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Hitting the Target: Natural History of the Hip Based on Achieving an Acetabular Safe Zone Following Periacetabular Osteotomy

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Investigation performed at the Mayo Clinic, Rochester, Minnesota, Washington University in St. Louis, St. Louis, Missouri, and the University of Utah, Salt Lake City, Utah

Background: Periacetabular osteotomy (PAO) remains the gold-standard treatment for acetabular dysplasia in skeletally mature patients with preserved cartilage. The purpose of this multicenter cohort study was to delineate the long-term radiographic natural history of the dysplastic hip following PAO based on the final position of the acetabular fragment.

Methods: We evaluated patients who underwent PAO performed by 4 hip preservation surgeons to treat acetabular dysplasia with or without concomitant retroversion from 1996 to 2012 at 3 academic institutions. There were 288 patients with a mean clinical and radiographic follow-up of 9 years (range, 5 to 21 years). Postoperative radiographs made at the first clinical visit were used to determine if the acetabular fragment fell into a safe zone according to the absence of retroversion, a lateral center-edge angle (LCEA) of 25° to 40°, an anterior center-edge angle (ACEA) of 25° to 40°, and a Tönnis angle of 0° to 10°. Every available subsequent radiograph was assessed for degenerative changes by the Tönnis classification (grades 0 to 3). The time to progression was analyzed using Cox proportional hazards regression and multistate modeling.

Results: Only the absence of retroversion was independently associated with a decreased risk of progressing at least 1 Tönnis grade during follow-up: hazard ratio (HR), 0.60 (95% confidence interval [CI], 0.38 to 0.94; p = 0.025). Achieving the ACEA safe zone yielded the greatest time increase for remaining in Tönnis grade 0 or 1 (43 years for having an ACEA in the safe zone compared with 28 years for not having an ACEA in the safe zone), followed by the absence of retroversion (34 years for the absence of retroversion compared with 24 years for the presence of retroversion). However, attaining the Tönnis angle or LCEA safe zones did not delay progression. The achievement of additional safe zones generally increased the length of time that patients spent in Tönnis grade 0 or 1: 25 years for 0 safe zones, 36 years for 1 safe zone, 29 years for 2 safe zones, 37 years for 3 safe zones, and 44 years for 4 safe zones.

Conclusions: This study demonstrates the importance of achieving appropriate acetabular reorientation to enhance the longevity of the native hip following PAO. Although the LCEA and the Tönnis angle are the most common metrics used to assess appropriate acetabular correction, this study shows that adequately addressing retroversion and the ACEA has a greater impact on improving the natural history.

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

Acetabular dysplasia portends the worst prognosis for osteoarthritis progression along the spectrum of described hip morphologies from undercoverage to overcoverage[1]. Periacetabular osteotomy (PAO) remains the gold-standard treatment for acetabular dysplasia in skeletally mature patients with preserved articular cartilage. Although many studies have documented good intermediate-term and long-term survivorship outcomes up to 30 years[2-6], a recent study was the first to show that PAO can unequivocally improve the natural history in patients with hip dysplasia[7].

A variety of studies have evaluated factors that impact the survivorship of the native hip following PAO. It has been demonstrated that an increased Tönnis grade of osteoarthritis prior to PAO, particularly if it is a Tönnis grade of ≥2, leads to

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TABLE I Patient Characteristics for the Study Cohort (N = 288)

Patient Factor	
Age* *(yr)*	29.2 ± 11.1 (11 to 50)
Female sex†	238 (82.6%)
BMI‡ *(kg/m²)*	25.4 ± 4.4
Preoperative values	
Tönnis grade†	
0	150 (52.1%)
1	115 (39.9%)
2	21 (7.3%)
3	2 (0.7%)
Minimum joint space‡ *(mm)*	5.3 ± 3.0
LCEA‡ *(deg)*	6.9 ± 10.4
Tönnis angle‡ *(deg)*	22.1 ± 7.1
ACEA‡ *(deg)*	4.6 ± 14.4
Presence of retroversion† *(%)*	72 (25.0%)
Postoperative values	
Tönnis grade†,§	
0	71 (24.7%)
1	130 (45.1%)
2	36 (12.5%)
3	9 (3.1%)
Total hip arthroplasty†	42 (14.6%)
Minimum joint space‡ *(mm)*	4.3 ± 1.7
LCEA‡ *(deg)*	27.4 ± 10.6
Tönnis angle‡ *(deg)*	6.7 ± 8.1
ACEA‡ *(deg)*	30.6 ± 13.4
Presence of retroversion†	43 (14.9%)

*The values are given as the mean and the standard deviation, with the range in parentheses. †The values are given as the number of patients, with the percentage in parentheses. ‡The values are given as the mean and the standard deviation. §The Tönnis grade at the time of the final follow-up.

inferior outcomes[2-5]. Further work has identified demographic factors such as older age, higher body mass index (BMI), and female sex as predictive of worse survivorship[8,9]. The presence of concomitant impingement with dysplasia has also been implicated in a poor prognosis[2,6]. Nevertheless, there is a paucity of data on how the quality of acetabular correction impacts longevity of the native hip. This deficiency is likely multifactorial. First, acetabular reorientation is a complex 3-dimensional task. The original description by Ganz et al. entailed the goals of lateral femoral head coverage, center of rotation medialization, and proper femoral head coverage from anterior to posterior[10]. Furthermore, as the surgical technique evolved, additional emphasis was placed on achieving the appropriate acetabular version. Second, it remains unclear what the ideal position should be for each patient to optimize biomechanics. There have been descriptions of normal radiographic parameters for hip morphology, which could be considered to represent a type of acetabular safe zone similar to that described by Lewinnek et al. for the positioning of the acetabular component in total hip arthroplasty[11]. This multicenter cohort study aimed to delineate the radiographic natural history following PAO based on the final position of the acetabular fragment. We hypothesized that obtaining an acetabular correction within safe zones as determined by radiographic descriptions of normative ranges would portend an improved prognosis for the radiographic natural history of the native hip.

Materials and Methods

Following local institutional review board approval, we retrospectively evaluated all patients undergoing PAO from 1996 to 2012 at the Mayo Clinic in Rochester, Minnesota, Washington University in Saint Louis, Missouri, and the University of Utah in Salt Lake City, Utah. We endeavored to establish a relatively homogenous cohort of patients with intermediate-term clinical and radiographic follow-up who had undergone PAO performed with the modern technique. As such, inclusion criteria were PAO for classic acetabular dysplasia with or without concomitant retroversion with a minimum 5-year radiographic follow-up. The exclusion criteria were PAO for isolated acetabular retroversion, neurogenic dysplasia, Legg-Calvé-Perthes disease, and any prior surgical procedure about the hip including arthroscopy and childhood osteotomies. There were 288 patients meeting all criteria in the final cohort, with 139 patients from the Mayo Clinic, 119 patients from Washington University, and 30 patients from the University of Utah. Eighty-three percent of the patients were female, the mean age was 29 years, and the mean body mass index (BMI) was 25 kg/m² (Table I). The mean clinical and radiographic follow-up was 9 years (range, 5 to 21 years). There were no significant differences in any demographic parameters between the 3 participating centers. The cohort in this study was described previously[7]. The original study focused on the natural history of the

TABLE II Risk of Progressing At Least 1 Tönnis Grade Based on the Achievement of Acetabular Safe Zones

	HR*	P Value
LCEA in safe zone (yes vs. no)	1.00 (0.70 to 1.43)	0.99
ACEA in safe zone (yes vs. no)	1.02 (0.70 to 1.48)	0.91
Tönnis angle in safe zone (yes vs. no)	1.19 (0.83 to 1.69)	0.35
Version in safe zone (yes vs. no)	0.60 (0.38 to 0.94)	0.025
No. of safe zones		
0	Reference	
1	0.24 (0.08 to 0.73)	0.011
2	0.24 (0.08 to 0.70)	0.009
3	0.24 (0.08 to 0.69)	0.008
4	0.29 (0.10 to 0.86)	0.026

*The values are given as the HR, with the 95% CI in parentheses.

TABLE III Time Spent in Each Tönnis Grade Based on the Achievement of Acetabular Safe Zones

	Tönnis 0 and 1*	Tönnis 2*	Tönnis 3*
LCEA in safe zone			
Yes	32.0 (23.3 to 44.0)	9.5 (6.2 to 14.6)	3.2 (2.0 to 5.2)
No	33.1 (22.5 to 48.6)	6.8 (4.6 to 10.2)	4.3 (2.8 to 6.7)
LCEA in safe zone or change >30°			
Yes	33.5 (24.6 to 45.5)	10.0 (6.6 to 15.3)	3.2 (2.1 to 5.1)
No	34.1 (22.0 to 52.9)	5.5 (3.5 to 8.7)	5.3 (3.1 to 9.0)
LCEA in safe zone or change >10°			
Yes	33.4 (25.6 to 43.5)	9.2 (6.4 to 13.1)	4.3 (3.0 to 6.4)
No	36.4 (16.3 to 81.1)	3.7 (1.8 to 7.4)	3.2 (1.4 to 7.0)
ACEA in safe zone			
Yes	43.1 (29.1 to 63.9)	10.6 (5.9 to 19.1)	2.1 (1.0 to 4.4)
No	28.4 (20.0 to 40.1)	7.6 (5.2 to 11.1)	4.0 (2.6 to 5.9)
ACEA in safe zone or change >10°			
Yes	35.5 (27.0 to 46.8)	9.5 (6.6 to 13.7)	2.4 (1.5 to 3.7)
No	32.0 (10.3 to 99.2)	1.0 (0.2 to 4.9)	9.2 (4.1 to 20.5)
Tönnis angle in safe zone			
Yes	30.2 (22.2 to 41.1)	9.2 (6.2 to 13.8)	3.1 (2.0 to 4.8)
No	36.5 (24.2 to 54.9)	6.7 (4.4 to 10.3)	4.7 (2.9 to 7.6)
Tönnis angle in safe zone or change >5°			
Yes	29.6 (22.0 to 40.0)	9.2 (6.3 to 13.5)	3.2 (2.1 to 4.9)
No	44.6 (27.7 to 71.8)	5.7 (3.3 to 9.8)	5.9 (3.2 to 10.9)
Version in safe zone			
Yes	34.4 (26.1 to 45.4)	7.8 (5.7 to 10.8)	3.7 (2.6 to 5.4)
No	24.3 (13.8 to 42.8)	8.7 (4.0 to 19.0)	4.1 (2.0 to 8.3)
No. of safe zones			
0	24.5 (3.5 to 174.5)	2.8 (0.7 to 11.8)	1.8 (0.4 to 8.1)
1	35.7 (18.6 to 68.6)	6.6 (3.7 to 11.8)	5.4 (2.8 to 10.7)
2	28.5 (17.7 to 45.8)	11.1 (5.4 to 22.5)	4.2 (2.1 to 8.3)
3	36.6 (23.3 to 57.5)	8.9 (5.2 to 15.4)	1.7 (0.9 to 3.1)
4	44.1 (22.9 to 84.7)	8.9 (3.6 to 21.8)	5.6 (1.3 to 24.0)

*The values are given as the mean time in years, with the 95% CI in parentheses.

native dysplastic hip following modern PAO compared with a control group of nonoperatively managed patients with acetabular dysplasia. The present study reexamined this cohort with additional data to specifically focus on how the quality of acetabular correction influences the natural history following a PAO.

The surgical technique was performed as described by Ganz et al.[10] with additional attention to acetabular version that became common in the mid-1990s[12]. Concomitant procedures at the time of the PAO were performed in 137 patients as follows: 88 open osteochondroplasties, 31 labral debridements, 19 labral repairs, 11 varus-producing or derotational femoral osteotomies, and 1 trochanteric advancement. Additional procedures have been performed following PAO in 82 patients as follows: 42 total hip arthroplasties, 38 implant removals, 6 arthroscopic explorations, 4 irrigations and debridements, 3 labral repairs, 1 hematoma evacuation, and 1 psoas tendon release.

Postoperative radiographs were used to determine if the acetabular fragment fell into a safe zone, based on the reported values for normal acetabular morphology[13] of the absence of retroversion (no posterior wall sign or crossover sign on an anteroposterior pelvic radiograph), a lateral center-edge angle (LCEA) of 25° to 40°, an anterior center-edge angle (ACEA) of 25° to 40°, and a Tönnis angle of 0° to 10°. Every available hip radiograph was independently assessed by 2 authors (C.C.W. and J.S.V.) to evaluate the degree of degenerative change by the Tönnis classification (grades 0 to 3). A summary of the preoperative and postoperative radiographic parameters is detailed in Table I.

Statistical Methods

Continuous variables were reported as means and ranges and continuous variables were reported as counts and percentages with 95% confidence intervals (CIs) when appropriate. Cox proportional

TABLE IV Risk of Tönnis Grade Progression Based on the Achievement of Acetabular Safe Zones

	Tönnis 0 to 1*	Tönnis 1 to 2*	Tönnis 2 to 3*	Tönnis 3 to Total Hip Arthroplasty*
LCEA in safe zone (yes vs. no)	1.12 (0.71 to 1.75)	0.88 (0.53 to 1.45)	0.70 (0.39 to 1.27)	1.34 (0.70 to 2.56)
ACEA in safe zone (yes vs. no)	1.57 (0.98 to 2.52)	0.65 (0.38 to 1.10)	0.71 (0.36 to 1.43)	1.89 (0.81 to 4.42)
Tönnis angle in safe zone (yes vs. no)	1.45 (0.92 to 2.29)	0.94 (0.56 to 1.57)	0.73 (0.41 to 1.32)	1.51 (0.79 to 2.89)
Version in safe zone (yes vs. no)	0.56 (0.31 to 1.01)	0.85 (0.45 to 1.61)	1.11 (0.48 to 2.56)	1.10 (0.50 to 2.44)
No. of safe zones				
0	Reference	Reference	Reference	Reference
1	0.04 (0.01 to 0.18)	1.38 (0.17 to 10.9)	0.42 (0.09 to 2.01)	0.33 (0.06 to 1.72)
2	0.05 (0.01 to 0.20)	1.63 (0.22 to 12.3)	0.25 (0.05 to 1.27)	0.44 (0.08 to 2.30)
3	0.06 (0.01 to 0.25)	1.04 (0.14 to 7.80)	0.31 (0.07 to 1.44)	1.06 (0.21 to 5.34)
4	0.08 (0.02 to 0.36)	0.80 (0.10 to 6.35)	0.31 (0.06 to 1.71)	0.32 (0.04 to 2.65)

*The values are given as the HR, with the 95% CI in parentheses.

hazards regression models evaluated the Tönnis grade from baseline to further progression of disease or total hip arthroplasty. The construction of multistate Markov models was performed using all anteroposterior radiographs for each patient[14]. The Markov models enable the creation of probabilistic estimates for transition through progressive Tönnis grades or total hip arthroplasty. Furthermore, the models capture the amount of time that a patient is predicted to spend in each Tönnis grade, with an advantage of superior precision compared with Kaplan-Meier techniques. The functional forms of the radiographic parameters were assessed using spline plots to see if the current safe zone cutoffs were predictive of a lower risk of progression. Each radiographic safe zone was individually assessed for an association with progression, as was the total number of safe zones achieved. The analysis containing the total number of safe zones achieved was limited to be among those that had all 4 radiographic parameters measured (n = 265), and the number of safe zones achieved was treated as a categorical variable. All analysis was conducted using R version 3.4.2 (R Core Team, R Foundation for Statistical Computing, 2017) and SAS version 9.4 (SAS Institute).

Results

Among the 4 assessed postoperative radiographic parameters, only the absence of retroversion was independently associated with a decreased risk of progressing at least 1 Tönnis grade during follow-up: hazard ratio (HR), 0.60 (95% CI, 0.38 to 0.94; p = 0.025) (Table II). The achievement of 1 to 4 safe zones was associated with a decreased risk of progressing at least 1 Tönnis grade (HR, 0.24 to 0.29; p ≤ 0.026) (Table II).

Multistate modeling assessed the length of time spent in Tönnis grade 0 or 1 based on attaining individual safe zones. Achieving the ACEA safe zone yielded the greatest time increase for remaining in Tönnis 0 or 1 (43 years for achieving this safe zone compared with 28 years for not achieving it), followed by the absence of retroversion (34 years for the absence of retroversion compared with 24 years for the presence of retroversion) (Table III). However, attaining the LCEA safe zone did not delay progression (32 years for attaining the LCEA safe zone compared with 33 years for not attaining it) and attaining the Tönnis angle safe zone was associated with accelerated progression (30 years for attaining the Tönnis angle safe zone compared with 37 years for not attaining it) (Table III). Sensitivity analyses were conducted to assess whether larger degrees of correction in a particular plane were associated with rates of progression and whether or not the safe zone was achieved. In the case of the LCEA, no substantial change was observed with corrections of >10° or >30° compared with smaller corrections (Table III). However, with an ACEA correction of >10°, differences in attaining the safe zone were attenuated (36 years for attaining the ACEA safe zone compared with 32 years for not attaining it), suggesting that a large relative correction in this plane changes biomechanics such that attainment of the safe zone is not as critical (Table III). By contrast, Tönnis angle changes of >5° were associated with acceleration of progression in the setting of safe zone attainment (30 years for attaining the Tönnis angle safe zone compared with 45 years for not attaining it), suggesting that large corrections in this plane in an attempt to reach the safe zone are not well tolerated (Table III). The achievement of additional safe zones generally increased the length of time patients spent in Tönnis grades 0 or 1: 25 years for 0 safe zones, 36 years for 1 safe zone, 29 years for 2 safe zones, 37 years for 3 safe zones, and 44 years for 4 safe zones (Table III). Multistate modeling was unable to demonstrate a consistent pattern with regard to the risk of progression when analyzed by transition between individual Tönnis grades (Table IV).

Evaluating the ACEA as a continuous variable showed that the risk of radiographic osteoarthritis progression decreased with an ACEA of ≥25° and was neutral or increased with an ACEA of <25° (Fig. 1-A). A similar analysis of the LCEA demonstrated that the risk of radiographic osteoarthritis progression decreased with an LCEA of ≥32°, was neutral with an LCEA of 15° to 32°, and was increased with an LCEA of <15° (Fig. 1-B). Finally, the analysis of the Tönnis angle indicated that the risk of radiographic osteoarthritis progression decreased with a Tönnis angle of <0°, increased with a Tönnis angle of 0° to 10°, was neutral with a Tönnis angle of 11° to 13°, and increased with a Tönnis angle of >13° (Fig. 1-C).

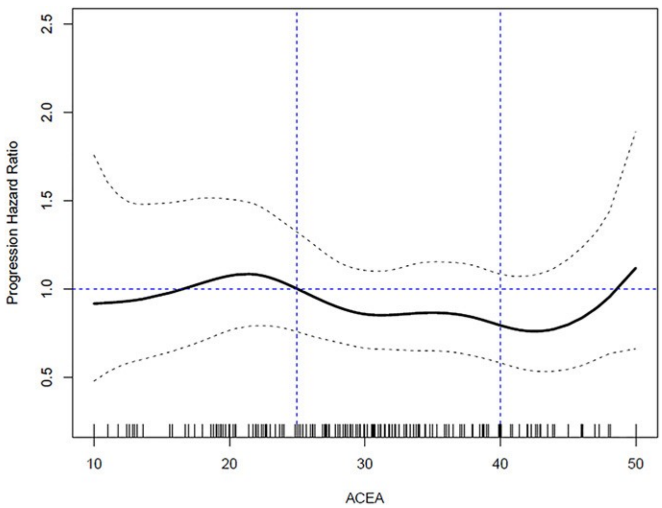

Fig. 1-A

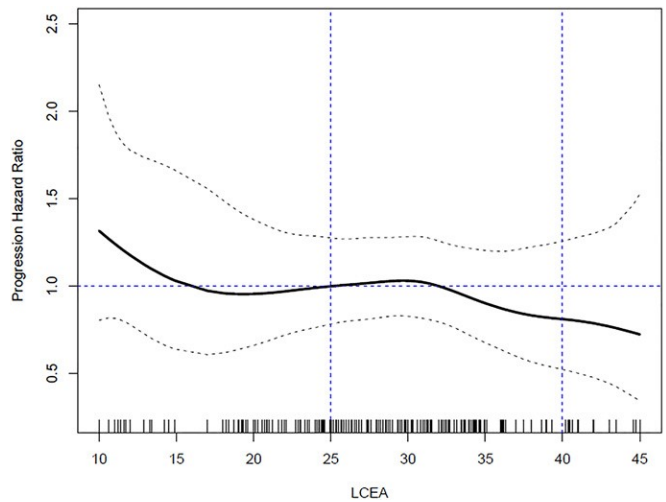

Fig. 1-B

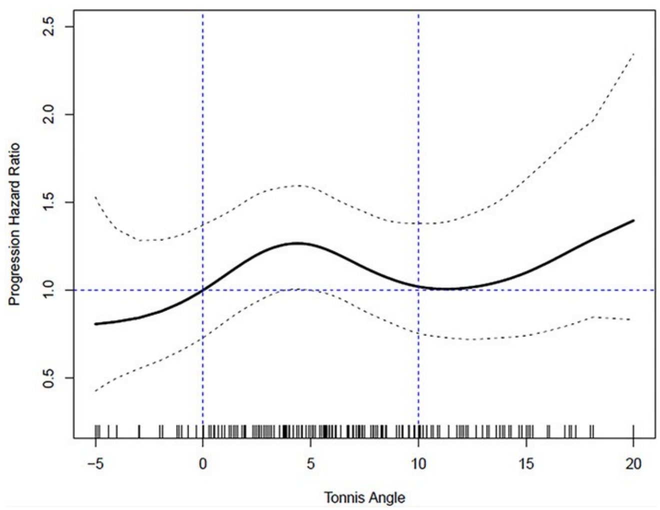

Fig. 1-C

Figs. 1-A, 1-B, and 1-C Risk of progression by at least 1 Tönnis grade based on the final acetabular position as determined by the ACEA (**Fig. 1-A**), LCEA (**Fig. 1-B**), and Tönnis angle (**Fig. 1-C**). Spline plots show risk as a continuous variable, with the curvilinear bordering dashed lines showing the 95% CI. The horizontal dashed line demonstrates a neutral relative risk of 1.0. The 2 vertical dashed lines show the safe zone for that radiographic metric.

Discussion

Reports on the impact of achieving adequate acetabular reorientation during PAO have been limited. This current study demonstrates the importance of obtaining appropriate multiplanar acetabular correction to enhance longevity of the native hip following PAO. Although the LCEA and the Tönnis angle are the most common metrics used to assess appropriate acetabular correction, this study shows that adequately addressing retroversion and the ACEA has a greater impact on improving the natural history.

Multiple previous studies have demonstrated that risk factors for poor native hip survivorship include Tönnis grade ≥2, poor preoperative joint congruency, and older patient age[3,4,6,8,9]. However, it remains unknown how the acetabular fragment should be positioned to optimize hip joint biomechanics following PAO. In reality, 1 optimal correction exists for every individual patient that must account for many factors including acetabular and femoral morphology and soft-tissue considerations[15]. Many hip preservation surgeons aim to correct the acetabular fragment to comply with described radiographic normative ranges[16,17]. These parameters for the acetabular version, ACEA, LCEA, and Tönnis angle[13] can be regarded as a theoretical acetabular safe zone, similar to how targets are used for acetabular inclination and version in total hip arthroplasty. We sought to determine if attainment of these radiographic metrics correlated with survivorship of the native hip following PAO. Data from the current study show, in general, that achieving these targets improves the prognosis. However, we were surprised to discover that obtaining the ACEA and appropriate version yielded the strongest correlation with improved hip survivorship. By contrast, most reports in the literature have focused on the LCEA and the Tönnis angle[2-5,8,9,18-20]. These parameters are easier to judge intraoperatively and radiographically, which may explain why they have been the gold standard for decades. Hartig-Andreasen et al.[8] showed that PAO outcomes were optimized with the LCEA between 30° and 40°, and Wells et al.[6] demonstrated worse survivorship with the LCEA of >38°. In contradistinction, we showed little effect from postoperative LCEA; however, the trend was for slightly delayed osteoarthritis progression with a higher LCEA of ≥32°. It should be noted that, despite these results,

we still believe that attaining the LCEA and Tönnis angle safe zones are important and we endeavor to do so for each patient.

Nevertheless, increasing attention has been paid to anterior-posterior coverage and version as the PAO surgical technique has matured over time[12]. Initiating or exacerbating acetabular retroversion or anterior overcoverage can result in iatrogenic impingement, which can decrease range of motion, increase pain, and compromise native hip survivorship[2,3]. Lending further credence to this phenomenon, 2 studies[2,6] have demonstrated that concurrent treatment of secondary impingement after the PAO with femoral osteoplasty is associated with improved long-term outcomes. Conversely, placing a patient in too much anteversion with anterior undercoverage has the potential to propagate instability and static point loading that is the hallmark of classic acetabular dysplasia[21]. Furthermore, this situation can be exacerbated by excess femoral version, which is a common concomitant hip joint abnormality in patients undergoing PAO for symptomatic acetabular dysplasia[15,22].

The multistate modeling technique in this study bears some discussion as it is unfamiliar to most orthopaedic surgeons. This methodology provides a more robust and precise analysis of survivorship compared with Kaplan-Meier analysis when multiple states of transition are possible, such as progression of osteoarthritis[14]. Time spent in each individual state can be predicted by leveraging inputs from every clinical observation: in this case, every available follow-up radiograph. An additional advantage is that the curves generated enable extrapolation of an expected time in a given state, even if the next state is not achieved. The statistical explanation behind this is complex, but relies on the calculation of the area under the curve for multistate modeling survivorship analyses. Thus, the expected time spent in a given Tönnis grade can be predicted well beyond the longest available clinical follow-up. As an example, we show that achieving the ACEA safe zone predicts a total time of 43 years spent in Tönnis grades 0 or 1, despite the fact that the longest clinical and radiographic follow-up was 21 years.

This study had noted limitations. The cohort size of 288 was relatively small for the type of analysis performed, which impeded the ability to assess secular trends over time. However, the power of the ultimate analysis was compromised by the aim of subanalyzing transitions between individual Tönnis grades and evaluating the impact of various radiographic predictors on this outcome. As such, there was a possibility of a type-II error in some of our results. There was also the potential for clustering and expertise bias as the group of 4 participating surgeons in this study are all high-volume open hip preservation surgeons in academic referral centers. Furthermore, the presented work utilizes the Tönnis system for the projection of degenerative changes over time. However, a host of patient features play a composite role in determining survivorship of the native hip after PAO, including the morphology of the proximal part of the femur and also the integrity of the chondrolabral complex, which is not captured by radiographs. In recognition of this point, another limitation was that, although we applied strict inclusion criteria including the absence of a prior hip surgical procedure, there were many patients in this study who had undergone a variety of concomitant procedures at the time of the PAO and procedures after the PAO. Although we had insufficient numbers to account for this statistically, it remains possible that undergoing additional procedures impacted the natural history of the natural hip or at least served as a marker of hip disease severity. The study was also limited by variability in the measurement of the radiographic parameters used in this work. Radiographic variables are prone to interobserver variability; however, we demonstrated good reliability between and within sites, with a kappa value of 0.8. Finally, it should be noted that the optimal acetabular reduction varied from case to case and was dependent on multiple factors, including the 3-dimensional acetabular and femoral morphology. Because of this morphological heterogeneity, patient-specific factors should be considered when determining optimal acetabular reduction parameters.

In conclusion, 2 of the most important unresolved questions with regard to PAO are (1) what the optimal target is for acetabular reorientation, and (2) whether surgeons can reproducibly hit this target. This study sheds light on the former and demonstrates that adequately correcting the ACEA and retroversion portends the best prognosis for native hip longevity following PAO. The LCEA and the Tönnis angle are the most common metrics used to assess appropriate acetabular correction; thus, great attention ought to be paid to the ACEA and version to obtain an ideal multiplanar correction. What remains unknown is whether the radiographically defined normal ranges for these metrics represent the true safe zone for a dysplastic hip following PAO. Future work should endeavor to identify more precise, patient-specific targets for optimal acetabular reorientation. ■

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