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Systematic Review

Total Hip Arthroplasty in Patients With Neurological Conditions: A Systematic Review

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A B S T R A C T

Background: As operative techniques and implant design have evolved over time, total hip arthroplasty (THA) is increasingly being carried out for patients with neurological impairment. This patient group places unique surgical challenges to the arthroplasty surgeon, which may include contractures, instability, and altered muscular tone. The purpose of this systematic review is to report the patient outcomes, complications, and implant survival following THA for patients with neurological conditions affecting the hip. Thus, we aim to support orthopaedic surgeon decision-making when considering and planning THA for these patients.

Methods: A systematic review was performed as per Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines using the PubMed/Medline OVID, Cochrane, and Embase databases. All studies reporting the outcomes of THA in the neurological population which met defined inclusion criteria were included.

Results: From an initial screen of 1820 studies, 45 studies with a total of 36,251 THAs were included in the final selection. All 45 studies reported complication rates, with controls included in 16 for comparison. High complication rates were observed following THA in the neurologically impaired population, most notably dislocation with observed rates up to 10.6%. An improvement was noted in all 36 studies (1811 THAs) which reported upon patient-reported outcomes.

Conclusions: THA may be beneficial in the selected patients with neurological conditions, to reduce pain and improve function. There is an increased risk of complications which require careful consideration when planning the operation and open discussion with prospective patients and caregivers before proceeding with surgery.

Search Strategies and Materials Available Online. Prospero Registration: CRD42022332353; https://www.crd.york.ac.uk/PROSPERO/.

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Introduction

Total hip arthroplasty (THA) reliably alleviates pain and improves quality of life in patients with osteoarthritis [1]. Patient factors associated with a successful recovery include a high level of preoperative physical function and balanced muscular strength [2]. Patients with neurological conditions pose unique surgical

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challenges, including contractures, paresis, and muscular imbalance, [3] ranging from flaccidity in conditions affecting the lower motor neurons to spasticity in those affecting the upper motor neurons [4]. Dislocation and aseptic loosening concerns led to a historical reluctance from surgeons to perform THA for patients with neurological conditions, with many proceeding towards salvage procedures in the primary instance such as arthrodesis or resection arthroplasty [5–8]. Operative techniques and implant designs have evolved to broaden the indications for THA, [9–13] with a greater understanding of the biomechanical environment surrounding prosthetic hips, which has naturally extended to the neurological population [3,14–16].

In 2009, Queally et al. identified that the clinical data pertaining to the outcomes of THA in the neurological population were lacking [3]. Such interventions have become increasingly more common over the past 10 years, and as such, the available literature has greatly expanded. The aim of this systematic review is to build upon the previous work of Queally et al and report on the complete literature relating to THA for patients affected by neurological conditions [3]. This review will serve as a guide for orthopaedic surgeons planning THAs in the neurologically impaired population and to enable an informed discussion with patients and their caregivers regarding potential complications and anticipated outcomes.

Material and methods

Search strategy and eligibility

In February 2022, a systematic review of the literature was performed by 2 independent reviewers (C.S.O.D. and A.J.H.) with respect to Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines [17]. The PubMed/Medline OVID, Cochrane, and Embase databases were screened from their inception to February 2, 2022, inclusively. The search strategy was adapted from the study by Queally et al. [3], with predetermined search terms utilized for each of the aforementioned databases, including THA Population, Neurological Impairment, and Outcome (see attached in Appendix).

Following the removal of duplicate studies, both independent reviewers manually screened the titles and abstracts of the returned studies while applying our predetermined exclusion criteria, with the senior authors (B.J.O.D. and J.M.Q.) acting as arbitrators in cases of discrepancy of opinion. Following the removal of excluded studies, both independent reviewers applied the predetermined inclusion criteria to the remaining studies to evaluate all potential studies for definitive inclusion. Thereafter, the reference lists of all included studies were screened for further studies that potentially may meet the inclusion criteria.

Inclusion criteria encompassed (1) studies reporting the outcomes of THA in patients with neurological conditions, (2) studies published in English language, and (3) published in a peer review journal with full text available. Exclusion criteria included (1) case reports, (2) review articles, (3) abstract-only studies, and (4) cadaveric or biomechanical studies.

Outcomes of interest

The results from each study were tabulated following a quality assessment using the GRADE tool (Grading of Recommendation, Assessment, Development and Evaluation) [18] and Oxford Centre for Evidence-Based Medicine criteria [19].

A predesigned data-collection template was then collated including (1) study population, including neurological condition, study type, follow-up period, patient demographics; (2) implants utilized and surgical technique; (3) patient-reported outcomes; (4) complications; and (5) arthroplasty revision rate.

Descriptive statistics were performed using Stata software version 16.1 (StataCorp, College Station, TX). A Meta-analysis of the included studies was not performed due to the significant heterogeneity in study location, patient age, disease severity, implant type, surgical technique, and reporting of outcomes.

Results

There were 1820 studies collated in the initial database search, which was subsequently reduced to 1514 following duplicate removal. Following abstract screening, 108 full-text articles were assessed, leaving 45 studies, with 36,251 patients, included in the final review. Of the 45 studies, 36 reported functional outcomes of 1811 patients, using various rating scales, and all 45 reported complications. The PRISMA flow chart with reasons for exclusion is illustrated in Figure 1.

Parkinson's disease

Parkinson's disease (PD) is a progressive neurodegenerative disorder characterized by elevated tone and classical motor symptoms such as bradykinesia, rigidity, rest tremor, as well as both postural and gait impairment, in addition to cognitive effects such as memory impairment which may complicate rehabilitation [20]. PD affects greater than 1% of the population older than 60 years, [21] and advances in medical care have led to increased life expectancy [22]. Between 2000 and 2014, the incidence of THAs performed for patients with PD increased from 946 to 1655 within the United States Nationwide Inpatient Sample (NIS) [14].

Focusing on the primary admission and immediate perioperative period, 2 studies using the United States NIS and carried out by Kleiner et al. and Newman et al. [14,23] observed an increased length of stay for PD patients compared to control. Medical complications were common in the PD cohort and included delirium and respiratory and urinary tract infections, replicating the experiences of PD patients undergoing nonorthopedic surgeries, thus highlighting the need for medical optimization and multidisciplinary care [24].

Eight studies with a total of 1296 THAs reported medium-term follow-up of over 2 years. These were primarily elective primary THAs (949 THAs), with several revision (58 THAs) and trauma (26 THAs) cases also classified. The mean age was 72.6 years, with a range of disability levels included from Hoehn and Yahr Classification stage I and II to severely affected grade IV and V patients [25].

Higher dislocation rates were reported in all studies comparing PD patients to control, ranging from 1.6% to 8.3% [26,27]. This followed through to higher revision rates due to recurrent dislocation in Joint Registry–based studies by Wojtowicz et al. in Sweden and Jamsen et al. in Finland, for their cohorts of 495 and 297 PD THAs compared to matched control [28,29]. With respect to surgical indication, the dislocation rates in the trauma and revision THA group of the study by Weber et al., 12.2%, were higher than those in the elective group which experienced no dislocations [30]. Periprosthetic infection rates were over 2 times greater within the PD group in each of the 3 studies by Wojtowicz et al., Shah et al., and Rondon et al., which included matched control patients without neurological conditions [26–28].

Patient-reported outcome measures were documented in 6 studies [26,28,30–33]. Notwithstanding the higher complication and implant revision rates experienced by the PD group, an improvement in functional activity and pain was reported in each of the studies postoperatively. A point of note made by Weber et al. was that beyond an initial improvement in function at 1 year

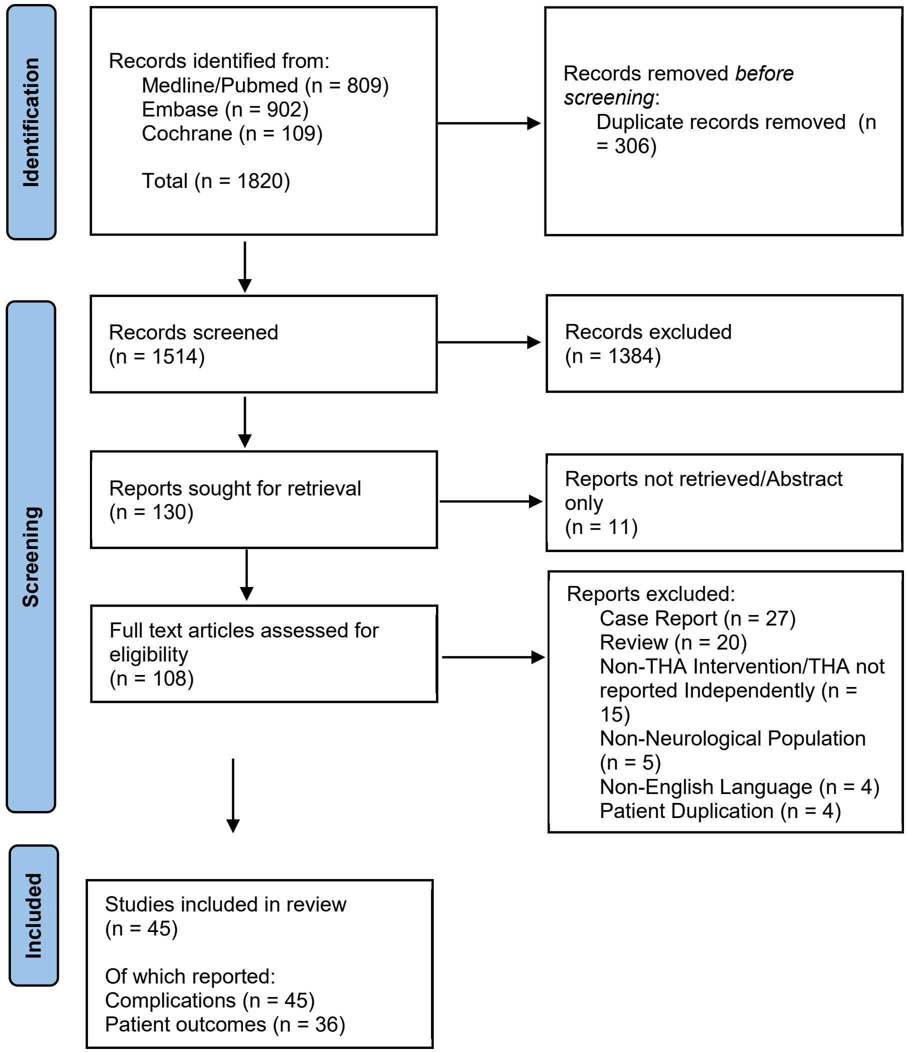

Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) flowchart.

postoperatively, longer term outcomes were often limited by PD disease progression, as shown by a parallel deterioration in Hoehn and Yahr disease scores [30].

The results of THA in the PD population are displayed in Figure 2.

Cerebral palsy

Cerebral palsy describes a group of permanent disorders of movement and posture attributable to nonprogressive disturbances that occurred in the developing brain [34].Spasticity is the most common movement disorder, occurring in 80%, [35] which may lead to periarticular contractures about the hip joint and migration of the femoral head leading to subluxation and dislocation [36]. Abnormal loading leads to dysplastic changes of the femoral head and acetabulum with associated pain and disability [3,37].

Within the primary admission period, Moon et al. using the US NIS database reported a longer length of stay and increased risk of perioperative medical complications despite a younger mean age at the time of surgery in their cohort of 2062 Cerebral Palsy (CP) patients matched 10:1 to a non-CP control group [38]. Over the first 90 days, Moore et al. in their study of 864 CP patients matched 4:1, from the US Mariner patients records database, found a statistically significant increased odds ratio of medical complications such as urinary (odds ratio [OR] 2.42, 95% confidence interval 1.25-4.58) or respiratory tract infection (OR 3.77, 95% confidence interval 1.64-8.56) and periprosthetic fracture (OR 2.55, 95% confidence interval 1.42-4.46) [39].

Reviewing the England and Wales Joint Registry data from 389 CP patients undergoing THA, King et al. reported cumulative revision rates of 2.6% and 6.4% at 1 year and 5 years, respectively [15]. Hybrid implants had the lowest 5-year revision rate of 1.2%, with uncemented (7.1%) and resurfacing (11.5%) implants faring less favorably. For comparison, the unmatched control cumulative revision rate was 0.79% at 1 year and 2.9% at 5 years. Among seven other retrospective studies, at varying lengths of follow-up, revision rates ranged from 0% to 27%. These studies with a combined 189 patients at mean 94 months of follow-up, reported 20 dislocations (10.6%), 11 cases of aseptic loosening (5.8%), 6 infections (3.2%), and 6 periprosthetic fractures (3.2%) [40–46]. While there was considerable heterogeneity across the studies with regard to severity of CP symptoms, functional improvements were noted in multiple studies, including cases of both mild and severe impairment [41]. Results for the cerebral palsy THA population are displayed in Figure 3.

Author + Year	LOE	GRADE	Population	Number	Implant/Technique	Mean Age (Years)	Follow Up (Years)	Functional Outcome	Survivorship	Complications
Shah, N. V., et al. (2020) [27]	4	Low	Multicentre, New York State DOH Database	235, 1:1 Control	Not specified	74.3	Minimum 2	NA	**Revision Rate,** PD 6.4%; C 4.7%.	**Dislocation:** PD 7 (3%), C 6 (2.5%). **Wound Infection:** PD 19 (8.1%), C 6 (2.6%). **Prosthetic Joint Infection:** PD 9 (3%), C 3 (1.3%)
Wojtowicz, A. L., et al. (2019) [28]	3	Low/Moderate	Swedish Hip Arthroplasty Register. 1999-2012	490, 1:1 Control Matched	**Implants** Cemented, 442 (90%); Uncemented, 23 (5%); Hybrid, 6 (1%); Reverse Hybrid, 19 (4%)	73	4.7	**EQ-SD** Pre-op PD 0.32, C 0.40. 1 year PD 0.62, C 0.82.	**Mortality**; **90 Day**, PD 0.62% C 0.61% **1 Year,** PD 2.56%, C 2.11% **9 Year,** PD 54.35%, 28.05%. **Implant Revision Rate 90 Day** PD 1.03%, C 0.41%. **1 Year**, PD 2.10%; C 0.41%. **9 Year** PD 5.44% C 1.75%.	**Complications leading to Revision., Dislocation**, PD 11 (2.2%), C 1 (0.2%); **Aseptic Loosening**, PD 5 (1%), C 3 (0.6%); **Prosthetic Joint Infection**, PD 4 (0.8%), C 1 (0.2%); Fracture, PD 2 (0.4%), C 1 (0.2%)
Rong, X., et al. (2019) [31]	4	Low	West China Hospital, China. 2009-2016	Total, 28. Subgroup 1, H&Y Stage I and II, 12 (43%). Subgroup 2, H&Y Stage IV and V, 12 (43%)	Not specified	65 (47-80)	4.3	**HHS** Pre-op, 39.00; Post-op, 71.39. **SF-12 (0-100)** Pre-op PCS 13.96, MCS 17.96 Post-op PCS 17.54, MCS 21.41. **WOMAC** Pain (0-20) Pre-op 10.63, Post-op 2.96. Function (0-68) Pre-op 44.08, Post-op 34.63.	**Implant Revision Rate** at 5 years. 5.9 %	**Periprosthetic Osteolysis and Polyethylene Wear**, 1 (3.5%); **Periprosthetic Fracture**, 1 (3.5%); Infection/Dislocation/Aseptic Loosening, nil;
Kleiner, J. E., et al. (2019) [14]	3	Low	Healthcare Cost and Utilization NIS Database, USA. 2000-2014.	4001, 1:3 Control Matched	Not specified	74.5	Primary admission	NA	**Mortality** (In hospital) PD 0.50%, C 0.47%	**All Complications** PD 14.6 %, C 11.7%. **Mechanical Complications** (including dislocation, prosthetic loosening and PPF) PD, 1.5%.
Rondon, A. J., et al. (2018) [26]	3	Low/Moderate	Thomas Jefferson University, Philadelphia. 2000-2016	52, 93 Control Matched	Not specified	68.7	5.3	**SF-12** (26 PD, 47 Control) Pre-op: PD 28.4, C, 34.4. Post-op: PD, 37.4; C, 44.7. Change: PD, 6.2; C, 11.8	**Implant Survivorship** 2 Year 94.3%. 5 Year 85.3%, 10 Year 78.7%.	**Periprosthetic Fracture** 4 (7.7%). **Dislocation** 4 (7.7%). **Aseptic Loosening** 4 (7.7%). **Periprosthetic Joint Infection** 1 (1.9%).
Newman, J. M., et al. (2018) [23]	3	Low	NIS Database, Sample from over 1000 US Hospitals. 2002-2013.	10528, 1:3 Control Matched	Not specified	73	Primary admission	NA	NA	**Surgical Complication** PD:C Odds Ratio 1.3:1, Haematoma/Seroma OR 1.3, Peripheral Nerve Injury, OR 3.0. Irrigation/Debridement, OR 0.75. No infection or dislocation reported.
Lazennec, J. Y., et al. (2018) [32]	4	Low	Pitie-Salpetriere Hospital, France. 2002-2012	63 (59 patients). 42 Primary, 21 Revision.	**Approach,** Direct lateral **Implants Acetabular** Cementless with DM. **Femoral** Primary, Uncemented 38 (90%) Modular Stem 4 (10%); Revision, Uncemented 17 (81%) Cemented 4 (9%).	72.5 (55-79)	8.3	Pain Relief at 2 year follow up 53/57 rated good to excellent.	**Implant survivorship** 2 Year 91.5%, 5 Year 79.7%.	**Periprosthetic Fracture,** 4 (6.4%); **Surgical Site Infection,** 2 (3.2%); **Dislocation,** 1 (1.6%).
Šponer, P., et al. (2017) [33]	4	Low/Very Low	University Hospital Hradec Kralove, Czech Republic 2005-2012	Total 24 (10 Elective, 14 Trauma)	**Elective Acetabular** Cemented 8 (80%) Uncemented 2 (20%). **Femoral Stem** Cemented 9 (90%) Cementless 1 (10%) **Trauma Acetabular** Cemented 13 (93%), Cementless 1 (7%). **Femoral Stem** Cemented 12 (86%), Cementless 2 (14%)	Elective 74 (65-82). Trauma 76 (67-83)	Elective 6.8, Trauma 4.5.	**Merle d'Aubigne Score** (0-18) **Elective** Pre-op, 8; 6 Months, 14; 36 Months, 14. **Trauma** Pre-op, 3; 6 Months. 12; 36 Months, 12.	Nil Implant Revision	**Dislocation** E 1 (10%), T 1 (7.1%). **Periprosthetic Fracture** E 1 (10%), T 1 (7.1%). **Prosthetic Joint Infection** E 0, T 1 (7.1%).
Jämsen, E., et al. (2014) [29]	4	Low	Multicentre, PERFECT Database, Finland; 1998-2009.	297, 1:3 Control Matched. Note with 560 TKA	**Implants** Cemented 165 (55.6%)	72	1-13	NA	**Implant Survival** PD 1 Year, 98% (CI 96.4-99.6). 3 Year, 96.8 % (CI 94.6 – 99.0). Implant Revision THA First 2 years post op PD:C, 1.13:1 (CI 0.50-2.56)	**Complications leading to Revision, Dislocation** 1 Year 3.36%, Total 6.06%. Relative Risk 1 year, PD:C 2.33 Total 1.29.
Weber, M., et al. (2002) [30]	4	Low	Mayo Clinic, Rochester. 1970-1994.	107 (98 Patients). 58 Primary, 49 Revision/Trauma. H&Y Stage **Primary** I-19%, II-69%, III-10%, Unknown 2%. **Revision/Trauma** I-6%, II-24%, III-65%, IV-4%, Unknown-2%.	**Approach** Anterolateral,56 (52%); transtrochanteric, 36 (34%); posterior, 12 (11%); direct lateral, 3 (3%). **Procedures** Adductor tenotomy, 7 (6.5%); Psoas tenotomy, 1 (1%). **Implants** Cemented, Acetabulum 94 (88%) Femoral 103 (96%)	72 (57-87)	Followed up over 2 years P, 44 (76%); R/T 31 (63%)	**Pain** Good to Excellent relief 93%. **Functional** Primary Group Improvement noted during first year with subsequent deterioration in line with primary Parkinson's Disease related disability. 78% Neurological Progression 57% Hoehn and Yahr Stage 4 or 5.	**Perioperative mortality**, 4 (3.7%) LRTI 2, PE 1, CVA 1 **THA Reoperated**, 9 (8.4%) PJI 1, PPF 1, Trochanteric Nonunion 1, Instability 1, trochanteric wire removal 1, aseptic loosening 3. **THA Survival** 93% at 5 years for Primary and Total Groups	**Dislocation** Primary 0, Revision/Trauma 6 (12.2%). **Prosthetic Joint Infection** P 0; R/T 1 (2%). Trochanteric Nonunion P 2 (3.4%); R/T 2 (4%). DVT P 2 (3.4%); R/T 1 (2%). PE P 2 (3.4%); R/T 0. Transient Peroneal Palsy P 1 (1.7%); R/T 1 (2%).

Figure 2. Total hip arthroplasty in Parkinson's disease results.

Multiple sclerosis

Multiple sclerosis (MS) is a chronic inflammatory autoimmune condition primarily affecting the central nervous system via demyelination of the axonal sheaths, which disrupts transmission [47]. MS is the leading cause of nontraumatic disability in young adults, affecting approximately 400,000 in the United States alone [48]. Neuromuscular manifestations are common and vary according to the location affected [4]. These may include rigidity, spasticity, weakness, contractures, and functional limitation, with increased risk of falls and poor postural control [49].

Newman et al. found that during the primary admission, the rate of perioperative and surgical complications was higher for MS patients than for the control, based on an US NIS Inpatient Sample of 5899 MS patients who underwent THA [16]. There was also an increased average length of hospital stay and likelihood of requiring admittance to step-down care facilities before returning home from hospital in the MS cohort.

Among those studies that reported THA complications individually, the 2018 retrospective review of Newman et al. with 41 THAs in the Cleveland Clinic observed dislocation, infection, and aseptic loosening at higher rates than those in control [50]. With regard to implant revision rates, Quinlan et al. estimated the rate at 2 years to be 4.23% from their analysis of US Medicare analytical files [51], while Rondon et al. reported a corresponding 2-year rate of 2.1% among their 62 THAs [52]. At longer term follow-up of 7 and 8

Author + Year	LOE	GRADE	Population	Number	Implant/Technique	Mean Age (Years)	Follow Up (Years)	Functional Outcome	Survivorship	Complications
Moore, H.G. et al. (2021) [39]	4	Low	Mariner administrative database, USA. 2010-2018	864, 1:4 Control matched.	Not specified	56.3	90 day / Revision to 5 years	NA	5 year survival 94.2%, Control 95.2%	**90 Day Dislocation** 23 (2.7%) OR versus control 1.52, **Surgical Site Infection** 14 (1.6%) OR 0.72. **Periprosthetic Fracture** 23 (2.7%) OR 2.55 Readmission 131 (15.2%) OR 1.13
Moon, A. S., et al. (2020) [38]	4	Low	Healthcare Cost and Utilization NIS Database, USA. 2005-2014.	2062, 1:10 Control Unmatched	Not Specified	CP 49.2, Control 64.8.	Primary admission	NA	Not reported	**Length of Stay,** CP 3.8 days, Control 3.2 days**.** Surgical site infection CP 0.3%, C, 0.1%. Perioperative Haemorrhage, CP 0.7%; C 0.8%**.** Postoperative Anaemia CP 30.2%, C 24.5%. Mechanical Failure CP 0.74% C 0.45%**. Overall** CP 34.3%, C, 27.9%.
Houdek MT, et al. (2017) [40]	3	Low/Moderate	Mayo Clinic, Rochester, USA. 1990-2013.	41, (39 With 2 Year Follow Up) 1:2 Control Matched. CP GMFCS I, 3 (7%). II, 18 (44%). III, 12 (29%). IV, 6 (15%).	**Approach** Posterior 20 (49%), Anterolateral 19 (46%). **Implants Acetabulum** Uncemented all. Dual Mobility implant 5 (12%), Lipped Liner 2 (5%). **Femoral** Cemented, 44%. Femoral head augmentation 4 (10%). **Procedures** Adductor tenotomy 7 (17%), Psoas tenotomy 2 (5%).	49 (21-74)	7 (2-20)	**Pain**, Pre-op moderate to severe hip pain all. Post-op moderate to severe pain nil. **Ambulation** Pre-op Independent 10%, Use of Aid 70%, Non-Ambulatory 19.5%. Post-op Independent 54%, Use of Aid 46%, Non-Ambulatory 0%. **Flexion contracture greater than 15 degrees**, Pre-op 9 (29%), Post-op 0. **Harris Hip Score (0-100)** Pre-op 36, Post-op 78	**THA Revision** 5/39 (12.8%) CP mean 3yrs. Aseptic loosening: 2 (5.1%)**;** Recurrent instability: 2 (5.1%); Deep Infection: 1 (2.6%) Mean THA Survival, 2yr 92%, 5yr 88%, 10yr 81%, 15yr 81%.	**Dislocation**, 3 (7.3%) (OR 2.0); **Aseptic loosening**, 2 (4.9%) (OR 1.0); Wound Dehiscence, 1 (2.4%); **Deep Infection**, 1 (2.4%) (OR 1.0); DVT, 1 (2.4%).
Morin, C., et al. (2016) [41]	4	Low	Institut Calot, France. 2001-2014.	40 THA on 33 pts. Non ambulatory CP GMFCS V. 21 (52.5%) previous surgery including 9 (22.5%) adductor tenotomy, 9 (22.5%) femoral and pelvic osteotomies, 1 (2.5%) Proximal Femoral Replacement, 2 (5%) Osteoma Resections. 23 (57.5%) Scoliosis with Vertebral fusion	**Approach** Lateral with trochanteric osteotomy. **Implants Acetabulum** Dual Mobility implant all, 15 (37.5%) supported by femoral bone block. 5 (12.5%) with 4-hole plate. **Femoral** Small "dysplastic" implant. Cemented, 37 (92.5%); Uncemented, 3 (7.5%).	19.2 (13.5-31.7)	5.3 (0.75-12.25)	**Function** Independent Sitting Pre-op 5 (15%), Post-op 6 (18%). Pain Permanent Pre-op 16 (40%), Post-op 0. Pain Sitting Pre-op 20 (50%), Post-op 1 (2.5%). Pain on Transfer Pre-op 28 (70%) Post-op 0 **Motion** Flexion >80 Pre-op 19 (47.5%) Post-op 34 (85%)	**Implant Revision**: 6 (15%). Deep Infection with femoral loosening 1; Delayed Femoral Osteotomy Union 2; Greater Trochanter Detachment 1; Osteoma 1; Dislocation (Intraprosthetic) 1.	**Deep Infection**, 2 (5%) (1 early, 1 late); **Periprosthetic fracture**, 3 (7.5%). **Osteolysis/Loosening**, 2 (5%), Dislocation (Intraprosthetic) 1 (2.5%).
King, G., et al. (2016) [15]	3	Low/Moderate	Multicentre-England and Wales National joint Registry. 2003-2012	389 (265 Surgeons) 425813 Control (4531 Surgeons)	**Implants** Cemented CP 72 (18%), C 166654 (39%). Uncemented CP 163 (42%), C 161539 (38%). Hybrid CP 85 (22%), C 64701 (15%). Reverse Hybrid CP 14 (3.6%), C 10358 (2.5%). Resurfacing (all MoM) CP 55 (14%, C 22531 (5.3%).	CP 53 Control 69	Unspecified	**Oxford Hip Score (0-48)** CP (47 Complete Pairs)**.** Pre-Op 12, 6 months 34. Control (92073 Complete Pairs). Pre-Op 18, 6 months 41. **EQ-5D Health Scale (0-100)** CP (43 Complete Pairs). Pre-Op 60, 6 months 70. Control (80341 Complete Pairs) Pre-Op 70, 6 months 80.	**THA Implant Revision** Total CP 22 (5.7%)**,** C 9776 (2.3%). 1 Year CP 10 (2.6%), C 3212 (0.75%). At 5 years by implant type in CP population Cemented 1.5%, Hybrid 1.2%, Uncemented 7.1%, Resurfacing 11.5%. **Mortality** 90 Days CP 0.26%, C 0.54%. 1 Year CP 1.4%, C 1.6%. 3 Year CP 3.7%, C 5.2%. 5 Year CP 6.9%, C 10%.	Complications Leading to Revision in CP with prosthesis time incident rate (PTIR) per 1000 patient years **Periprosthetic Fracture** 7 cases PTIR 5.0 (CI 2.4-10.5) Control PTIR 0.7 (CI 0.66-0.75) **Aseptic Loosening** 6 cases PTIR 4.3 (CI 1.9-9.6) Control PTIR 1.6 (CI 1.32-1.43) Pain 5 cases PTIR 3.6 (CI 1.5-8.6) control PTIR 1.37 (CI-1.32-1.43) **Dislocation** 4 cases PTIR 2.9 (CI 1.1-7.6) control PTIR 1.22 (CI 1.16-1.43)
Yoon, B.H., et al. (2015) [42]	4	Very Low	KEPCO Medical Centre, South Korea. 2005-2007.	5 THA. Prior surgery, 2 (40%); Resection arthroplasty, 1; Open reduction, 1.	**Approach** Posterolateral**. Implants** Uncemented Ceramic on Ceramic	35.9 (20.2-55.6)	6.8 (5.8-8.3)	**Pain** Complete Pain Relief 3 (60%). Reduction in Preoperative Pain 2 (40%). **GMFCS Function Score** Improvement 3 (60%), Unchanged 2 (40%).	Nil Revision	**Dislocation** 1 (20%). **Periprosthetic Fracture** 1 (20%).
Sanders, R. J., et al. (2013) [43]	4	Low/Very Low	Sint Maartensklinii ek, Netherlands. 2008-2010	10 (9 Elective, 1 Trauma) GMFCS II, 3 (30%), III, 3 (30%), IV, 4 (40%).	**Approach** Posterolateral. **Implants** Dual Mobility Cemented Cup **Procedures** Adductor tenotomy, 1 (10%)	54 (43-61)	3.2	**SF–36 (0-100)** Post-op Physical Function 35, Pain 75.6, General Health 59.5.	**Reoperation** Periprosthetic Fracture 1 (10%)	Nil Dislocation
Schroeder, K., et al. (2010) [44]	4	Low	Heidelberg University Hospital, Germany. 1988-2004.	15 (13 Patients)	**Approach** Transgluteal Lateral Bauer **Implants** Uncemented 11 (73%) incl 1 constrained acetabular cup. Cemented 4 (27%). **Procedures** 6 (40%) incl 5 adductor tenotomy, 1 lengthening of adductor tendons, 4 psoas and rectus tendon release, 1 transposition of outer rotators)	42 (32-58)	10.5 (2-18)	**Pain (0-10)** Pre-op 8.4, Post-op 1.1.	**THA Revision** Total 4 (27%). Aseptic loosening 2 (15.4%), Infection 1 (7.7%), Recurrent dislocation 1 (7.7%).	**Dislocation**, 2 (15.4%) **Infection**, 1 (7.7%) **Aseptic Loosening**, 2 (15.4%)
Raphael, B. S., et al. (2010) [45]	4	Low	Hospital for Special Surgery, USA. 1972-2006.	59 (56 Patients) Prior surgery 37 (63%), 21 soft tissue release, 17 osteotomy, 1 resection arthroplasty, 2 arthrodesis	**Approach** Posterolateral 45 (76%), Transtrochanteric 14 (24%). Abductor tendon release if abduction preoperative limited to 30 degrees or less, 28 (47%). **Implants** Cemented 20 (34%) (early cases), Hybrid (cemented stem, uncemented acetabulum), 35 (59%), with screws placed in 17 (29%). Uncemented 2 (3%); S ROM Components 2 (3%). Superolateral augmentation with autologous femoral head bone graft 4 (7%).	30.7 (14-61)	9.7 (2-28)	**Pain (0-10)** Pre-op 8, Post-op 0.7 **Function** Same or improved in all cases pre-operative to post-operative. 52 (88%) return to GMFCS Level of function before onset of hip pain.	**THA Revision** Total 9 (15.3%), Dislocation/Subluxation 5 (8.5%), Loosening and Pain 2 (3.3%), Infection 1 (1.7%), Periprosthetic Fracture 1 (1.7%). Reported Proportion of subjects who had Prosthesis removed. 0.5yr 3.39%, 1.5yr 5.08%, 3yr 6.95%, 6yr 12.42%, 8yr 15.66%, 17yr 29.16%.	**Dislocations** 8 (13.6%), 2 early within 6 weeks. 6 late after 6 months. **Infection** 2 (3.4%). **Periprosthetic Fracture** 1 (1.7%). **Aseptic Loosening**, 4 (6.8%) 3 acetabular, 1 femoral. Trochanteric Nonunion 1 from 14 osteotomies (7%). Trochanteric Bursitis 5 (8.5%). PE 1 (1.7%).
Weber, M. and M. E. Cabanela	4	Low/Very Low	Mayo Clinic, Rochester, USA	Total 16 (11 Elective, 5 Trauma)	**Approach** Anterolateral, 8 (50%); Transtrochanteric, 7 (44%). Posterolateral, 1 (6%). **Implants** Cemented, 12 (75%); Uncemented, 2	48.5 (22-79)	9.7 (2.5-21)	Pain 87% good to excellent relief. **Function** Improvement 79%	**Revision**, 1 (6.3%) aseptic loosening at 13 years. 2 (13%) repeat surgeries, 1 trochanter avulsion ORIF, 1 adductor	**Periprosthetic Fracture**, 2 (12.5%); **Aseptic loosening** 1 (6.3%). Nil Dislocation
(1999) [46]					(12.5%); Hybrid, 2 (12.5%)				tenotomy.	

Figure 3. Total hip arthroplasty in cerebral palsy results.

Author + Year	LOE	GRADE	Population	Number	Implant/Technique	Mean Age (years)	Follow Up (years)	Functional Outcome	Survivorship	Complications
Quinlan, N. D., et al. (2019) [51]	3	Low/Very Low	Multicentre, Pearldiver Patient Records Database from Medicare Standard Analytical. 2005-2014.	3360, 1:10 Control Matched	NA	<65, 47.9%. 65-69, 20.7%.70-74, 15.2%. 75-80, 8.3%. 80-84, 5.0%. >85, 2.0%.	NA	NA	**In Hospital Mortality** (1 Year) MS 22(0.65%), C 231 (0.69%). **Revision THA** (2 Year) MS 142 (4.23%), C (2.87%).	Hospital admission (30 day) MS 250(7.44%), C 1272(3.79%). ED visit (30 day) MS 232(6.9%), C 1608(4.79%). **Prosthetic Joint Infection** (2 Year) MS 162(4.82%), C 1199(3.57%). **Hip Dislocation** (1 Year) MS 127(3.78%), C 786 (2.34%). Length of Stay MS 3.73, C 3.46.
Rondon, A. J., et al. (2018) [52]	3	Low	Rothman Institute Thomas Jefferson University, Philadelphia, USA. 2000-2016.	62 THA, 1:2 Control Matched. Note study also included TKA.	NA	57.2	6.2	**SF-12** Note including TKA. Mean SF12 MS Group Pre-Op 26.6, Post-Op 37.7. Control Group Pre-Op 29.0, Post-Op 44.8	**Implant Survival THA** 2 year 97.9%, 5 year, 91.9%, 7 year 77.8%.	Infection 2 (3.2%).
Newman, J. M., et al. (2018) [50]	3	Low	Cleveland Clinic, Ohio, USA. 2008-2016.	41 (34 Patients), 1:2 Control Matched	**Implants** Uncemented **Approach** Anterior/Anterolateral MS 8 (20%), C 16 (20%). Direct Lateral MS 6 (15), C 20 (24%). Posterolateral MS 27 (66%), C 46 (56%).	57 (38-79)	4 (2-8)	Functional At latest follow up **mHHS (0-100)** MS 66, C 80. **HOOS JR (0-100)** MS 79, C 88. Mean Physiotherapy Duration MS 5wk, C 3wk. Mean Return to Baseline MS 7wk, C 5wk.	**Implant Revision** 8 Year MS 3 (7.3%). PJI and multiple dislocations 1 (2.4%), Periprosthetic Fracture 1 (2.4%), Aseptic Loosening 1 (2.4%). Control 1 (1.2%), Periprosthetic Fracture.	Length of Stay MS 4 days (2 – 8), C 4 days (1 – 19). **Dislocation** MS 4 (9.8%), C 0. **Aseptic Loosening** MS 3 (7.3%), C 0. **Prosthetic Joint Infection** MS 2 (4.9%), C 0. **Wound Infection** MS 1 (2.4%), C 0. **Stress Fracture** MS 1 (2.4%), C 0. **Periprosthetic Fracture** MS 1 (2.4%), C 1 (1.2%).
Gutman, J. M., et al. (2018) [53]	4	Low/Very Low	NYU MS Care Centre, New York, USA. 2012 - 2016.	13 THA. (Elective 10 Elective, 3 Trauma). Note study also included TKA.	Approach/Components not specified	53	3.75 (0.25-12.7)	Ambulatory Aid Requirements Reduction, 5 (38%), No Change, 3 (23%), Increase, 5 (38%) (following fracture in 3)	Revision 1 (7.7%), Recurrent Instability	Not Reported Specifically for THA.
Newman, J. M., et al. (2017) (16)	3	Low/Very Low	Multicentre Healthcare Cost and Utilization NIS Database, USA. 2002-2013.	5899, 1:3 Control Matched	NA	57 (SD 10.9)	Primary Admission	NA	NA	Length of Stay (Days) MS 3.55, C 3.41. All peri-operative complications OR 1.37. Any Surgical Complication: OR 1.18. Any Medical Complication: OR 1.55.

Figure 4. Total hip arthroplasty in multiple sclerosis results.

years, revision rates of 22.2% and 7.3%, respectively, were reported [50,52].

Newman et al. also reported variable functional outcome scores depending upon MS phenotype, with a higher mean Hip Disability and Osteoarthritis Outcome Score Joint Replacement score of 95 in the primary progressive subtype, as opposed to 70 in the secondary progressive group [50]. MS patients demonstrated lower modified Harris Hip Score and Hip Disability and Osteoarthritis Outcome Score Joint Replacement hip function scores than control despite receiving increased physiotherapy care although this may be partly reflective of progression of their disease during the period of this study as demonstrated by worsening of mMSIS scores. Results from the included MS THA studies are displayed in [53] Figure 4.

Poliomyelitis

Poliomyelitis is an infectious viral disease caused by the polio enterovirus, in which loss and degradation of anterior horn cells in the lower motor neuron system leads to varying degrees of muscle wasting, hyporeflexia, and flaccid paralysis [54]. Hip joint instability and muscular imbalance, [55] particularly gluteus medius weakness, [56] may lead to subluxation and abnormal loading throughout hip development during childhood, with resultant bony dysplasia and painful degenerative hip arthritis [3]. Commonly associated leg length discrepancy [56–59] and soft-tissue envelope laxity pose additional challenges when seeking optimum tension intraoperatively [60].

The largest study was by DeDeugd et al. in the Mayo Clinic including 59 patients spread over 42 years [60]. They found an improvement in functional outcomes both in a polio-affected and unaffected limb. Their component revision rate at 6-year follow-up was 5.1%, with osteolysis (10.2%) and dislocation (5.1%) being the most commonly encountered complications. A further 8 retrospective case series with a total of 78 THAs also reported improved functional outcomes through a variety of scoring systems, [56–59,61–64] which are detailed in Figure 5.

Charcot hip

Charcot or neuropathic arthropathy occurs in patients with reduced sensory and nociceptive feedback in a joint susceptible to repetitive microtrauma, leading to progressive joint destruction and deformity [65]. Five studies met our inclusion criteria which reported upon THA outcomes in the neuropathic or "Charcot" hip population [65–69].

The largest of these was from Chalmers et al. in 2018 who described a case series of 12 THAs in 11 patients, with a range of underlying medical conditions, including Charcot-Marie-Tooth disease and diabetes mellitus [65]. They reported considerable improvements in pain and function, which correlated with a mean rise in HHS at 5-year follow-up, notwithstanding a high rate of complications, as seen in Figure 6.

Neurological assorted

Further studies reported experiences with THA in the setting of an assortment of other neurological conditions, such as stroke, traumatic brain injury, spinal cord injury, brain tumors, and spondylotic neuropathy. A number of these studies grouped multiple underlying conditions together. Although these studies did not

Author + Year	LOE	GRADE	Population	Number	Implant/Technique	Mean Age (Years)	Follow Up (Years)	Functional Outcome	Survivorship	Complications
Zhuang, T.F., et al. (2021) [61]	4	Low	The First Affiliated Hospital, Guangzhou, China. 2006-2016	17, (100%) on affected limb, Trauma	**Approach** Posterolateral **Implants** Uncemented	66.95	6.4	**Oxford (0-48)** Pre-op 32.9, Post-op 36.2. **UCLA (0-10)** Pre-op 4.96, Post-op 3.96.	Nil revision, Repeat Operation, 1 (5.9%) (Dislocation, Closed reduction)	**Dislocation**, 1 (5.9%), **Periprosthetic Fracture**, 1 (5.9%). Nil aseptic loosening/infection.
Sonekatsu, M., et al. (2018) [56]	4	Very Low	Saga University Hospital, Japan. 2001-2011.	6 (5 Patients). 2 (40%) on paralytic side, 4 (60%) on non-paralytic side. Previous surgery 6 (100%), (2 foot arthrodesis, 1 achilles tendon lengthening, 1 hip osteotomy and unspecified ankle surgery)	**Approach** Posterolateral **Implants** Uncemented	54.7 (49-63)	8.4 (4.5-15)	**Japanese Orthopaedic Association Hip Score (0-100)** Pre-op 42.8, Post-op 78.8	Nil revision	Nil Dislocation/loosening/infection/nerve palsy observed
DeDeugd, C. M., et al. (2018) [60]	4	Low	Mayo Clinic, Minnesota, USA. 1970-2012.	59 (51 Patients). 32 (54%) on polio affected limb, 27 (46%) on polio unaffected limb	**Approach** Anterolateral, 36 (61%); Posterolateral, 23 (39%). **Implants** Femoral Uncemented, 38 (64%) used in modern cases. Cemented, 21 (36%) used in older cases. Acetabular Uncemented, 58 (98%); Cemented, 1 (2%). Elevated or face changing acetabular lining used in 3 (5%)	66 (38-88)	6 (2-20)	**HHS (0-100)** Affected Side Pre-op 23, Post-op 81. Unaffected Side Pre-op 54, Post-op 80. **Hip Flexion** Affected Side Pre-op 73, Post-op 99. Unaffected Side Pre-op 89, Post-op 96. **Hip Abduction** Affected Side Pre-op 15, Post-op 21. Unaffected Side Pre-op 22, Post-op 28.	Component Revision 3 (5%), Osteolysis and Loosening 2 (3.4%). Trochanteric osteolysis, 1 (1.7%). Repeat Operations, 2 (3.4%) Periprosthetic Fracture, Open Reduction Internal Fixation.	**Osteolysis**, 6 (10.2%), 3 Revised, 3 Unrevised. **Dislocation**, 3 (5.1%). **Periprosthetic Fractures**, 2 (3.4%). Common peroneal nerve palsy 1 (1.7%). Superficial Wound Dehiscence, 1 (1.7%). Superficial Surgical Site Infection 1 (1.7%).
Sobrón, F. B., et al. (2017) [57]	4	Very Low	Hospital General Universitaio Gregario Maranon, Madrid, Spain. 2008-2012.	5, (100%) on polio affected limb	**Approach** Posterolateral 4 (80%) Trochanteric 1 (20%). **Implants** Uncemented 5 (100%). Dual Mobility Cup 2 (40%), Autologous Bone graft 2 (40%), Modular Femoral Stem 2 (40%).	47 (38-64)	4.6	**HHS (0-100)** Pre-op 30, 6 Months 75, 2 Year 81. **Limb Length Discrepancy (Median),** Pre-op 30mm, 3 Months 17mm.	Revision 1 (20%), Recurrent dislocation	**Periprosthetic Fracture**, 1 (20%) **Dislocation,** 1 (20%) Pseudoarthrosis, 1 (20%) – at site of greater trochanter osteotomy in trans-trochanteric approach.
Faldini, C., et al. (2017) [62]	4	Low/Very Low	Rizzoli Orthopaedic Institute Bageria, Palermo, Italy. 1999-2011.	14, Elective THA	**Approach** Direct Lateral. **Implants** Uncemented 13 (93%), Hybrid (Cemented Femoral and Uncemented Acetabular) 1 (7%).	51 (26-66)	7.7 (4.3-13)	**HHS (0-100)** Pre-op 52 (32-78), Post-op 83.3 (72-91).	**Implant Revision**, 2 (14.3%) Periprosthetic Fracture, 1 (7.1%), Aseptic loosening 1 (7.1%).	Transient Sensory Sciatic Nerve Palsy, 1 (7.1%) following limb lengthening of 34mm, **Aseptic Loosening**, 1 (7.1%), **Periprosthetic Fracture**, 1 (7.1%).
Cho, Y. J., et al. (2016) [58]	4	Very Low	Kyung Hee University, South Korea. 2004-2012.	11. 4 (36%) Polio affected side. 7 (64%) Polio unaffected side	**Approach** Posterior **Implants** Uncemented	57 (41-64)	6.7 (2.7-10.9)	**HHS (0-100)** Pre-op 52.5 (21-78), Post-op 85.8 (70-100) **UCLA (0-10)** Pre-op, 3.9 (2-7) Post-op 6.2 (4-10). **WOMAC Score (0-68)** Pre-op 52.4 (41-69), Post-op 12.5 (0-55).	Repeat operations, 1 (9%), Rotational osteotomy of ipsilateral femur due to in-toeing	**Dislocation,** 1 (9.1%). **Instability**, 1 (9.1%). Nil loosening/osteolysis/infection/periprosthetic fracture
Buttaro, M. et al (2016) [63]	4	Low	Italian Hospital of Buenos Aires, Argentina.	6, (100%) on polio affected limb, Elective THA. 2 () prior achilles tendon lengthening. 1 () prior pelvic and femoral osteotomy	**Approach** Posterolateral, 5 (83%); Transtrochanteric, 1 (17%). **Implants** Cemented 4 (67%), Hybrid 1 (17%), Uncemented 1 (17%).	51.3	10 (7-12)	**HHS (0-100)** Pre-op 67.6, Post-op 87.3. **VAS (0-10)** Pre-op 7.7, Post-op 2.	Revision 1 (17%), Dislocation/Instability	**Dislocation,** 1 (33%). Nil osteolysis/aseptic loosening/fracture/infection
Yoon, B. H., et al. (2014) [59]	4	Very Low	Seoul National University Bundang Hospital, South Korea. 2000-2009.	10. 4 (40%) on polio affected limb, 6 (60%) on polio unaffected limb. 5 (50%) prior achilles tendon lengthening. 3 (30%) prior foot arthrodesis.	**Approach** Posterolateral 9 (90%) Transgluteal Lateral 1 (10%) **Implants** Uncemented	48 (32-59)	7 (3.4-13)	**HHS (0-100)** Pre-op 70. Post-op 92. **Pain (0-10)** Pre-op 7. Post-op 0.9. **Limb Length Discrepancy** in cm Pre op 2.1 (0-4), Post 1.7 (0-4).	Nil reported	**Dislocation,** 1 (10%). Nil osteolysis/aseptic loosening/fracture/infection reported
Hosalkar, H. S., et al. (2010) [64]	4	Very Low	Rady Childrens Hospital, San Diego. USA. 1991-2005.	9 THA 8 Patients. Note study also included TKA.	**Approach** Posterior **Implants** Uncemented	66.5 (52-77)	Over 2 Years	**HHS (0-100)** Pre-op 94, Post-op 173. **Range of Motion** Flexion/Extension Pre-op 20-83. Post-op 0-110.	Nil Reported	Nil Dislocation observed.

Figure 5. Total hip arthroplasty in poliomyelitis results.

Author + Year	LOE	GRADE	Population	Number	Underlying Neurological	Implant/Technique	Mean Age (Years)	Follow Up (Years)	Functional Outcome	Survivorship	Complications
Inoue, D., et al. (2018) [66]	4	Very Low	Orthopaedic Department, Kanazawa University, Japan.	2	Congenital insensitivity to Pain	**Approach** Posterolateral **Implants** Uncemented	38	0.5	Functional improvement ambulation 1 (50%)	NA	Dislocation, 1 (50%)
Chalmers, B. P., et al. (2018) [65]	4	Low	Mayo Clinic, Minnesota, USA. 2007-2014.	12 (11 Patients)	Charcot-Marie-Tooth 3 (25%), T2DM 3 (25%), Spinal Cord Injury 2 (17%), Lysosomal storage disorder 1 (8%), Guillain-Barre 1 (8%), Head Injury 1 (8%), CVA 1 (8%).	**Approach** Anterolateral 9 (75%), Posterolateral 3 (25%). **Implants** Acetabular uncemented with adjuvant screw fixation. 2 (17%) Dual Mobility. Femoral Uncemented 11 (92%), Cemented 1 (8%).	54 (31-79)	5 (2-9)	**HHS (0-100)** Pre-op 43 (34-56), Post-op 81 (67-90). **Pain** Pre-op No pain nil, Mild pain 4 (33%), Moderate Pain 7 (58%), Severe pain 1 (8.3%). Post-op No Pain 9 (75%), Mild Pain 3 (25%). **Ambulation** Pre-op Wheelchair 5 (45%), Full time aid 6 (55%), Post-op Wheelchair 0, Full time aid 7 (64%), Aid for long distances 2 (18%), Unaided 2 (18%). Limb Length Discrepancy Pre-op 36.7mm, Post-op 6.7mm	Revision 4 (25%), Recurrent dislocation 2 (17%), Aseptic femoral loosening 1 (8%), Periprosthetic Fracture 1 (8%).	**Dislocation**, 3 (25%). **Periprosthetic Fracture**, 2 (17%). **Deep Prosthetic Joint Infection**, 2 (17%). Superficial Surgical Site Infection, 1 (8%).
Rapała, K. and M. Obrebski (2007) [67]	4	Very Low	Konarskiego Department of Orthopedics, Poland. 1994-1995	3 (2 patients)	Syphilis	**Implants** Cemented	NA	9.75 (9.5-10)	Improvement all	Revision 1 (33%), recurrent dislocation	Dislocation 2 (67%)

Figure 6. Total hip arthroplasty in Charcot joint results.

differentiate results by the underlying condition, the functional results were positive in each case.

The outcomes of THA on the affected hemiplegic limb following stroke were investigated by Henawy and Badie through a retrospective review of 24 patients in both the trauma and elective settings between 2013 and 2015 [68]. Following stroke, patients may experience upper motor neuron signs such as spasticity in the affected limb, posing similar challenges to that of CP, both intraoperatively and in the rehabilitation period. Excellent functional improvements were reported following arthroplasty, and they quantified this using the Harris and Merle d'Aubigne Hip Scores [68]. Studies by Wang et al., Ryu et al., Abdelazim and Michael, Alosh et al., and Park et al. also included patients with a history of stroke among their neurological THA groups, [69–75] which are detailed in Figure 7.

Discussion

Surgery setting

Often, arthroplasty surgeons operate on a limited number of patients with neurological conditions. A British joint registry–based study of 389 THAs for CP patients by King et al. found that only 23% of surgeons performed more than 1 THA procedure on a CP patient during the study period of 2003-2012 [15]. Across the arthroplasty field, it has been shown that a higher surgeon procedure volume is associated with lower dislocation and revision rates [76,77]. A study of nearly 38,000 Canadian patients found that surgeons who performed <35 THAs a year had a dislocation rate of 1.9% vs 1.3% for surgeons with greater volumes [77]. While patient and caregiver preference may favor a local hospital with accessible follow-up, it is worth considering that arthroplasty procedures in patients with neurological conditions should ideally be performed by specialists with sufficient case volume. In addition, given the increased perioperative care needs as detailed in the following section, centers with well-integrated multidisciplinary teams are preferable. This can create a virtuous circle of specialty knowledge, surgeon's and theatre staff's familiarity with novel components, and multidisciplinary expertise.

Perioperative care

Advance THA planning allows for medical optimization, surgical planning with possible lead in time for implant delivery, as well as patient and caregiver education. Multidisciplinary input from health-care professionals is crucial. Many patients with neurological conditions, such as PD, MS, and CP, receive regular disease-modifying medication. A perioperative neurological assessment can help optimize their regimen to minimize spasticity and tremor. Patients with spasticity may also benefit from botulinum toxin injection prior to THA [40,78]. Postoperatively, patients are at increased risk of medical complications such as delirium, respiratory tract infections, falls, and periprosthetic fractures, alongside an increased length of stay, [14,16,23,38] and dedicated medical care helps mitigate these risks [79].

Higher order 3-dimensional imaging, such as CT scans of the hip and pelvis, can be used for accurately framing bony dysplasia, [80] commonly encountered in neurological conditions associated with

Author + Year	LOE	GRADE	Population	Number	Underlying Neurological	Implant/Technique	Mean Age (Years)	Follow Up (Years)	Functional Outcome	Survivorship	Complications
Wang, Y. et al. (2021) [69]	4	Low	The 3rd Hospital of Hebei, China. 2014-2019	52, Trauma	CVA 37 (71%), Parkinsons Disease 6 (12%), Poliomyelitis 5 (10%), Epilepsy 2 (4%), Dementia 2 (4%)	**Approach** Posterolateral	71.1 (60-85)	3.5 Minimum	**HHS (0-100)** Post-op 82.3 **VAS (0-10)** Post-op 1.6	Revision 0. Reoperation 5 (10%), Periprosthetic Fracture 2 (4%) ORIF, Dislocation 3 (6%) Closed Reduction.	**Dislocation** 3 (6%), **Periprosthetic Fracture** 2 (4%), Heterotopic Ossification 21 (40%), Nil Loosening/Infection
Ryu, H.G. et al (2021) [70]	4	Low	Guro Hospital, Seoul, South Korea. 2013-2015	35, Trauma. Control 127	Unspecified, including Parkinson's Disease, Cerebral Palsy, Poliomyelitis, Hemiplegia, Paraplegia.	**Approach** Posterolateral 20 (57%), Anterolateral 15 (43%). **Implants** Uncemented Dual Mobility	77.6 Control 76.2	6.2 (5-7.3)	**HHS (0-100)** Post-op 81.3, Control 82.2. **UCLA (0-10)** Pre-op 4.6, Post-op 3.7 Control Pre-op 4.7, Post-op 4.1.	Revision unspecified. Reoperation 3 (8.6%), 2 dislocation, 1 superficial wound infection	**Dislocation** 2 (5.7%), Control 5 (3.9%). **Infection** 1 (2.9%) Loosening/Periprosthetic Fracture unspecified
Henawy, A. T., & Abdel Badie, A. (2017) [68]	4	Low	Suez Canal University Hospital, Egypt. 2013-2015.	24 (16 Trauma, 8 Elective).	CVA. Mean Time post CVA 30 months (6-67)	**Approach** Lateral transgluteal. **Implants** Acetabulum Uncemented Dual Mobility, all. Femoral Cemented, 18 (75%), Uncemented, 6 (25%).	68 (53-79)	Minimum 1 year Range 1-2	**Merle D'Aubigne (0-18)** Pre-op 8 (0-16), Post-op 17 (14-18). **HSS Hip Score (0-100)** Pre-op 36 (0-73), Post-op 94 (88-100).	Revision, 1 (4%) Prosthetic Joint Infection	DVT, 3 (12.5%). **Prosthetic Joint Infection**, 1 (4%). Dislocation, 0. **Osteolysis**, 4 (17%). Loosening, 0.
Blizzard, D. J., et al. (2016) [71]	4	Low	Multicentre Database, Medicare Standard Analytical Files. 2005 – 2011.	CSM 6021. CSM + D 1173. Control 707460.	Cervical spondylotic myelopathy with subgroup of CSM previously decompressed	NA	**<65** CSM (19%), CSM+D (20%), Control (9.5%). **65-69** CSM (30%), CSM+D, (34%), Control, (22%). **70-74** CSM (35%), CSM+D (41%), Control, (22%). **75-79** CSM (28%), CSM+D (28%), Control, (20%). **80-84** CSM (16%), CSM+D (14%), Control (15%). **>85** CSM (6%), CSM+D (3%), Control (1%).	Minimum 1 year	NA	**90 Day** CSM 200 (3.3%), CSM + D 47 (4%), Control 12125 (1.7%). **Overall** CSM 459 (7.6%), CSM + D 113 (9.6%), Control 31344 (4.4%).	**90 Day: Periprosthetic Infection** CSM 1.8%, CSM + D 2%, Control 1.1%. **Arthrotomy/I&D** CSM 1.5%, CSM + D 2.2%, Control 0.8%. **Dislocation** CSM 3.5%, CSM + D 3.1%, Control 1.5%. **Periprosthetic Fracture** CSM 1.4%, CSM + D 1.5%, Control 0.7%. **Wound Complication** CSM 2%, CSM + D 3.2%, Control 0.7%. **Overall Follow Up: Periprosthetic Infection** CSM 4.6%, CSM + D 6.6%, Control 2.5%. **Arthrotomy/I&D** CSM 3.1%, CSM + D 7.2%, Control 1.5%. **Dislocation** CSM 5.7%, CSM + D 6.1%, Control 2.8%. **Periprosthetic Fracture** CSM 2.8%, CSM + D 3.1%, Control 1.6%. **Wound Complication** CSM 4.9%, CSM + D 7.5%, Control 2.2%.
Abdelazim, H. and F. Michael (2015) [72]	4	Low	Ain Shams University, Egypt. 2012-2014.	30 (12 Trauma, 18 Revision)	CVA 14 (47%), Parkinsons Disease 6 (20%), Poliomyelitis 6 (20%), Brain Tumor 2 (7%), MS 2 (7%).	**Approach** Modified lateral. **Implants** Acetabulum Cemented Dual Mobility. Femoral Unspecified	64.6 (48 – 79)	1.1	Functional Evaluation Follow up results Excellent 7 (23%), Good 12 (40%); Fair, 6 (20%); Poor, 4 (13%)	Mortality, 1 - CVA 6 months post op. Nil implant revision reported	Nil Dislocation/Prosthetic Joint Infection
Li, J., et al. (2014) [73]	4	Low	Changhai Hospital, China. 2007 – 2009.	12, Trauma	Parkinsons Disease 8 (67%), Poliomyelitis 4 (33%).	**Approach** Posterolateral **Implants** Uncemented Large Diameter Metal on Metal.	65.7 (56-76)	5 (3.6-6)	**HHS (0-100)** Pre-op 10.1, Post-op 76.4. **UCLA (0-10)** Pre-op 2.3, Post-op 6.7.	Nil Revision	Nil Dislocation/Infection/Fracture/Nerve Injury/DVT/loosening observed Heterotopic Ossification, 1 (8.3%)
Alosh, H., et al. (2014) [74]	4	Low	University of Pennsylvania USA. 1993-2011.	30 THA 27 Patients	Cerebral Palsy 12 (40%), Traumatic Brain Injury 9 (30%), CVA 3 (10%), MS 2 (7%), Spinal Cord Injury 1 (3%).	**Approach** Posterolateral. **Implants** Acetabular Uncemented, Constrained liner 2 (7%), Augmentation 2 (7%). Femoral Uncemented, with modular components 3 (10%). **Concomitant procedure**, Adductor Tenotomy 11 (37%) (7 CP, 4 Other), Iliopsoas lengthening 6 (20%); Achilles tendon lengthening 6 (20%) (5 CP, 1 Other); Heterotopic ossification excision 7 (23%) (1 CP, 6 Other)	48.6 (SD 12.2)	2.5 (2.1-12.1)	**Pain Score** (Minimal 1-2, Mild 3-7, Severe 8-10) Pre-op Severe 30 (100%). Post-op 28pt. Minimal 14 (50%), Mild 11 (39%), Severe 3 (11%). **HHS (0-100)** Pre-op 15 (5-35), Post-op 67 (24-91).	Implant Revision 1, (3.3%) Resection Arthroplasty due to Deep Infection	Nil Dislocation reported. **Periprosthetic Fracture**, 1 (3%). **Infection**, 4 (13%) - Deep 1, superficial 3
Park, K.S. et al (2014) [75]	4	Low	Chonnam National University Hwasun Hospital, South Korea. 2008-2010.	19, Trauma	CVA, 15 (79%) (11 Infarction, 4 Haemorrhage), Parkinsons Disease, 4 (21%).	**Approach** Modified Minimally Invasive 2 Incision. **Implants** Uncemented. Large Diameter head >38mm, metal on metal **Concomitant procedure** Adductor tenotomy 4 (22%), Prophylactic femoral cabling 6 (32%).	72.6	1.4	Latest Follow Up. **HHS (0-100)** 41.5, **WOMAC (0-68)** 42.9.	Nil Implant Revision	Dislocation/Infection /Periprosthetic Fracture – Nil

Figure 7. Total hip arthroplasty in assorted neurological conditions results.

hip dysplasia, or in cases where there is concern for acetabular bone loss [81]. CT scanning may also be required if surgeons plan to use image-based navigation or robotic systems, which may be helpful in aiding accurate implant positioning in particularly challenging cases [82].

Physiotherapists can develop an individualized prehabilitation program tailored to the patient's capabilities. Advance occupational therapy assessment can anticipate assistive supports or ambulatory devices and address potential barriers to discharge from hospital, particularly for patients who experience concomitant upper-extremity spasticity and deformity [75]. Preoperative patient education regarding muscle rehabilitation and hip movement restrictions has also been shown in other arthroplasty settings to reduce the risk of dislocations [83]. Specialized postoperative physiotherapy can aid a challenging rehabilitation process, [84] with points of focus including maintenance of hip precautions, achieving a stable gait pattern, and maximizing neuromuscular control [75].

Operative considerations

The most common complication observed in our review was dislocation, and reducing its risk is a major focus of operative planning in patients with neurological conditions. Other complications such as infection were also observed at an increased rate within the neurological population, and standard measures to mitigate them, such as medical optimization, antibiotic prophylaxis, operating environment, and meticulous asepsis, are advised [85].

An uncemented prosthesis were favored in 69% of studies throughout our review. In those patients with particularly high risk of dislocation, such as severe Gross Motor Function Classification System level V CP, advanced PD, and poliomyelitis, implant designs such as dual-mobility (DM) implants and acetabular liners, with additional levels of constraint, were utilized. DM implants have a broad application in high-risk revision surgeries and are increasing in popularity. Neurological conditions in which DM implants have been used successfully over the last 10 years include PD, [32] CP, [40,41,43] polio, [57] Charcot arthropathy of the hip, and stroke [65,69,70,72]. The modular design of DM cups also allows for screw placement for additional cup fixation in cases of significant bone loss, which has been reported as a challenge when performing THA for patients with neurological conditions [45,65]. Lazennec et al. utilized DM components in their study of 63 PD THA cases, of whom 33% were undergoing revision arthroplasty and reported a single dislocation episode (1.6%) at a mean 8.3 years of follow-up [32]. Dislocation events observed in the setting of DM constructs cite the use of smaller outer polyethylene insert diameter (<38 mm), which corresponds to a smaller inner head size and cup malposition [86]. Morin et al. also reported a low dislocation rate of 2.5% in their group of 40 high Gross Motor Function Classification System grade 5 cerebral palsy THAs; however, this event was associated with an intraprosthetic dissociation requiring operative revision [41]. Intraprosthetic dissociation requiring operative reduction was also reported by Ryu et al. in their study of 35 patients affected by neurological conditions [70].

Constrained acetabular liners were used in limited numbers throughout the studies [33,40,56,60,75]. Such liners may be beneficial in reducing dislocation by containing the femoral head beyond its equator, thus preventing the head from dislocating out of socket. However, concerns arise regarding the significant reduction in primary arc range when constrained liners are utilized, which may paradoxically increase the risk of instability, and there is a high failure rate with poor initial placement, through liner dissociation, component loosening, and recurrent dislocations [87]. A simpler measure, widely adopted throughout the reviewed studies, is to use femoral heads with a larger diameter of greater than 36 mm, which increases the head-neck ratio, while also increasing the primary arc range prior to an impingement event, which could result in a dislocation [88]. Favorable results have been shown in large joint registry studies and have been adopted for neurological patients undergoing THA [45,89].

Surgical approach

There is no clear consensus regarding the optimal surgical approach, and thus, further research in this area would be of benefit. Of the included studies that detailed their surgical approach, the posterior approach was favored most in 14 of the 25 studies, highlighting the necessity to achieve a robust soft-tissue repair to minimize dislocation risk [90]. Achieving a robust envelop is difficult due to the degree of soft-tissue laxity in common neurological conditions, and for this reason, surgeons made use of additional combined anteversion and extended postoperative restrictions such as abduction braces and knee immobilizers, while hip spica casts were prevalent in the past [40,45].

Limitations

There are a number of limitations regarding the findings of this review. Bias may have been introduced in the reporting of complications by virtue of the retrospective nature of included studies which are heterogenic by nature. Our initial search found a number of studies from the same institution with overlapping patient groups, whereby the series of the largest cohort was selected for inclusion. The statistical analysis for subgroups was limited due to discrepancies in reporting of results among the included studies.

Conclusion

THA reliably improves symptoms of painful hip arthritis for patients with neurological conditions affecting the hip. It is important for surgeons, patients, and caregivers to be aware of the increased risk of associated complications, most notably dislocation with specific risk data presented herein, before proceeding with surgery. As a technically challenging operation, it should be undertaken by experienced arthroplasty surgeons allowing for familiarity with novel techniques and implants, with sufficient multidisciplinary support to meet their perioperative care requirements.

Conflicts of interest

The authors declare there are no conflicts of interest.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2022.11.001.

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Medline/PubMed search strategy.

#1 THR population	"Total hip arthroplasty" OR THA OR "total hip replacement" OR THR OR "arthroplasty, replacement, Hip"[Mesh]
#2 Neurological Population	"cerebral palsy" OR "spina bifida" OR myelomeningocele OR poliomyelitis OR "Parkinson disease" OR "multiple sclerosis" OR stroke OR CVA OR "acquired brain injury" OR Charcot OR "neuropathic arthropathy" OR "neuromuscular disease" OR "spinal injury" OR "paralytic hip" OR "Cerebral Palsy"[Mesh] OR "Spinal Dysraphism"[Mesh] OR "Meningomyelocele"[Mesh] OR "poliomyelitis"[Mesh] OR "Parkinson Disease"[Mesh] OR "Multiple Sclerosis"[Mesh] OR "Stroke"[Mesh] OR "Brain Injuries"[Mesh] OR "Arthropathy, Neurogenic"[Mesh] OR "Neuromuscular Diseases"[Mesh] OR "Spinal Injuries"[Mesh]
#3 Outcome	outcome OR "clinical outcome" OR "patient outcome" OR revision OR mortality OR death OR infection OR complication OR dislocation OR "patient reported outcome measure" OR PROM OR "Treatment Outcome"[Mesh] OR "Patient Reported Outcome Measures"[Mesh] OR "Reoperation"[Mesh] OR "Mortality"[Mesh] OR "Death"[Mesh] OR "Infections"[Mesh] OR "Intraoperative Complications"[Mesh] OR "Postoperative Complications"[Mesh] OR "Joint Dislocations"[Mesh]

Cochrane library search strategy

#1 THR population	"Total hip arthroplasty" OR THA OR "total hip replacement" OR THR OR MeSH descriptor: [Arthroplasty, replacement, hip] explode all trees
#2 Neurological Population	"cerebral palsy" OR "spina bifida" OR myelomeningocele OR poliomyelitis OR "Parkinson disease" OR "multiple sclerosis" OR stroke OR CVA OR "acquired brain injury" OR Charcot OR "neuropathic arthropathy" OR "neuromuscular disease" OR "spinal injury" OR "paralytic hip" OR MeSH descriptor: [Cerebral Palsy] explode all trees OR MeSH descriptor: [Spinal Dysraphism] explode all trees OR MeSH descriptor: [Meningomyelocele] explode all trees OR MeSH descriptor: [Poliomyelitis] explode all trees OR MeSH descriptor: [Parkinson Disease] explode all trees OR MeSH descriptor: [Multiple Sclerosis] explode all trees OR MeSH descriptor: [Stroke] explode all trees OR MeSH descriptor: [Arthropathy, Neurogenic] explode all trees OR MeSH descriptor: [Neuromuscular Disease] explode all trees OR MeSH descriptor: [Spinal Injuries] explode all trees
#3 Outcome	outcome OR "clinical outcome" OR "patient outcome" OR revision OR mortality OR death OR infection OR complication OR dislocation OR "patient reported outcome measure" OR PROM OR MeSH descriptor: [Patient Outcome Assessment] explode all trees OR MeSH descriptor: [Reoperation] explode all trees OR MeSH descriptor: [Mortality] explode all trees OR MeSH descriptor: [Death] explode all trees OR MeSH descriptor: [Infections] explode all trees OR MeSH descriptor: [Intraoperative Complications] explode all trees OR MeSH descriptor: [Postoperative Complications] explode all trees OR MeSH descriptor: [Hip Dislocation] explode all trees

Embase search strategy

#1 THR population	"Total hip arthroplasty" OR THA OR "total hip replacement" OR THR OR ′total hip replacement'/exp
#2 Neurological Population	"cerebral palsy" OR "spina bifida" OR myelomeningocele OR poliomyelitis OR "Parkinson disease" OR "multiple sclerosis" OR stroke OR CVA OR "acquired brain injury" OR Charcot OR "neuropathic arthropathy" OR "neuromuscular disease" OR "spinal injury" OR "paralytic hip" OR ′cerebral palsy'/exp OR ′spinal dysraphism'/exp OR 'meningomyelocele'/exp OR 'poliomyelitis'/exp OR ′Parkinson disease'/exp OR ′multiple sclerosis'/exp OR ′cerebrovascular accident'/exp OR ′acquired brain injury'/exp OR ′neuropathic joint disease'/exp OR ′neuromuscular disease'/exp OR ′spine injury'/exp
#3 Outcome	outcome OR "clinical outcome" OR "patient outcome" OR revision OR mortality OR death OR infection OR complication OR dislocation OR "patient reported outcome measure" OR PROM OR ′treatment outcome'/exp OR ′clinical outcome'/exp OR ′revision arthroplasty'/exp OR 'mortality'/exp OR 'death'/exp OR 'infection'/exp OR ′postoperative complication'/exp OR ′perioperative complication'/exp OR ′hip dislocation'/exp