Wykman et al. (1989); Sweden *Randomized trial* * **Since there is no healthy control group, this study was analysed based on before-after results regarding balance outcomes.*	21 (11 F)	**THA (cemented)** 10 (5 F) **THA (non-cemented)** 11 (6 F)	**THA (cemented)** 65.1 ± NR **THA (non-cemented)** 61.5 ± NR	The patient stood on a Statometer which is a circular platform supported by three cantilevers equally spaced around its periphery. Strain gauges are attached to each cantilever to give a continuous reading of the load.	Ten patients were selected randomly to have a Charnley low friction arthroplasty fixed with cement. The Charnley prosthesis was inserted through a lateral ap-proach, with detachment of the greater trochanter, and cemented in position. Eleven patients were in the non-cemented group having the HP-Garches femoral component (Howmedica). A posterolateral approach without trochanteric osteotomy was used for the HP-Garches prosthesis. Capsulectomy was carried out in both groups. The Harris hip score was used and a comparison made with the postural stability.	T0) Presurgery T1) 6 mo T2) 1 y	1) In patients with a Charnley low friction arthroplasty the postural sway areas ranged from 9 to 24 units (average 32 units) before operation. A year after operation, the areas ranged from 7 to 47 units (average 21). 2) Patients with the non-cemented HP-Garches arthroplasty had sway areas ranging from 14 to 161 units (average 64 units) before operation, and one year after operation the areas ranged from 6 to 93 units (average 29). 3) The difference in postural sway was not significant between the two groups, and the results after six months did not show any consistent pattern in relation to the preoperative findings.	Patients demonstrated an improvement in postural stability one year after hip replacement, but the findings at six months showed a wide range and no consistent pattern.

Legend: AL: Antero-lateral; AP: Anterior-posterior; CE: Closed eyes; COG: Center of gravity; COM: Center of mass; COP: Center of pressure; DC: Directional control; DL: Direct lateral; DLS: Double-limb support; EPE: Endpoint excursion; F: Female; M: Male; MD: Mean difference; ML: Medial-lateral; MO: Months MV: Maximum velocity; MXE: Maximum excursion; OE: Open eyes; RMS: Root mean square; ROM: Range of motion; RT: Reaction time; SD: Standard deviation; SLS: Single-limb support; SOT: Sensory organization test; THA: Total hip arthroplasty; Y: Years.

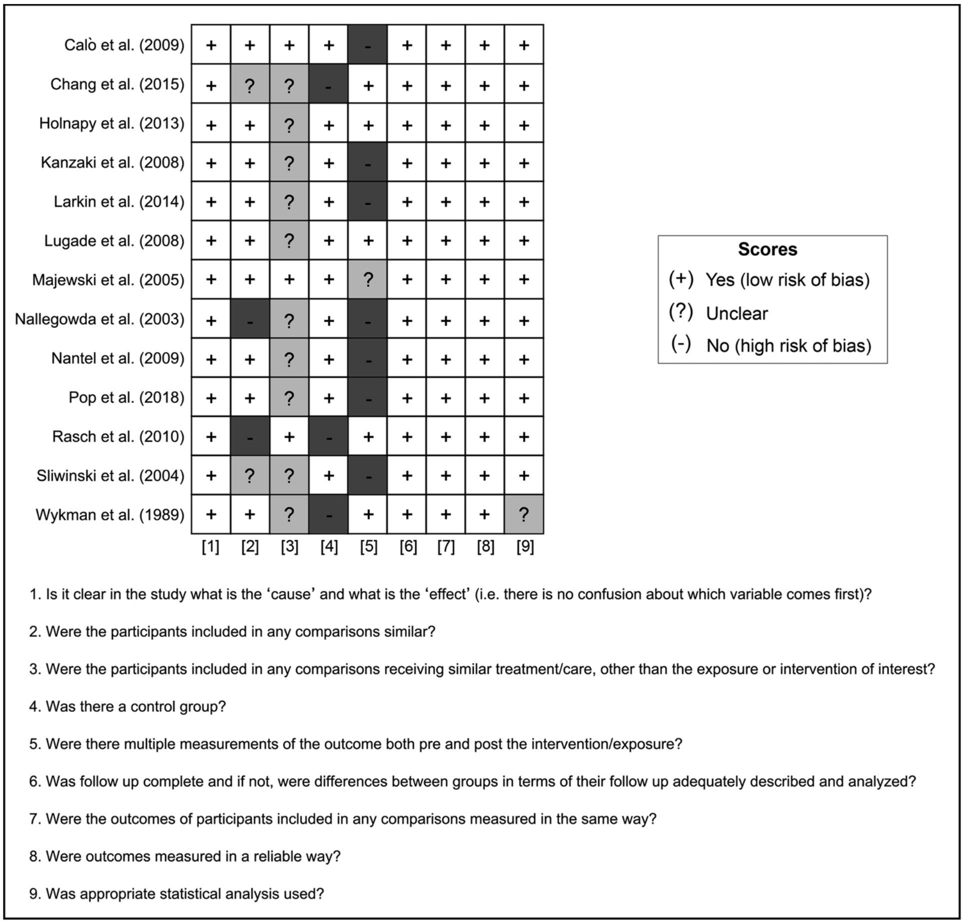

Fig. 2. Risk of bias summary, assessed by the Joanna Briggs Institute Critical Appraisal Tools for Quasi-Experimental Studies: author's judgments for each included study (generated using the software Review Manager 5.3, The Cochrane Collaboration).

meta-analysis was considered inappropriate.

From studies that included a healthy control group, improvements in the postural balance considering pre- and post-interventions were observed in the studies of Holnapy et al. [19], Kanzaki et al. [20], Nantel et al. [25], and Pop et al. [26] Meanwhile, the THA groups performed similarly to the healthy controls as reported by Larkin et al. [21]. Furthermore, the healthy controls had better postural balance than the THA individuals based on the studies conducted by Lugade et al. [22], Majewski et al. [23], Nallegowda et al. [24], and Sliwinski et al. [28] However, no differences between THA individuals and healthy controls were reported by Calò et al. [17]. Considering the studies that did not compare the results with healthy controls, improved postoperative postural balance was observed by Chang et al. [18], Rasch et al. [27], and Wykman et al. [29]

3.4. Risk of bias across studies

Substantial heterogeneity was observed across studies as no standardized postural balance assessment was found. Additionally, differences in follow-up times and postoperative supportive care (e.g., specific exercises) were major concerns as these covariates might potentially affect the results.

3.5. Confidence in cumulative evidence

Confidence in cumulative evidence was considered very low due to the risk of bias and inconsistency among studies. Detailed information is shown in Table 2.

4. Discussion

The potential effects of THA on postural balance were assessed in the present SR. By review and critical appraisal of available evidence, this SR aimed to better understand possible postural balance impairments and compensatory mechanisms that might occur after surgery. Findings from several studies suggested that THA significantly improved balance-related outcomes in up to 2 years following surgery [17,19–21,23]. However, some impairments were still observed, even after a long-term follow-up, compared to the healthy controls [25,26]. Considering that THA affects up to 3–5% of the elderly population, balance impairment following THA is clinically relevant, especially due to intrinsic risk of falls in this population [30]. Clinical practitioners should carefully consider these results to provide evidence-based recommendations to their patients.

Among the studies assessed for eligibility, only 13 studies were finally analyzed. Several studies were excluded due to assessment of specific physiotherapy protocols or rehabilitation programs [31–35]. These studies were considered ineligible because of possible confounding on the isolated effect of THA on balance outcomes. Nonetheless, it should be mentioned that poor description of standard physiotherapy care across included studies allowed no clear judgment on the true comparability on this topic; therefore, participants might not have been subjected to the same type, intensity, and duration of trainings, which might partially account for the variability observed. Furthermore, although studies investigating specific physiotherapy protocols were ineligible for inclusion, the authors of a recent SR proposed that this type of training may be used as a complement to standard physiotherapy care and improve function recovery following knee

Table 2
GRADE Summary of Findings Table. Question: Among adults, what are the effects of total hip arthroplasty for primary osteoarthritis on postural balance compared to no intervention or status before treatment?.

Quality assessment							№ of individuals		Quality
№ of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	THA	Healthy controls	
Postural balance									
13	Non-randomized studies	serious[a]	serious[b]	not serious	not serious	none	379	269	⨁◯◯◯ VERY LOW

Explanations.
[a] Three included studies did not compare results to healthy controls. Moreover, there were some major concerns regarding multiple measurements of the outcome both pre- and post-surgery, as these data were not reported in some studies and thus not permitting a clear judgment.
[b] There was substantial heterogeneity regarding postural balance assessment tools and follow-up times. Moreover, conflicting results were observed across studies.

arthroplasty. However, studies on hip arthroplasty were considered sparse and inconsistent, and thus, further studies were recommended [36].

Furthermore, the use of different balance assessment tools was considered as a major concern in included studies. In fact, previous studies suggested that physical therapists and surgeons utilized different tools to assess the recovery after joint arthroplasty [37], which might partially explain the lack of standardization observed. Therefore, generalization of results should be avoided and statistical pooling of data using meta-analysis was considered inappropriate. Nonetheless, although the results were not directly comparable, positive effects following surgery were consistently observed, especially compared to preoperative status [18,27,29].

The framework timeline of post-surgical measurements was also a concern in this SR. Although studies with less than 1 month of follow-up were excluded, it could be hypothesized that short follow-up times could be related to insufficient time for the body to adapt to a new movement or posture pattern [38]. Moreover, several included studies reported only a partial recovery on postural balance between 4 [22] and 6 months [25,29]. Therefore, long-term data are recommended to achieve precise results on the effects of THA on balance-related outcomes, and results at 6 months or less following surgery should be cautiously interpreted. Moreover, it must be highlighted that from the 13 included articles, 10 articles presented control groups, of which only 8 reported age-matched and 3 gender-matched controls. Since a rough age match and sex were not achieved in all included studies, this might weaken the comparison of THA and healthy controls.

Differences in balance parameters following THA might also be related to the invasiveness of the surgical procedures [38]. Only 2 studies used minimally invasive techniques [18,26], although no direct comparison of both minimally invasive and standard surgery was found. Moreover, substantial heterogeneity was observed on the incision site (e.g., lateral, anterior, or posterior approach). Nevertheless, separate data on surgical approaches were available in a single study, which reported that in patients who underwent direct lateral and antero-lateral exposure methods, the dynamic balancing ability of the affected limb varied from that of the control group in up to 6 months following surgery. However, no significant difference was noted in the balancing ability of the control group at 6 months after THA with posterior exposure [19]. No consensus on the advantages of posterior exposure among the other surgical techniques was achieved, since individuals who underwent posterior exposure showed balance deficits compared to the healthy controls such as abductor muscle weakness [25] or delayed motor response [24].

Findings from this SR suggested that balance-related outcomes might present improvements regardless of capsular damage caused by capsulotomy during THA. Therefore, it can be proposed that intracapsular components may have little influence on balance and other factors, such as the muscle receptors, could potentially play a prominent role in joint position sense [39]. Additionally, some variables related to the type of prosthesis may affect balance-related outcomes, such as the femoral head diameter. It is proposed that large femoral heads could provide better gait measures, stability, and abductor strength than standard femoral heads [40]. In this SR, the size of the femoral head was investigated in 2 studies [21,25]. Despite the differences in prostheses characteristics and joint reconstruction between large diameter head THA and total hip resurfacing, Nantel et al. [25] proposed that the large femoral head component seems to be the critical mechanical factor leading to postural stability. However, inconsistent results were observed, since full recovery of abductor muscle strength was not achieved 6 months after surgery. Therefore, longer rehabilitation programs to regain hip abductor strength should be considered to prevent falls and injuries [25]. Moreover, Larkin et al. [21] reported that improved proprioception after large femoral head or total hip resurfacing versus standard THA is not supported.

Although no current evidence reveal that THA might reduce the risk of fall compared to individuals with hip and knee OA who did not undergo this procedure, the risk of fracture may be lower in THA individuals [41]. Moreover, it is important to evaluate improvements in daily life activities that might be affected by balance deficiencies, such as standing up from a chair, walking, and climbing stairs [42]. Thus, it can be hypothesized that improvements in balance-related outcomes could potentially increase the patients' quality of life by providing more stability in performing these activities.

There were few studies investigating the differences in tests evaluating balance during single–double leg stances in this SR. Three included studies investigated this topic [19,21,28]. Sliwinski et al. [28] evaluated the dynamic stability during walking, and no differences in single leg support during dynamic stability tests were observed between the THA and healthy control groups. However, significant differences in double leg support were found. In contrast, Honalpy et al. [19] did not observe differences in double leg stance between both groups. Only a single study compared the non-operated side with the healthy controls [21]. Since the proprioception score of both operated and non-operated sides was virtually identical after rehabilitation, complete recovery was achieved following THA. Nonetheless, compared to the healthy controls, both operated and non-operated sides presented proprioception deficits, suggesting that proprioception deterioration might be associated with early asymptomatic osteoarthritic process on the non-operated hip side.

Some areas of uncertainty were still present in the light of evidence currently available in the literature. As previously depicted, balance improvements in THA individuals may not be accompanied by a decreased risk of falls compared to OA individuals who did not undergo this procedure. It could be proposed that studies with long follow-up time might contribute to the current knowledge on this topic. In addition, studies conducting formal assessments on the patients' quality of life based on balance deficiencies among patients who underwent THA might present valuable data and could be recommended to further explore this topic.

4.1. Study limitations

Some limitations on the findings of this SR should be highlighted.

Firstly, since the assessment methods were considerably heterogeneous, external validity of findings should be interpreted with caution. Secondly, the lack of comparison with the healthy controls in several studies might overestimate the observed findings. Lastly, measurements of both pre- and post-surgery were often lacking; thus, the magnitude of improvement was unclear. Therefore, further studies with standardized assessment methods and detailed reporting of findings are recommended to investigate the effects of THA on postural balance.

5. Conclusion

Available evidence on THA effects on postural balance was considerably heterogeneous. Overall, major post-surgical improvements were consistently observed compared to preoperative status, although postural balance impairment can still be noted compared to healthy controls. Further studies with a standardized balance assessment tool are recommended to further explore this topic.

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CRediT authorship contribution statement

Fernando de Lima: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft. **Daniel A. Fernandes:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing - review & editing. **Gilberto Melo:** Conceptualization, Methodology, Formal analysis, Data curation, Writing - review & editing. **Carlos R. de M. Roesler:** Conceptualization, Writing - review & editing. **Fabrício de S. Neves:** Conceptualization, Writing - review & editing. **Francisco Rosa Neto:** Conceptualization, Writing - review & editing, Supervision.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.gaitpost.2019.07.124.

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