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Outcomes and complications of patients undergoing Salter's innominate osteotomies for hip dysplasia: a systematic review of comparative studies

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ABSTRACT

The purpose of this systematic review is to assess outcomes and complications of patients undergoing Salter's innominate osteotomies (SIOs) for the correction of hip dysplasia along with patient and technical factors that can be optimized to improve outcomes after SIO. MEDLINE and EMBASE were searched from data inception to 9 October 2018. Data were presented descriptively. Twenty-seven studies were identified including 1818 hips (87.1%) treated with SIO (mean age of 2.1 ± 2.5 years and mean follow-up of 3.5 ± 5.0 years). Patients undergoing SIO had a post-operative center-edge angle (CEA) of $31.3° \pm 5.3°$ and an acetabular index (AI) angle of $16.1° \pm 5.2°$. Patients undergoing SIO with pre-operative traction had significantly lower ($P = 0.049$) post-operative McKay criteria scores compared to patients without pre-operative traction. Patients undergoing SIO between the ages of 1.5–2 years had significantly better ($P < 0.05$) post-operative McKay criteria scores compared to patients aged 4–6 years. The complication rate was 9.4% with avascular necrosis (2.5%) being most common. This review found that SIO for developmental dysplasia of the hip produces generally good post-operative clinical outcomes. The CEA and AI can be corrected to normal range after SIO. Patients may have superior outcomes if they have SIO at a younger age, were not treated with pre-operative traction and did not have untreated contralateral hip dysplasia. Outcomes appear to be similar between one-stage bilateral SIO and a two-stage procedure in the setting of bilateral hip dysplasia; however, more multicentered studies are needed to confirm these results.

INTRODUCTION

Developmental dysplasia of the hip (DDH) is a disorder, which can lead to various abnormalities in the growing hip, either in the femoral head and acetabulum, as well as laxity to the surrounding ligaments [1]. Studies have reported that the incidence of DDH ranges from as low as 1/1000 patients to as high as 34/1000 patients [2]. There are many associated risk factors that can pre-dispose individuals to DDH including; female sex, primiparity, breech position or a family history DDH [3].

Surgical and non-surgical options are available to treat DDH. Abduction devices are generally the preferred initial non-surgical treatment, with the Pavlik harness being the most common under the age of 6 months [4]. For older individuals with severe DDH surgical interventions are often required and include the Dega Osteotomy, Pemberton Osteotomy and Salter innominate osteotomy (SIO) [4]. The treatment for DDH is age dependent with the overall goal being to achieve and maintain concentric reduction of the femoral head in the acetabulum [5, 6].

The principle of SIO is to redirect the entire acetabulum in a way that the reduced hip is made stable in a functional position of weight bearing. During SIO, an osteotomy is performed from the greater sciatic notch to

the anterior inferior iliac spine [7]. The distal fragment can then be rotated inferolaterally, in part due to the flexibility of the symphysis pubis [7]. The distal fragment is rotated between the symphysis pubis and the greater sciatic notch [7]. The acetabulum is then able to be re-orientated as it is extended and adducted. The osteotomy site can then be held open using a bone graft.

The purpose of this systematic review is to assess the outcomes and complications of patients undergoing SIO for the correction of hip dysplasia as well as to determine the patient and technical factors that can be optimized to improve outcomes after SIO. It is hypothesized that the use of SIO for the treatment of DDH will produce favorable clinical outcomes and minimize complication rates. Furthermore, factors such as age and contralateral hip dysplasia will impact outcomes following SIO.

MATERIALS AND METHODS

Search strategy

EMBASE and MEDLINE (including Epub Ahead of Print) were searched for literature on SIO from data inception to 9 October 2018. The search terms included 'Salter's osteotomy', 'hip dysplasia' and similar phrases (Supplementary Table SI). The search terms were entered onto Google Scholar, to ensure that relevant articles were not missed. The research question and inclusion and exclusion criteria were established *a priori*. Inclusion criteria were: (i) patients treated with SIO; (ii) levels I–III evidence (i.e. comparative studies); (iii) human studies; (iv) English language; and (v) studies reporting at minimum one radiographic or clinical outcome. Exclusion criteria included: (i) review articles; (ii) non-surgical treatment studies (e.g. conservative treatment, technique articles without outcomes, etc.); (iii) case reports; and (iv) cadaver/non-human studies.

Study screening

A systematic screening approach in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) [8] and Revised Assessment of Multiple Systematic Reviews (R-AMSTAR) [9] were employed from title to full-text screening stages in duplicate by two independent reviewers. Discrepancies were discussed and resolved with input by a third reviewer. The references of included studies were also screened to capture any additional relevant articles.

Quality assessment

Using the Journal of Bone & Joint Surgery (JBJS) classification system for literature in the field of orthopedics, the level of evidence (I to IV) for each study was determined by the two reviewers independently and in duplicate [10]. The methodological quality of non-randomized comparative studies were evaluated using the methodological index for non-randomized studies (MINORS) [11]. A score of 0, 1 or 2 is given for each of the 12 items on the MINORS checklist with a maximum score of 24 for comparative studies. Methodological quality was categorized *a priori* as follows: a score of 0–12 was considered poor quality, 13–18 was considered fair quality and 19–24 was considered excellent quality for comparative studies.

Data abstraction

Two reviewers independently extracted relevant data from included articles and recorded the data onto a Google Spreadsheet designed *a priori*. Demographic data included author, year of publication, sample size, study design and location, level of evidence and patient demographics (e.g. gender, age, etc.). Information on post-operative outcomes (clinical and radiographic) including complications was documented.

Statistical analysis

Due to high statistical and methodological heterogeneity, a meta-analysis could not be performed, and the results are summarized descriptively. Descriptive statistics such as mean, range and measures of variance [e.g. standard deviations, 95% confidence interval (CI)] are presented where applicable. The intraclass correlation coefficient (ICC) was used to evaluate inter-reviewer agreement for the MINORS score. A kappa (κ) statistic was used to evaluate inter-reviewer agreement at all screening stages. Agreement was categorized *a priori* as follows: ICC/κ of 0.81–0.99 was considered as almost perfect agreement; ICC/κ of 0.61–0.80 was substantial agreement; ICC/κ of 0.41–0.60 was moderate agreement; 0.21–0.40 fair agreement and an ICC/κ value of 0.20 or less was considered slight agreement.

RESULTS

Study characteristics

The initial search yielded a total of 2968 articles. After excluding 745 duplicates, a systematic screening process yielded 27 articles that met inclusion (Fig. 1). No additional studies were found upon reviewing references of included studies or a manual search through Google Scholar. A total of 22 retrospective cohorts and 5 prospective cohorts were identified. The included studies were primarily conducted in Turkey ($n = 11$, 40.7%), Taiwan ($n = 4$, 14.8%), Japan ($n = 2$, 7.4%), Mexico ($n = 2$, 7.4%), UK ($n = 2$, 7.4%),
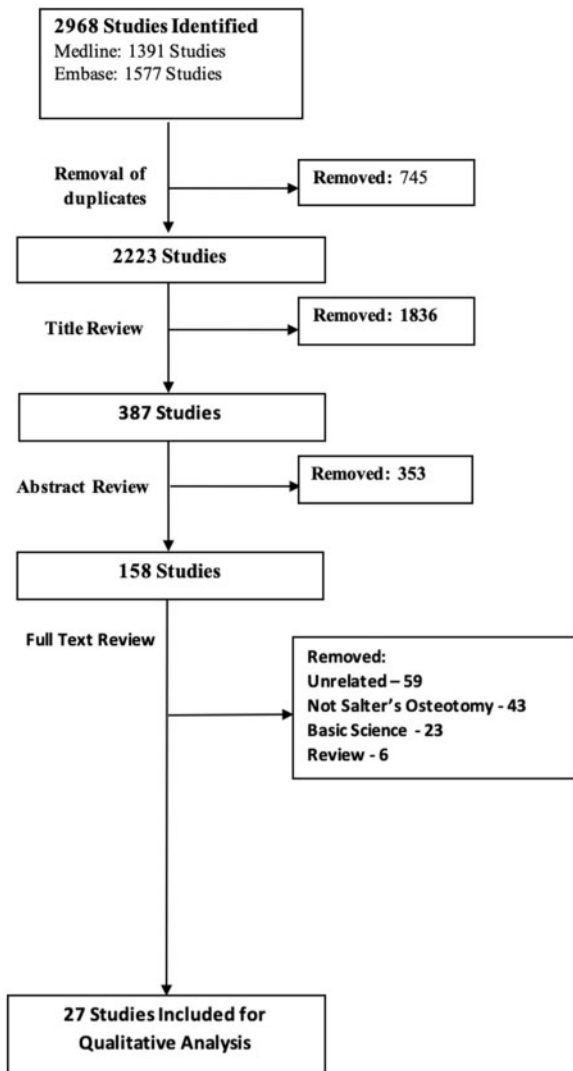
Fig. 1. PRISMA flow diagram.

Canada (*n* = 2, 7.4%), USA (*n* = 1, 3.7%), Iran (*n* = 1, 3.7%), Germany (*n* = 1, 3.7%), France (*n* = 1, 3.7%), China (*n* = 1, 3.7%) and Belgium (*n* = 1, 3.7%) (Table I).

Study quality
The majority of included were Level III evidence (81.5%; *n* = 22). There was substantial agreement amongst reviewers at the title [$\kappa = 0.732$ (95% CI 0.691–0.773)], abstract [$\kappa = 0.804$ (95% CI 0.743–0.866)] and full-text [$\kappa = 0.819$ (95% CI 0.732–0.906)] screening stages.

The mean MINORS score across all comparative studies was 16.3 ± 1.2 indicating fair quality of evidence for comparative studies. Overall, 21/27 (77.7%) had a clearly stated aim and each study (100%; *n* = 27) had endpoints appropriate to the aim of the study. All studies (100%;

n = 27) had appropriate follow-up periods. However, none of the studies had appropriate calculation of study size. There was near-perfect agreement amongst the reviewers for the quality assessment using the MINORS criteria (ICC = 0.922; 95% CI 0.828–0.964) (Table I).

Patient characteristics and surgical techniques
There were 1818 hips treated with SIO with a mean age of 2.1 ± 2.5 years and a mean follow-up of 3.5 ± 5.0 years. Among the treated population, of those who reported sex distribution, 12.4% (139/1118) were male.

Post-operative clinical and radiographic outcomes
A number of different clinical outcomes were used to measure the patient's functional status after SIO including the Harris Hip Score, SF-36, Sutherland pain scale and McKay criteria. The overall functional outcome scores reported after SIO were positive and are summarized in Table II.

The main radiographic outcomes that were reported throughout the studies included acetabular index (AI) angles and center-edge angle (CEA). The post-operative AI amongst individuals undergoing SIO was $16.1° \pm 5.2°$. This study found the average post-operative CEA following SIO to be $31.3° \pm 5.3°$.

SIO amongst different age groups
One study (*n* = 67) compared patients undergoing the SIO in different age groups [14]. Those aged between 1.5 and 2 years (*n* = 12) had significantly better ($P < 0.05$) post-operative McKay criteria scores compared to patients aged between 4 and 6 years (*n* = 11) at a mean follow-up of 4.00 ± 0.43 (range 3–6.8) years [14]. The McKay score assesses the patient's pain, range of motion of the affected and contralateral hips, instability, limp and Trendelenburg sign [38].

Another study (*n* = 21, 27 hips) found that rates of satisfactory results based on Severin grading were significantly higher in children treated with SIO under the age of 8 (*n* = 15, 18 hips) compared to children over the age of 8 (*n* = 6, 9 hips). However, there was no significant difference in the McKay score between the two groups [17].

Lastly, one study (*n* = 70) compared McKay scores between groups of patients who underwent SIO before (*n* = 38) and after the age of 3 (*n* = 32) and found no significant difference between the two groups [30].

Other comparisons
One study compared patients with frank dislocations of their hip secondary to hip dysplasia at age 13–17 months (*n* = 48; 49 hips), treated either with open reduction and

Table I. Study characteristics

Author	Location	Study design	Primary intervention	Sample size (hips)	% male	Consensus MINORS score
Wang *et al.* (2016) [12]	Taiwan	Retrospective Cohort (III)	SIO	14	0	16
Castañeda *et al.* (2016) [13]	Mexico	Retrospective Cohort (III)	SIO	108	NR	17
Chen *et al.* (2015) [14]	China	Retrospective Cohort (III)	Open reduction, SIO, femoral shortening, and derotational osteotomy	20 (group 1), 12 (group 2), 35 (group 3)	18.9—not stratified by group	16
Kaneko *et al.* (2014) [15]	Japan	Retrospective Cohort (III)	SIO, Pavlik Harness (<6 years), Gradual Reduction and Overhead Traction (>6)	22 (Normal CEA >20°), 17 (Borderline CEA, 20–25°), 7 (Dysplastic CEA, <20°)	6.5—not stratified by CEA	15
Wang *et al.* (2013) [16]	Taiwan	Retrospective Cohort (III)	SIO	14	0	16
Yagmurlu *et al.* (2013) [17]	Turkey	Retrospective Cohort (II)	SIO	17 (<8 years); 4 (>8 years)	7.1 (<8 years); 33.3 (>8 years)	16
Ertürk *et al.* (2013) [18]	Turkey	Retrospective Cohort (III)	SIO	47	21.2	15
Yildiz *et al* (2012) [19]	Turkey	Retrospective Cohort (III)	SIO, Pemberton Acetabuloplasty	63 (Concurrent); 55 (Consecutive)	9.5 (Concurrent); 10 (Consecutive)	15
Ertürk *et al.* (2011) [20]	Turkey	Retrospective Cohort (III)	SIO	24 (<3 years); 25 (≥3 years)	6.1—not stratified	18
Barnes *et al.* (2011) [21]	Canada and UK	Prospective Cohort (II)	Open reduction, Capsulorraphy and SIO	26	NR	17
López-Carreño *et al.* (2008) [22]	Mexico	Retrospective Cohort (III)	SIO	56	8.6—not stratified	15
Tukenmez and Tezeren (2007) [23]	Turkey	Retrospective Cohort (III)	SIO, Open Reduction	46 (<3 years); 33 (>3 years)	13.1—not stratified	15
Tezeren *et al.* (2005) [24]	Turkey	Retrospective Cohort (III)	SIO, Open Reduction (Group 1); SIO, Open Reduction, Femoral Shortening (Group 2)	16 (Group 1); 13 (Group 2)	14.2 (Group 1); 10 (Group 2)	16

(**continued**)

Table I. (continued)

Author	Location	Study design	Primary intervention	Sample size (hips)	% male	Consensus MINORS score
Macnicol and Bertol (2005) [25]	UK	Retrospective Cohort (III)	SIO, Open Reduction (Concurrent); SIO, Open Reduction (Consecutive)	125 (Concurrent), 63 (Consecutive)	11.6—not stratified	16
Keskin et al. (2003) [26]	Turkey	Retrospective Cohort (III)	SIO, Open Reduction	30 (<30 months), 30 (>30 months)	13.3—not stratified by group	16
Dora et al. (2002) [27]	France	Retrospective Cohort (III)	SIO	85	11.0—not stratified	15
Mellerowicz et al. (1995) [28]	Germany	Retrospective Cohort (III)	SIO, Open Reduction, Derotation Varisation Osteotomy	52	10.5	16
Barrett et al. (1986) [29]	USA	Retrospective Cohort (III)	SIO, Open Reduction (Group 1); SIO, Open Reduction, Femoral Shortening Varus Osteotomy (Group 2)	15 (Group 1), 8 (Group 2)	NR	16
Baghdadi et al. (2017) [30]	Iran	Retrospective Cohort (III)	SIO, Femoral Shortening	50 (<3 years)	10.5	15
Bayhan et al. (2016) [31]	Turkey	Retrospective Cohort (III)	SIO	25	15	17
Agus et al. (2014) [32]	Turkey	Prospective Cohort (III)	SIO, Open Reduction, Derotation Varisation Osteotomy	14	10.7	20
Ezirmik and Yildiz (2012) [33]	Turkey	Retrospective Cohort (III)	SIO	30	NR	16
Lin et al. (2000) [34]	Taiwan	Prospective Cohort (III)	SIO	53	NR	18
Tezeren et al. (2000) [24]	Turkey	Prospective Cohort (III)	SIO	28	19	
Spence et al. (2009) [35]	Canada	Retrospective Cohort (III)	SIO	47	10	18
Rossillon et al. (1999) [36]	Belgium	Retrospective Cohort (III)	SIO	21	NR	16
Huang and Wang (1997) [37]	Taiwan	Retrospective Cohort (III)	SIO, Open Reduction	32	3	16

Table II. Post-operative clinical outcomes for patients undergoing Salter's innominate osteotomy

Primary author, Year	Post-operative clinical outcomes
Wang, 2016 [12]	Harris Hip Score: 99 (97.77–99.94)
	SF-36: 83 (76.54–89.03)
	SF-36 Physical: 82 (75.81–88.34)
	SF-36 Mental: 78 (70.39–85.32)
Wang, 2013 [16]	Symptoms (pain, soreness, discomfort of surgically treated hip): 1
	Harris hip score: 99 (97.77–99.94)
	SF-36: 83 (76.54–89.03)
	SF-36 (physical): 82 (75.81–88.34)
	SF-36 (mental):78 (70.39–85.32)
	Kalamchi classification: 3 Grade 1, 7 Grade 2, 4 Grade 3
Yildiz, 2012 [19]	Sutherland pain scale: 92.7% no pain. 90.9% grade 1 (stable, no pain, no limp, negative Trendelenburg test, full ROM)
	Trendelenburg test: 2 (3.2%) positive
López-Carreño, 2008 [22]	37% had a slight limitation in the hip joint
	45% had a limp
Mellerowicz, 1995 [28]	Unimpeded gait: 71.1%
	Negative Trendelenburg: 69.2%
	Normal ROM: 50%
	Slightly impeded movement: 48.1%
	Free of pain: 77%
	Weather-dependent pain: 4%
	Occasional weight-bearing pain: 13%
	Continual weight-bearing pain: 6%
	Patient complaints: 92.5%
	Score results: 57% very good, 27% good, 14% average, 2% poor
Bayhan, 2016 [31]	McKay criteria: 22 (88%) excellent/good
Lin, 2000 [34]	McKay criteria: 45 (85%) excellent, 8 (15%) good

SIO ($n = 32$) or non-operatively with closed reduction and casting ($n = 16$; 17 hips) [37]. The non-operative group was found to have higher rates of avascular necrosis (AVN) (23.5% versus 6.2%, $P < 0.05$) and poorer Severin class ($P < 0.0001$). Post-operative data pertaining to AI and CEA were not provided in the non-operative group. In the open reduction and Salter osteotomy group, the AI pre-operatively and post-operatively were 38° and 13°, respectively. The average CEA at final follow-up in this group was 35° [37]. Ten of the 16 patients (62.5%) treated non-operatively had converted to the operative group by final follow-up. The Severin's criteria is used to

assess the radiographic results of surgeries performed for treating congenital dislocation of the hip [39].

One study ($n = 21$; 28 hips) found that patients undergoing SIO with pre-operative traction ($n = 9$; 12 hips) had significantly lower ($P = 0.049$) post-operative McKay criteria scores compared to patients undergoing SIO with no pre-operative traction ($n = 12$; 16 hips) [24].

One study ($n = 28$), compared patients undergoing bilateral SIO for bilateral hip dysplasia ($n = 14$) and a second group undergoing unilateral SIO for unilateral hip dysplasia ($n = 14$). It was found that both groups had significant post-operative improvements ($P < 0.01$) in the McKay criteria scores; however, no differences were found between the groups [32].

Three studies ($n = 208, 285$) compared McKay scores in patients who underwent SIO with concurrent open reduction ($n = 133, 183$ hips) versus those who were treated with a staged open reduction followed by SIO ($n = 75$, 102 hips). None of the three studies found any significant difference in McKay scores between the two groups [25, 29, 40].

When comparing patients who had SIO performed for a dysplastic hip, patients with contralateral untreated borderline hip dysplasia (CEA = 20–25°) or hip dysplasia (CEA < 20°) had significantly lower ($P < 0.001$) post-operative Severin's criteria scores at skeletal maturity [15].

One study ($n = 67$ hips) found patients undergoing an SIO ($n = 26$ hips) had no significant difference in anterior coverage, posterior coverage or estimated acetabular version compared to both their contralateral, non-dysplastic hip ($n = 20$ hips) and age- and sex-matched controls with 'normal hips' ($n = 21$) at final follow-up. However, those undergoing an SIO had a significantly lower ($P < 0.001$) contact area in the operated hip compared to the match controlled 'normal hips' [21].

Complications

The overall complication rate in this systematic review for patients undergoing SIO was 9.4% ($n = 179$) comprising mainly of avascular necrosis ($n = 45$; 2.5%), minor epiphyseal changes ($n = 39$; 2.1%), minor growth plate changes ($n = 30$; 1.7%), resubluxation ($n = 16$; 0.9%), redislocation ($n = 12$; 0.7%), superficial infection ($n = 6$; 0.3%) and revision surgery ($n = 6$; 0.3%).

DISCUSSION

Key findings

The main finding of this study was that patients undergoing SIO showed on average a post-operative CEA of 31.4° and AI of 16.1 [22, 33]. Overall, the clinical outcomes that were reported in patients treated with SIO were positive across several functional outcome scores. The complication rate for SIO in this systematic review was 9.4%, with AVN being the most common complication experienced by patients.

For children under the age of 15, a CEA of less than 20° is generally considered to be abnormal, while CEA of between 20° and 25° are often considered to be borderline dysplastic [15]. In this systematic review, we found that the average CEA value (31.3° ± 5.3°) of patients who underwent an SIO fell within the normal range post-operatively. The AI measurement is used to evaluate the sufficiency of femoral head coverage. Normally, the AI should be less than 28° at birth and should become progressively shallower with age. This study found that hips undergoing SIO had a post-operative AI of 16.1° ± 5.2° and therefore AI were on average also restored to within a normal range.

Although this systematic review found that patients with dysplastic hips treated with SIO had generally positive clinical outcome scores and correction of their CEA and AI into the normal ranges, it does not necessarily mean that an SIO is the ideal treatment in all cases of hip dysplasia. Alternative osteotomies such as the Pemberton, Dega or Ganz osteotomies may be preferable to SIO depending on the patient's age, severity of dysplasia, patient's medical history (e.g. cerebral palsy) and the surgeon's comfortability with each procedure. Generally, there are a number of indications for the use of SIO in DDH. This includes concentric reduction of the femoral head in the acetabulum, good range of motion, having reasonable congruent relationship between the femoral head and the acetabulum and being within the age group of 1.5–6 years old [41]. An AI greater than 30° or a CEA less than 5° are additional indications for SIO [42]. Typically, SIO are best reserved for younger patients with more moderate dysplasia as the SIO requires an open triradiate cartilage and provides less correction than other osteotomies such as the Dega osteotomy [22]. In contrast, older children with dysplasia and with closed triradiate cartilage are typically treated using the Bernese periacetabular osteotomy [43]. Additionally, for older patients with inadequate femoral head coverage and when concentric reduction cannot be achieved, salvage osteotomies such as the Shelf procedure and Chiari procedure are preferred [44]. However, a formal comparison of the different pelvic osteotomies was not included in this review as it was outside the scope of this study.

This review identified several factors that may affect patients' outcomes after SIO. Patients who had their SIO performed at a younger age (1.5–2 years) had better

functional outcome scores than those who had their SIO performed at an older age (4–6 years) [14]. For older children (over the age of 6 years), SIO is difficult due to the inability to meet a number of conditions required for operation [45]. In particular, in children older than 10 years of age, there is a decrease in flexibility of the pubic symphysis [46]. This hinders the re-orientation of the acetabulum as it primarily rotates through the symphysis [46]. Patients who underwent pre-operative traction prior to SIO had significantly worst outcome scores than those who did not have pre-operative traction [24]. This may be due to the decreased incidence rate of AVN in patients without pre-operative traction [24]. Additionally, the use of pre-operative traction tends to be preferred in more complicated congenital dislocations of the hip, which may result in worse outcomes reported in this group [47]. Lastly, surgeons must be careful not to miss contralateral hip dysplasia in patients undergoing SIO, as untreated contralateral hip dysplasia has been shown to worsen outcomes after SIO.

The available literature suggests that outcomes after simultaneous bilateral SIO osteotomy may not differ from a staged procedure [32]. Similarly, one study found no significant difference in outcomes between patients who had a simultaneous open reduction and SIO and those who had staged procedures [29]. A one-stage procedure reduces the need for further surgeries, reduces total recovery time and is more economically favorable. Furthermore, in a survey of parents of patients with bilateral hip dysplasia, all the parents stated that they would rather their child have a single-stage bilateral SIO as opposed to a staged procedure [32].

The strengths of this systematic review stems from the rigorous methodology used. The use of multiple databases, broad search strategy and a duplicate and systematic approach to reviewing the literature ensured that any relevant articles were not overlooked. Limitations to this study include the high heterogeneity of studies, lack of long-term follow-up and the lack of randomized studies. Due to the lack of adequate follow-up, it is difficult to determine the progression or development of osteoarthritis after SIO, outcomes at skeletal maturity, to ascertain accurate incidence rates of AVN, rates of conversion to total hip arthroplasty and the long-term functional outcomes and complications of SIO. Additionally, there were a lack of studies comparing SIO to other osteotomy techniques, thus limiting our ability to determine an optimal treatment method for DDH. Furthermore, the high heterogeneity between studies meant a meta-analysis between studies was not feasible. Future studies should address these limitations that exist within the current literature.

CONCLUSION

This systematic review found that SIO for DDH produces generally good post-operative clinical outcomes. The CEA and AI can be corrected to within normal range after SIO. Patients may have superior outcomes if they have SIO at a younger age, were not treated with pre-operative traction and did not have untreated contralateral hip dysplasia. Outcomes appear to be similar between one-stage bilateral SIO and a two-stage procedure in the setting of bilateral hip dysplasia; however, more multicentered studies are needed to confirm these results.

SUPPLEMENTARY DATA

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

CONFLICT OF INTEREST STATEMENT

O.R.A is an educational consultant for the Speaker's Bureau of ConMed.

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