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Patient Selection Criteria for Periacetabular Osteotomy or Rotational Acetabular Osteotomy

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Abstract
Background Hip dysplasia is the most common cause of secondary osteoarthritis (OA). Periacetabular osteotomy (PAO) or rotational acetabular osteotomy (RAO) has been used as a joint-preserving procedure. However, the patient selection criteria are not clearly defined.
Questions/purposes Based on a systematic review, we identified reported patient selection criteria for PAO or RAO.
Methods We performed a systematic review of RAO and 18 studies met our inclusion criteria. For the PAO, the systemic review performed by Clohisy et al. was used.
Where Are We Now? For patients with symptomatic hip dysplasia, lateral center-edge angle less than 10° to 30°, radiographic pre- or early OA, mean age at the time of surgery of 18 to 45 years, and improvement in joint congruency on AP radiograph with hip abduction, radiographic deformity correction consistently improved hip function in all studies. Radiographic OA progression was noted in 5% to 33% at 3.2 to 20 years postoperatively. Clinical score and prevention of radiographic OA progression of patients 50 years or older or with advanced stage were worse in younger patients or those with early stage.
Where Do We Need to Go? The key challenges are (1) preoperative evaluation of articular cartilage; (2) indication for older patients; (3) prevention of secondary femoroacetabular impingement; and (4) intraarticular treatment combined with PAO or RAO.
How Do We Get There? Future prospective, longitudinal cohort studies need to determine optimal patient selection criteria, risk factors for clinical failure, optimal deformity correction parameters, and the role of adjunctive surgical procedures.

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Introduction

Hip dysplasia is the most common cause of secondary osteoarthritis (OA) [1, 14]. Murphy et al. [33] noted that no patient in whom the hip functioned well until the age of 65 years had had a center-edge angle of less than 16°, an acetabular index of depth to width of less than 38%, an acetabular index of the weightbearing zone of more than 15°, uncovering of the femoral head of more than 31%, or an acetabulum in which the most proximal point of the dome had been at the lateral edge (zero peak-to-edge distance). To prevent the early onset of secondary OA, Nishio's transposition osteotomy [37], Steel's triple osteotomy [51], Eppright's dial osteotomy [9], Wagner's spherical acetabular osteotomy [59], Tagawa's rotational acetabular osteotomy (RAO) [36], and Ganz' periacetabular osteotomy (PAO) [11] have been proposed.

PAO and RAO are now commonly used as surgical treatment for symptomatic acetabular dysplasia in Europe, North America, and Japan. These procedures reorient the acetabulum to reduce superolateral acetabular inclination, improve femoral head coverage, translate the joint center medially, and normalize loading of the anterolateral acetabular rim [24, 36].

Clohisy et al. [5] reported a systematic literature review of PAO. Of 235 articles between 1980 and 2008, 13 articles [2–4, 6, 7, 23, 27, 28, 45, 47, 50, 56, 57] met their inclusion criteria and were analyzed for the level of evidence, deformity correction, clinical score, and complications for PAO. This study showed the clinical benefit of PAO was optimal in younger patients with no or mild preoperative OA and radiographic correction of dysplastic deformities was achieved reliably.

Although PAO or RAO is frequently performed, the patient selection criteria are not clearly defined in the literature. In this review, we explore the current state of patient selection criteria ("Where are we now?") based on the systematic review of PAO by Clohisy et al. [5] and our review of RAO and discuss the precise patient selection for improving the clinical score and prevention of radiographic OA progression ("Where do we need to go?") and the potential solutions ("How do we get there?").

Search Strategy and Criteria

We searched PubMed and Ovid MEDLINE for articles published between 1980 and 2011. Database search terms included: "rotational acetabular osteotomy" and "transposition osteotomy of acetabulum". Each term was searched individually, and searched articles were investigated to remove duplicate studies. A total of 136 articles were identified in our search and each abstract underwent review by two of the authors (YY, TY) (Fig. 1). We included only studies that were published in English, reported clinical and radiographic outcomes of the RAO, and transposition osteotomy of acetabulum, which had a followup of more than average 5 years, and a followup rate more than 50%. Of these 136 articles, 41 articles met inclusion criteria. We excluded articles if they were case reports, reviews, hip dysplasia associated with a false acetabulum (Severin Group V), specific syndromes (encephalopathy, osteonecrosis of the femoral head, Legg-Calvé-Perthes disease, chondral tumor, Down syndrome, and Gaucher's disease), and articles on Bernese periacetabular osteotomy by Ganz' technique. Of these 136 articles, 18 articles met inclusion and exclusion criteria.

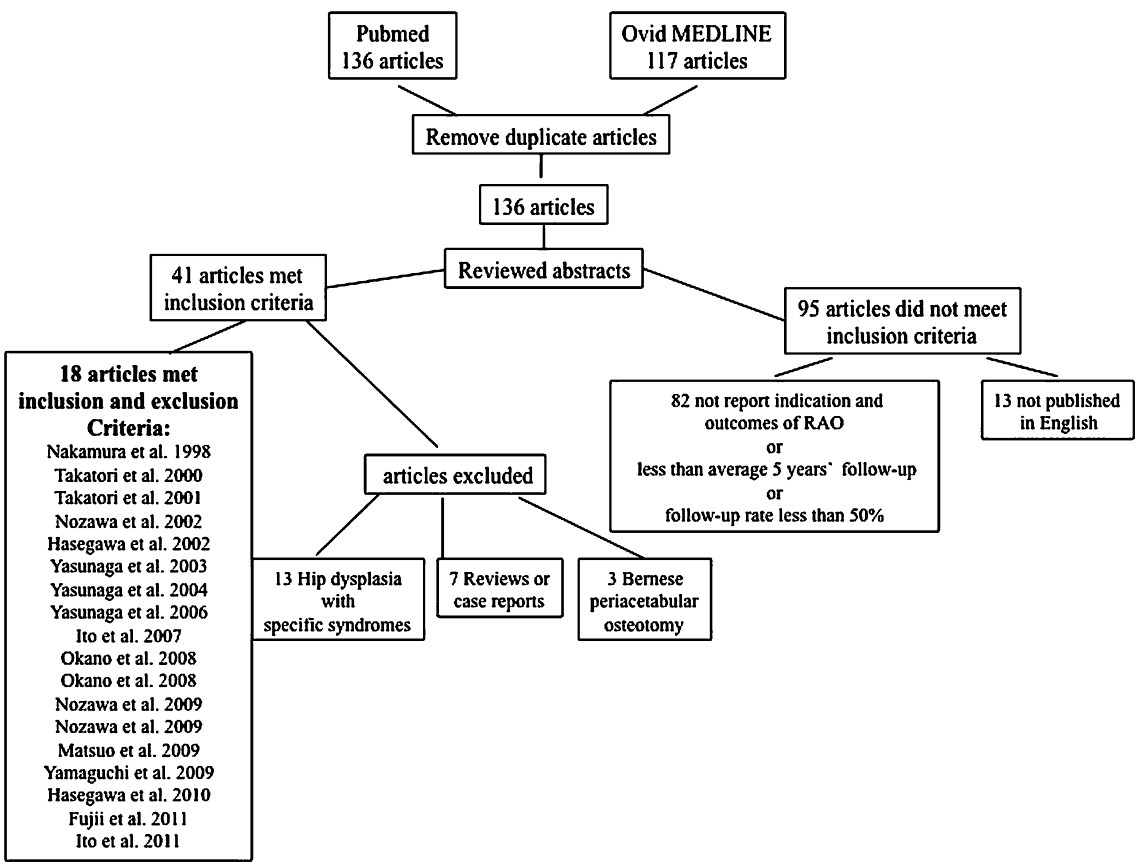

Fig. 1 A flow diagram illustrates the method of article selection for study inclusion.

From the 18 articles, we investigated the following items: study design, level of evidence, potential selection and treatment bias that may have affected the conclusions, the number of subjects, sex, followup period, followup rate, age at surgery, radiographic stage or unique features of the cohort, patient selection criteria, combined surgery with RAO, clinical outcome scores, the number of clinically "good" or "excellent" scores as judged by the various authors, change in hip score, failure definition, failure rate, the number of conversions to THA, the number of progressions of radiographic OA, mean change in acetabular inclination, mean correction of anterior and lateral center-edge angle, translation of joint center, mean reduction of clinical score for ROM of the hip, and intra- or postoperative complications.

Each article underwent review by two of the authors (YY, TY). Any differences noted between the two reviewers were discussed and consensus was reached regarding the item in question. The quality of this systematic review was not determined.

Where Are We Now?

The level of evidence for PAO [5] and RAO is low with 11 of the 13 articles and all 18 articles being Level IV (Table 1), respectively.

The primary indications for PAO included pain greater than 6 months [47, 56], adequate ROM [3, 27, 47], radiographic evidence of residual hip dysplasia [2–4, 6, 7, 23, 27, 28, 45, 47, 50, 56, 57], and closure of triradiate cartilage [7, 27]. In a number of studies [2, 3, 7, 27, 28, 47, 56, 57], an abduction and internal rotation radiograph was used to determine if the femoral head would roll into the acetabulum and obtain the expected congruity after surgery. The indications for surgery for RAO were similar to PAO [10, 15, 16, 20, 21, 26, 35, 39, 42, 53, 54, 61, 63–65] (Table 1).

The preoperative maximum lateral center-edge angle was 10° to 30° in PAO [4, 6, 7, 23, 27, 45, 47, 50, 56, 57] and 10° to 20° in RAO [10, 15, 16, 20, 21, 26, 35, 39–43, 53, 54, 61, 63–65].

The mean age at the time of surgery was 17.6 to 34 years in PAO [5] and 27 to 53 years in RAO (Table 1).

Clinical followup showed pain relief and improved hip function in 40% to 97% patients at short- to midterm followup in both procedures [5] (Table 2). Improved hip function was most predictable for hips with little or no preoperative osteoarthritis. Takatori et al. [53] reported the longest followup study (mean, 20 years; range, 15–22 years) with a good or excellent clinical score (> 15 points) of Merle d'Aubigné score occurring in 73% of patients with early OA. However, these procedures were associated with decreased hip ROM [5] (Table 3).

These data derived from various surgeons and institutions indicate PAO and RAO can reliably achieve deformity correction [5] (Table 3). The mean change in acetabular inclination ranged from 4.5° to 25.9° in PAO and 12° to 36° in RAO. Similarly, the mean change in lateral center-edge angle ranged from 20° to 44.6° and 32° to 48°, respectively. The procedures also provide medial translation of the hip center with an average change ranging from 5 mm to 10 mm in PAO and 1 mm to 7 mm in RAO. The magnitude of deformity correction is dependent on the underlying severity of deformity.

Regarding preoperative radiographic stage, cases of Tönnis Grade 0 or 1 and JOA Stage 1 or 2 were mainly indicated for surgery [5] (Table 1). In PAO, radiographic OA progression was noted in 5% to 33% at 3.2 years to 11.3 years postoperatively [5]. In RAO, it was noted in 5% to 53% at 7.5 years to 20 years postoperatively (Table 2). Prevention of radiographic OA progression depended on the grade of OA preoperatively [6, 15, 20, 23, 27, 35, 41, 50, 53, 56, 57]. Radiographic outcomes with cases of Tönnis Grade 0 or 1 and JOA Stage 1 or 2 were better than Grade 3 or 4 and Stage 3 or 4.

At present, there are some controversies on the patient selection criteria of PAO or RAO on the advanced stage or age at the time of surgery. Trousdale et al. [56] reported on 42 patients who underwent the PAO on Tönnis Grade 1, 2, and 3 and were followed for a mean of 4 years. The results were best in patients with Grade 1 involvement and poor with Grade 2 and 3. Nakamura et al. [35] reported the long-term results of RAO in 131 patients (145 hips) followed for a mean of 13 years. A Merle d'Aubigné score of greater than 15 points occurred in 90 (80%) of 112 hips with prearthritic or early-stage arthritis but in only nine of 33 hips with advanced-stage or end-stage arthritis. Siebenrock et al. [50] suggested the factors that mitigate against a good clinical score of Merle d'Aubigné score (> 15 points) and prevention of OA progression after a PAO were advanced stage and older age at the time of surgery. Recent studies [16, 43, 64] reported that properly selected patients with advanced-stage OA could have a good clinical score (> 80 points of Harris hip score or > 15 points of Merle d'Aubigne score) after RAO. Yasunaga et al. [64] proposed the essential criteria for advanced-stage OA were a good postoperative joint congruency expected and a preoperative minimum joint space width of > 2.2 mm. Hasegawa et al. [16] also noticed preoperative joint space wider than 2 mm was essential for cases with advanced stage. Okano et al. [43] emphasized the roundness of the femoral head for advanced stage.

With regard to age at the time of surgery, several authors suggest the indication for osteotomy in older patients should be restricted to those with pre- or early-stage OA [31, 65], with unilateral involvement [61], or with postoperative good joint congruency expected [31, 65].

Table 1. Participant demographics for studies of rotational acetabular osteotomy

Study	Study design, level of evidence	Bias	Hips/patients	Female: male	Followup (years)	Percent followup	Age (years)	Radiographic stage or unique features of cohort	Patient selection criteria
Nakamura et al. [35] (1998)	Retrospective case series, IV	NA	145/131	120:11	13 (10–23)	59%	28 (11–52)	JOA Stage I; 63, II; 49, III; 21, IV; 12	1) Increasing hip pain; 2) dysplastic hip; 3) AP radiograph showing improved congruity in abduction
Takatori et al. [53] (2000)	Retrospective case series, IV	NA	28/28	26:2	13 (10–18)	74%	33 (19–40)	JOA Stage III; 21, IV; 7	1) Significant hip pain; 2) dysplastic hip; 3) AP radiograph showing improved congruity in abduction
Takatori et al. [54] (2001)	Retrospective case series, IV	NA	15/15	15:0	20 (15–22)	68%	24 (20–28)	JOA Stage II; 15	1) Significant hip pain; 2) dysplastic hip; 3) AP radiograph showing improved congruity in abduction
Nozawa et al. [41] (2002)	Retrospective case series, VI	NA	50/49	46:3	11 (10–15)	91%	32 (13–53)	Tönnis Grade 0; 23, 1; 16, 2; 11	NA
Hasegawa et al. [15] (2002)	Retrospective case series, VI	NA	132/126	119:7	7.5 (5–10)	100%	37 (15–59)	JOA Stage I; 18, II; 53, III; 61	1) CE angle < 10°; 2) unsuccessful conservative treatment; 3) age 15–60 years; 4) joint congruity and femoral head coverage in maximum abduction
Yasunaga et al. [65] (2003)	Retrospective case series, VI	NA	26/24 (older) 63/60 (younger)	21:3 53:7	8 (5–13) 8 (5–14)	92% 100%	51 (46–58) 34 (13–45)	JOA Stage II; 26 Stage II; 63	1) CE angle < 20°; 2) progressive pain that interfered with daily activity; 3) AP radiograph showing improved joint congruity and femoral head coverage in abduction
Yasunaga et al. [63] (2004)	Retrospective case series, VI	NA	61/54	48:6	11 (8–15)	95%	35 (13–58)	JOA Stage I; 12, II; 49	Same as above
Yasunaga et al. [64] (2006]	Retrospective case series, VI	NA	43/43	41:2	9 (2–16)	90%	44 (21–57)	JOA Stage III; 43	Same as above
Ito et al. [20] (2007)	Retrospective case series, VI	NA	110/101	88:13	8 (5–16)	96%	33 (14–56)	Tönnis Grade 0; 24, 1; 82, 2; 4	Hip dysplasia with moderate to severe hip pain

Table 1. continued

Study	Study design, level of evidence	Bias	Hips/patients	Female: male	Followup (years)	Percent followup	Age (years)	Radiographic stage or unique features of cohort	Patient selection criteria
Okano et al. [42] (2008)	Retrospective case series, VI	NA	49/48	43:5	13 (10–17)	81%	33 (13–54)	JOA Stage II; 49	1) CE angle < 20°; 2) improvement or no decrease in joint congruency on AP radiograph with hip in abduction
Okano et al. [43] (2008)	Retrospective case series, VI	NA	44/42	40:2	12 (8–19)	86%	41 (13–54)	JOA Stage III; 44	NA
Nozawa et al. [39] (2009)	Retrospective case series, VI	NA	57/52	50:2	12 (2–21)	83%	45 (21–59)	JOA Stage III; 57	Improved femoral head coverage, joint congruency and widening of the joint space on preoperative AP plain radiographs of the hip in abduction
Nozawa et al. [40] (2009)	Retrospective case series, VI	NA	27/25	23:2	12 (3–12)	100%	27 (14–48)	All hips with previous surgical treatment	NA
Matsuo et al. [26] (2009)	Retrospective case series, VI	NA	16/16	16:0	7 (5–9)	94%	48 (38–56)	JOA Stage III; 16	Improvement of joint congruity and containment on AP radiograph with hip in abduction
Yamaguchi et al. [61] (2009)	Retrospective case series, IV	NA	41/41 (older) 123/123 (younger)	NA	8.8 9.3	96%	53 (50–59)	JOA Stage I or II	1) CE angle less than 10°; 2) 30 minutes' walk without rest dependent on hip pain; 3) unsuccessful nonoperative treatment for 6 months; 4) AP radiograph showing improved congruity in abduction
Hasegawa et al. [16] (2010)	Retrospective case series, IV	NA	116/113	NA	Minimum joint space	100%		Minimum joint space < 3 mm	1) unsuccessful conservative treatment; 2) age 15–60 years; 3) ROM; flexion 60°, abdudction.20°; 4) JOA stage 1, 2, 3 with better congruence was assessed by an abduction AP radiographic study
			18		≦ 1 mm; 10		40		
			49		≧1.1 but < 2 mm; 10		44		
			49		≧2.1 but < 3 mm; 10		43		

Table 1. continued

Study	Study design, level of evidence	Bias	Hips/patients	Female: male	Followup (years)	Percent followup	Age (years)	Radiographic stage or unique features of cohort	Patient selection criteria
Fujii et al. [10] (2011)	Retrospective case series, VI	NA	121/121	NA	10 (2–18)	100%	40 (13–64)	Kellgren-Lawrence Grade 1; 25, 2; 68, 3; 28	1) CE angle < 20°; 2) pain in the hip that interfered with daily activities; 3) improvement of joint congruity and containment on AP radiograph with hip in abduction
Ito et al. [21] (2011)	Retrospective case series, IV	NA	41/41 (older) 117/117 (younger)	34:7 100:17	11 (5–19) 11 (5–20)	95%	47 (40–56) 27 (12–39)	Tönnis 0; 10, 1; 29, 2; 2 0; 30, 1; 83, 2; 4	1) CE angle less than 16°; 2) congruent hip joint with hip abduction

NA = data not available; JOA = Japanese Orthopaedic Association; CE = center-edge

Failure of these procedures with conversion to THA occurred in 0% to 17% of the cases in PAO at mean followup times ranging from 3 to 7 years [5] and in 0% to 10% in RAO at followup times ranging from 7 [53] to 10 years [41] (Table 2).

Major complications [8] occurred in 6% to 37% of the cases in PAO. The most common major complications included symptomatic heterotopic ossification, wound hematomas, nerve palsies, intraarticular osteotomies, loss of fixation, and malreductions. Eight of the studies acknowledged the substantial learning curve associated with PAO [5]. On the other hand, in RAO, major complications occurred in 0% to 18% of the cases (Table 3).

Discussion

PAO and RAO are preferred reconstructive osteotomies for treatment of symptomatic acetabular dysplasia. Nevertheless, the clinical evidence to support these procedures based on a large patient cohort has not been established. The purpose of this study was to elucidate the patient selection criteria for PAO or RAO regarding the age at the time of surgery and the radiographic stage and factors affecting clinical results based on the systematic review.

Despite the predominance of Level IV evidence, there is consensus regarding certain aspects of patient selection criteria for PAO or RAO. The clinical benefit of these procedures is optimal in younger patients with pre- or early OA.

Where Do We Need to Go?

The key challenges are (1) preoperative evaluation of articular cartilage; (2) indication for older patients; (3) prevention of secondary femoroacetabular impingement; and (4) intraarticular treatment combined with PAO or RAO.

According to Millis et al. [30, 32], the success of PAO depends on articular cartilage that is sufficiently healthy to sustain normal load transmission. Shimogaki et al. [49] also reported RAO caused considerable changes in joint morphology and histological changes in the articular cartilage, particularly in the medial part of the acetabulum. Noguchi et al. [38] in their arthroscopic evaluation of the articular cartilage of dysplastic hips reported that even at the early stage radiographically, severe degeneration of articular cartilage with subchondral exposure could be present. Yasunaga et al. [62] found that even when postoperative joint congruency was classified as good in their criteria, there was the possibility of OA progression if the intraoperative arthroscopic evaluation is Outerbridge's

Table 2. Surgical techniques and outcomes reported from studies evaluating rotational acetabular osteotomy

Study	Hips/patients	RAO isolated,* TOA	RAO with other	Clinical outcome scores	Number clinically good or excellent outcome	Change in hips score (points)	Failure definition	Failure	Conversion to THA	Radiographic OA progression
Nakamura et al. [35] (1998)	145/131	145 hips (100%)		Merle d'Aubigne	99 hips (68%)	1.2 (14.2–15.4)	< 14 points	46 hips (32%)	7 hips (5%)	33 hips (23%)
Takatori et al. [53] (2000)	28/28	24 hips (86%)	4 hips (14%)	Merle d'Aubigne	11 hips (40%)	0.4 (13–13.4)	Conversion to THA	1 hip (4%)	←	5 hips (17%)
Takatori et al. [54] (2001)	15/15	15 hips (100%)		Merle d'Aubigne	11 hips (73%)	0.8 (15.1–15.9)	Conversion to THA	None	None	8 hips (53%)
Nozawa et al. [41] (2002)	50/49	48 hips (96%)	2 hips (4%)	JOA score	40 hips (80%)	18 (72–90)	Radiographic OA progression	10 hips (20%)	one hip (2%)	←
				Merle d'Aubigne	NA	2.5 (13.8–16.3)				
Hasegawa et al. [15] (2002)	132/126	109 hips (83%)	23 hips (17%)	Harris hip score	NA	17 (71–89)	Radiographic OA progression	7 hips (5%)	None	←
Yasunaga et al. [65] (2003)	26/24 (older)	26 hips (100%)		Merle d'Aubigne	21 hips (81%)	2.7 (13.9–16.6)	Radiographic OA progression	5 hips (19%)	None	←
	63/60 (younger)	63 hips (100%)			59 hips (94%)	2.5 (14.1–16.6)		4 hips (6%)	None	←
Yasunaga et al. [63] (2004)	61/54	61 hips (100%)		Merle d'Aubigne	49 hips (80%)	2.6 (14.2–16.8)	Radiographic OA progression	6 hips (10%)	None	←
Yasunaga et al. [64] (2006)	43/43	43 hips (100%)		Merle d'Aubigne	34 hips (79%)	2.1 (13.3–15.4)	Minimum joint space < 1 mm	10 hips (23%)	2 hips (4%)	←
Ito et al. [20] (2007)	110/101	109 hips (99%)	2 hips (1%)	Harris hip score	96 hips (87%)	16 (73–89)	Radiographic OA progression	14 hips (13%)	NA	←
Okano et al. [42] (2008)	49/48	49 hips (100%)		Merle d'Aubigne	44 hips (90%)	4 (13–17)	Radiographic OA progression	11 hips (22%)	NA	←
Okano et al. [43] (2008)	44/42	44 hips (100%)		Merle d'Aubigne	33 hips (75%)	2.7 (10.8–13.5)	Radiographic OA progression	11 hips (25%)	4 hips (10%)	←
Nozawa et al. [39] (2009)	57/52	57 hips (100%)		Merle d'Aubigne	35 hips (61%)	1.7 (12.6–14.3)	Conversion to THA	7 hips (12%)	←	23 hips (40%)
Nozawa et al. [40] (2009)	27/25	27 hips (100%)		Merle d'Aubigne	19 hips (70%)	1.7 (14.1–15.8)	Radiographic OA progression	5 hips (19%)	2 hips (7%)	←
Matsuo et al. [26] (2009)	16/16	16 hips* (100%)		JOA hip score	NA	17 (66–83)	NA	NA	None	3 hips (19%)
Yamaguchi et al. [61] (2009)	41/41 (older)	164 hips (100%)		Harris hip score	NA	29 (60–89)	Conversion to THA or HHS < 80	NA	4 hips (10%)	NA
	123/123 (younger)					29 (63–92)			4 hips (3%)	
Hasegawa et al. [16] (2010)	116/113	116 hips (100%)		Harris hip score	Minimum joint space ≦ 1 mm 14 hips (77%)	21	Conversion to THA or HHS < 80	NA	3 hips (17%)	NA
					≧ 1.1 but < 2 mm 33 hips (67%)	19			9 hips (18%)	
					≧ 2.1 but < 3 mm 38 hips (78%)	20			2 hips (4%)	

Table 2. continued

Study	Hips/ patients	RAO isolated,* TOA	RAO with other	Clinical outcome scores	Number clinically good or excellent outcome	Change in hips score (points)	Failure definition	Failure	Conversion to THA	Radiographic OA progression
Fujii et al. [10] (2011)	121/121	114 hips* (94%)	7 hips (6%)	Merle d'Aubigne	NA	3.3 (13.1–16.4)	Progression toKellgren Lawrence Grade 4 or conversion to THA	8 hips (7%)	1 hip (0.8%)	16 hips (13%)
Ito et al. [21] (2011)	41/41 (older)	158 hips (100%)		Harris hip score	143 hips (93%)	19 (69–88)	Radiographic OA progression	11 hips (27%)	3 hips (7%)	8 hips (20%)
	117/117 (younger)					21 (70–91)		13 hips (13%)	4 hips (3%)	9 hips (8%)

RAO = rotational acetabular osteotomy; TOA = transposition osteotomy of acetabulum; OA = osteoarthritis; NA = data not available; HHS = Harris hip score; JOA = Japanese Orthopaedic Association.

Grade 4 [44]. Cunningham et al. [7] reported a Level II prognostic study. They concluded patients whose hips have a lower dGEMRIC index are less likely to benefit from PAO.

MRI can better assess the health of cartilage before surgery and predict which joints will still be painful postoperatively than plain radiographs [22]. Delayed gadolinium-enhanced MRI [22], MR arthrography [25], or T2 mapping MRI [60] is valuable for the preoperative precise evaluation of articular cartilage. Based on the evidence, the preoperative precise evaluation of articular cartilage is important for patient selection of PAO and RAO even in early OA.

For symptomatic patients older than 40 years of age who have a dysplastic hip, the operative indications for THA or joint-preserving procedures are controversial [12, 19, 48, 55, 58]. Sharifi et al. [48] concluded PAO was more cost-effective than THA for patients with Tönnis Grade 0, 1, and 2 OA. Hsieh et al. [19] evaluated 31 patients who were managed with PAO for the treatment of Tönnis Grade 0 to 2 OA in one hip and THA for the treatment of Tönnis Grade 3 OA in the other hip. More patients preferred PAO to THA (53% compared with 23%) at a mean of 6 years after PAO and 7 years after THA. McAuley et al. [29] reported the survivorships of THA in patients 50 years of age and younger were 89% at 10 years followup and 60% at 15 years followup.

PAO and RAO remain important options for older patients with early OA or younger patients with advanced OA who are not yet willing to undergo THA because of the high rates of revision THA needed owing to prolongation of the average lifespan. Although it is unclear why the outcome of RAO with cases of older age or advanced stage is acceptable, the cause may be the result of Asian patients with short stature and low body mass index.

Myers et al. [34] noted that excessive lateral and anterior correction in the PAO might lead to the femoroacetabular impingement (FAI), which induced residual pain and limited ROM. Peters et al. [45] concluded that recognition of the true preoperative acetabular version and reorientation of the acetabulum into an appropriately anteverted position have become important factors in surgical decision-making. Steppacher et al. [52] found a nonspherical shape of the femoral head and acetabulum in dysplastic hips could potentially induce a painful FAI or influence the result of a reorientation procedure. Fujii et al. [10] and Yasunaga et al. [66] observed no difference in the prevalence of a crossover sign between hips with and without progression of osteoarthritis. Garras et al. [13] also found no major effects associated with postoperative acetabular retroversion. Because proximal femoral morphology and depth of acetabulum also affect postoperative FAI, further study is needed to appreciate fully the effect of acetabular

Table 3. Radiographic outcomes, ROM outcomes, and complications reported from studies evaluating rotational acetabular osteotomy

Study	Mean change in acetabular inclination	Mean anterior center-edge angle correction	Mean lateral center-edge angle correction	Medialization HLI; head lateralization index LI; lateralization index	Reduction of ROM (Score)	Complications
Nakamura et al. [35] (1998)	27°	NA	38°	NA	–0.5 (5.4–4.9)	Major (9: 6%); bone necrosis and delayed union of the acetabular fragment (4) severe destruction of the acetabular fragment (2), penetration of osteotome (2), displacement of the acetabular fragment soon after the surgery (1) Moderate (2:1%); pelvic fracture at donor site (2)
Takatori et al. [53] (2000)	29°	NA	41°	NA	−1.2 (5.2–4.0)	Major (5:18%); snapping of the rectus femoris tendon (1), chondrolysis (1), additional intertrochanteric valgus osteotomy (3)
Takatori et al. [54] (2001)	31°	NA	38°	NA	−0.9 (5.8–4.9)	None
Nozawa et al. [41] (2002)	Stage 1; 28° Stage 2; 24° Stage 3; 27°	NA	34° 37° 34°	2 mm 1 mm 7 mm	JOA-1 (19–18) JOA-1 (20–19) JOA-1 (18–17)	Major (2:4%); loss of cover after removal of the Kirschner wire (2) Minor (4:8%); dysesthesia in the distribution of the lateral femoral cutaneous nerve (4)
Hasegawa et al. [15] (2002)	NA	NA	Stage 1; 39° Stage 2; 38° Stage 3; 38°	5 mm 5 mm 3 mm	NA	Moderate (5:4%); hematoma (5) Minor (4:3%); heterotopic bone (3), injury of lateral femoral cutaneous nerve (1)
Yasunaga et al. [65] (2003)	19° (older) 25° (younger)	NA	34° 37°	HLI; 0.03 (0.67–0.64) HLI; 0.05 (0.66–0.61)	−0.1 (5.8–5.7) 0 (5.8–5.8)	None
Yasunaga et al. [63] (2004)	27°	NA	36°	HLI; 0.04 (0.66–0.62)	−0.1 (5.9–5.8)	NA
Yasunaga et al. [64] (2006)	12°	NA	34°	HLI; 0.04 (0.69–0.65)	−0.1 (6.0–5.9)	None
Ito et al. [20] (2007)	12°	NA	37°	5 mm	NA	Major (8:7%); pulmonary embolism (1), necrosis of acetabulum (2), greater trochanter displacement (4), infection (1) Moderate (4:4%); ischial fracture (4) Minor (7:6%); pubic nonunion(5), heterotopic bone formation (2)

Table 3. continued

Study	Mean change in acetabular inclination	Mean anterior center-edge angle correction	Mean lateral center-edge angle correction	Medialization HLI; head lateralization index LI; lateralization index	Reduction of ROM (Score)	Complications
Okano et al. [42] (2008)	Good group; 36° Poor group; 32°	NA	Good group;44° Poor group;48°	NA	−0.4 (5.7–5.3)	Major (2:4%); deep vein thrombosis (1), intraarticular damage (1) Minor (2:4%);transient irritation of the lateral femoral cutaneous nerve (2)
Okano et al. [43] (2008)	NA	NA	Good group; 42° Poor group; 42°	NA	−0.8 (5.3–4.5)	None
Nozawa et al. [39] (2009)	NA	NA	36°	1.1 mm	−0.5 (5.4–4.9)	None
Nozawa et al. [40] (2009)	NA	NA	36°	1.3 mm	−0.3 (5.5–5.2)	NA
Matsuo et al. [26] (2009)	NA	NA	35°	LI; 0.03 (0.63–0.60)	NA	Major (1: 6%); pulmonary embolism (1) Minor (4:25%); injury of lateral femoral cutaneous nerve (2), superficial infection (2)
Yamaguchi et al. [61] (2009)	NA	NA	NA	NA	−0.1 (4.9–4.8) (older) −0.1 (5.3–5.2) (younger)	insufficiency of gluteal muscle recovery (1 older patient) nonunion of greater trochanter (1 younger patient)
Hasegawa et al. [16] (2010)	NA	NA	Minimum joint space ≦ 1 mm 32° ≧ 1.1 but < 2 mm 33° ≧ 2.1 but < 3 mm 35°	NA	NA	NA
Fujii et al. [10] (2011)	NA	NA	34°	NA	0 (5.9–5.9)	Major (1:1%); pulmonary embolism (1) Minor (4:3%); superficial infection (3), pubic nonunion (1)
Ito et al. [21] (2011)	NA	NA	37° (younger) 38° (older)	6.9 mm (16.8–9.9) 4.4 mm (15.8–11.4)	NA	Major; older (3:7.3%); pulmonary embolism (1), necrosis of acetabulum (1), nonunion of greater trochanter (1) younger (6:5.1%); necrosis of acetabulum (2), nonunion of greater trochanter (3), deep infection (1) Moderate; older (2:4.9%); ischial fracture (2) younger (3:2.6%); ischial fracture (3) Minor; older (1:2.4%); pubic nonunion (1) younger (6:5.1%); pubic nonunion (4), heterotopic bone formation (2)

HLI = head lateralization index; LI = lateralization index; NA = data not available; JOA = Japanese Orthopaedic Association.

retroversion on the clinical results. Hipp et al. [18] suggested that reorientation of a dysplastic acetabulum to increase the anterior coverage might decrease posterior coverage, which increased the contact pressure while stairclimbing in some cases. The best position of acetabulum depends on the amount and geometric distribution of the loadbearing surface area and type of loads that the hip needs to support. Individualized preoperative planning of PAO or RAO using three-dimensional data can be used to calculate the position of the acetabulum that maximally reduces the contact pressures for specific activities.

In some cases, PAO or RAO may be indicated for hips with lateral joint space narrowing and MRI evidence of articular cartilage damage but with widened and congruent joint space in the abduction view. In these cases, severe articular cartilage degeneration can be observed under the arthroscope during surgery. Recently, arthroscopic femoral osteochondroplasty for cam impingement with microfracture in degenerated cartilage of the acetabulum has been reported [17, 67]. The drilling procedure for damaged articular cartilage as a bone marrow-stimulating procedure was first reported by Pridie in 1959 [46] and is often performed as a treatment of osteochondral lesions of knees. For cases with degenerated cartilage, microfracture or drilling combined with PAO or RAO has potential for the regeneration of articular cartilage.

How Do We Get There?

As Clohisy et al. [5] described, future prospective, longitudinal cohort studies need to determine optimal patient selection criteria for surgery, risk factors for clinical failure, optimal deformity correction parameters, and the role of adjunctive surgical procedures (hip arthroscopy, labral and articular cartilage débridement/repair/stimulation, femoral osteochondroplasty, proximal femoral osteotomy).

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