Journal of Hip Preservation Surgery, 2022, **9**, 78–83
DOI: https://doi.org/10.1093/jhps/hnac022
Advance access publication date: 16 April 2022
Research article

OXFORD

Prone Apprehension Relocation Test significantly correlates with radiological instability scores of the hip

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This study was approved by IRB/Ethikkommission Landesärztekammer Baden-Württemberg, Germany.

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ABSTRACT

Recently, there was a debate about whether borderline dysplastic hips should be treated surgically with hip arthroscopy or periacetabular osteotomy (PAO). Current studies recommend a classification into stable and unstable hips. Therefore, radiological scores have been described in recent years. Likewise, a new clinical stability test with the Prone Apprehension Relocation Test (PART) has been described. However, there has been no correlation between the modern radiological scores and the PART. We prospectively studied a consecutive group of patients who presented to our clinic. The PART and radiological scores were assessed in these patients. We divided the patients into a PART-positive and a PART-negative group and analyzed the associated clinical and radiological findings. Out of 126 patients (126 hips) included, 36 hips (29%) were evaluated as PART positive. There were significantly more females in the PART positive group ($P = 0.005$). Comparing the PART groups, significant differences ($P < 0.0001$) were found for the lateral center edge angle (LCEA), Femoro-Epiphyseal Acetabular Roof (FEAR) index, Gothic arch angle (GAA), anterior wall index (AWI), the occurrence of the upsloping lateral sourcil (ULS) and signs of acetabular retroversion. The correlation analysis showed an association between LCEA, FEAR index, GAA, AWI, ULS and the PART. A chi-square automatic interaction detection algorithm revealed that the strongest predictor of positive PART was the GAA. In conclusion, a high correlation between the PART and known radiological instability parameters was found. Consequently, a combination of clinical instability testing and radiological instability parameters should be applied to detect unstable hips.

INTRODUCTION

Developmental dysplasia of the hip is traditionally characterized as a bony deficiency of the acetabulum with aberrant coverage of the femoral head, which can subsequently lead to overloading and instability of the hip joint resulting in damage to the labrum and the acetabular cartilage [1–3]. In recent years, (micro)instability represents an increasing diagnosis [4–6] and there has been an increasing debate about whether borderline dysplastic hips with a lateral center edge angle (LCEA) between 18 and 25° should be treated surgically with hip arthroscopy or periacetabular osteotomy (PAO) [7–11]. Some research groups have proposed a distinction between stable and unstable hips in this regard, suggesting that stable hips should be more likely to undergo arthroscopy and unstable hips should be more likely to undergo acetabular reorientation [12–14]. However, the most challenging difficulty is the adequate recognition and classification into stable and unstable hips since there are no recognized diagnostic criteria for hip instability and objective criteria are lacking to date [4, 6, 15]. As a result, intraoperative verification by the ease of hip distraction, visualization of capsular thinning or redundancy on manual probing is still the gold standard [16, 17].

To address this challenge, radiological criteria have been described in recent years that may be used to assess the stability of a hip. These newly described criteria include the Femoro-Epiphyseal Acetabular Roof (FEAR) index, the sign of an upsloping lateral sourcil (ULS) or the very recently described Gothic arch angle (GAA) [12–14]. However, what all these scores have in common is that they represent only a static radiological description and do not allow conclusions to be drawn about the clinical examination. Moreover, it must be mentioned that these parameters only correlate with instabilities but cannot determine the final diagnosis of instability [5].

A very recently described clinical test for the detection of hip instability is the Prone Apprehension Relocation Test (PART) [18, 19]. A correlation between anterior undercoverage detected by computed tomography (CT) and a positive Part was demonstrated, as PART-positive patients had significantly more acetabular anteversion at the 3 o'clock position [18]. The authors thus recommend this test in the evaluation of potentially unstable

Submitted 4 December 2021; Revised 26 February 2022; Accepted 27 March 2022

hips. However, Spiker *et al.*'s study only collected the conventional radiological parameters such as the LCEA; thus, no correlation between the PART and the new radiological instability scores as described above has been analyzed so far.

Therefore, the aim of this study was to correlate the recently described PART with modern radiological signs of hip instability. We hypothesized that there is a significant correlation between these clinical and radiological instability parameters.

METHODS

After approval by the local ethics committee (F-2019-006), all patients presenting to the hip joint preservation consultation at our institution between January and March 2021 were prospectively enrolled. Inclusion criteria for patients selected for this study were as follows: hip pain without acute trauma, age >18 years, no previous hip joint surgery, Tönnis osteoarthritis degree <2, and no history of childhood hip pathologies [e.g. Perthes disease and slipped capital femoral epiphysis (SCFE)]. Patients were excluded if they met the following criteria: acute trauma, age <18 years, osteoarthritis (Tönnis >1), prior hip surgery, infections and history of childhood hip pathologies. All patients gave their informed consent.

All patients were clinically examined according to a standardized examination protocol. The clinical examination included gait pattern, hip range of motion, hip muscle strength and specific tests such as the log-roll test, Trendelenburg sign, flexion/abduction/external rotation test and flexion/adduction/internal rotation test. In addition, instability tests were performed, which included the already established hyperextension-external rotation test (HEER test) [20] and the prone instability test [21]. Moreover, the newly described PART was conducted. The PART is performed as follows: The patient lies in a prone position on the examination table and the examiner stands at the ipsilateral side. The examiner raises the patient's knee, extends the hip about 10–15° and supports the patient's 90° flexed knee. The hip is rotated neutrally during the test. The leg is abducted about 10° from the midline. The examiner then presses downward on the femur distal to the inferior gluteal crease. A positive PART is a replication of anterior hip pain due to the downward pressure on the femur. Anterior hip pain subsides when the downward pressure is released (Fig. 1) [18]. All clinical investigations were performed by the senior author (A.Z.).

Fig. 1. Performance of the PART. (a) The patient lies in a prone position on the examination table and the examiner stands at the ipsilateral side. The examiner raises the patient's knee, extends the hip about 10–15°, and supports the patient's 90° flexed knee. The hip is rotated neutrally during the test. The leg is abducted about 10° from the midline. (b) The examiner then presses downward on the femur distal to the inferior gluteal crease. A positive PART is a replication of anterior hip pain. (c) Anterior hip pain subsides when downward pressure is released by the examiner.

Radiological assessment included a standardized AP pelvic and 45° DUNN view. The AP pelvic images had to meet the following criteria to be considered neutrally rotated and tilted: 3 cm between the tip of the coccygeal apex and the upper aspect of the symphysis pubis and symmetrical foramen obturatorum [22, 23]. The following parameters were assessed on the radiographs (Fig. 2): Tönnis osteoarthritis degree [24], LCEA [25], anterior and posterior wall index (AWI/PWI) [26], cross-over sign (COS) [27], posterior wall sign (PWS) [28], ischial spine sign [29], FEAR [13], GAA [12], ULS [14] and alpha angle [30].

All radiographs were analyzed by two investigators (S.G. and A.Z.) independently and blinded to the PART results at two different time points using the software mediCAD (mediCAD Hectec GmbH, Altdorf, Germany). Radiographs that did not meet the above quality criteria were excluded from the analysis.

Statistical analysis

Continuous variables are presented as means ± SD with ranges, and categorical variables are presented as frequencies and percentages. Patients with positive PART examination and those with negative PART examination were tested for continuous variables using Student's t test and for count variables using Fisher's exact or χ^2 test. The Spearman coefficient analysis was used to identify correlations between the HEER test, the prone instability test and the PART and the radiological measurements. Correlation coefficients were classified by the strength of the correlation: excellent (>0.80), very good (0.71–0.80), good (0.61–0.70), fair (0.41–0.60) and poor (0.21–0.40). A chi-square automatic interaction detection (CHAID) model was used to analyze the relationship between the PART and radiographic parameters to predict the PART outcome [31]. Intra- and interobserver reliabilities regarding the radiological evaluation were determined according to intraclass correlation coefficients (ICCs). A perfect agreement is indicated by an ICC of 1. The sample size was determined a priori using G*Power software (version 3.1.9.4). The sample size was estimated to achieve a power $(1 - \beta)$ of 0.8 at a significance level of 0.05 and an effect size of 0.3. A total group size of 84 patients was required. The threshold for statistical significance was set to 0.05. Data were entered in Microsoft Excel (Microsoft Corp. Redmond, WA, USA) and analyzed using XLstat software (ADDINSOFT, Paris, France).

RESULTS

A total of 197 patients have been reviewed. After excluding 71 patients based on the exclusion criteria, 126 patients (126 hips) have been included. The patient characteristics are presented in Table I. There were significantly more women in the PART-positive group than in the PART-negative group. Likewise, the body mass index (BMI) was significantly lower in the PART-positive group.

Thirty-six patients (29%) had a positive PART. Comparing the PART-positive and negative groups, significant differences were found for the LCEA, AWI, FEAR, GAA, occurrence of ULS, and for radiological signs of acetabular retroversion. PART-positive hips were significantly less likely to present with signs of acetabular retroversion (Table II). We found very good ICC

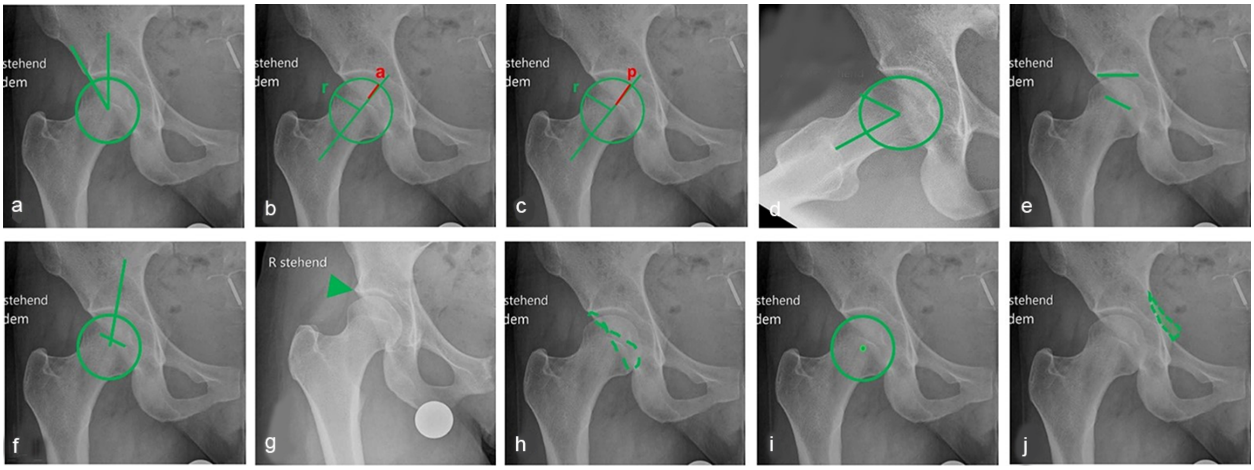

Fig. 2. Radiographic measurements. (a) LCEA: calculated by drawing a best fit circle around the femoral head. The angle is measured between two lines drawn from the center of the circle, one running vertically along the long axis of the pelvis and the other running vertically along the acetabular sourcil edge [25]. (b) AWI: measured by drawing a circle to approximate the femoral head and determining the radius of the head (r). Line from the medial edge of the circle to the anterior (a) wall is drawn and measured along the femoral neck axis. The AWI is calculated as a/r [26]. (c) PWI: measured by drawing a circle to approximate the femoral head and determining the radius of the head (r). Line from the medial edge of the circle to the posterior (p) wall is drawn and measured along the femoral neck axis. The PWI is calculated as p/r [26]. (d) Alpha angle: measured angle between the line connecting the point of no sphericity of the femoral head from the center of the femoral head and another line extending up to the center of the femoral head from the center of the femoral neck at the narrowest point [30]. (e) FEAR: formed by two lines connecting the inclination of the acetabular roof and the physeal scar of the femoral head [13]. (f) GAA: the angle is measured by drawing two lines: a line through the middle femoral physeal scar and a line connecting the center of the femoral head and the tip of the Gothic arch [12]. (g) ULS: A positive ULS is defined as a slope from caudal to cranial of the mid to far lateral aspect of the acetabulum with loss of normal lateral acetabular concavity [14]. (h) COS: describes the appearance of the anterior acetabular wall anterior to the posterior acetabular wall in the superior part of the joint. A line drawn along the anterior wall intersects with a line drawn along the posterior wall [27]. (i) PWS: A positive PWS is defined when the outline of the posterior acetabulum is visible medial to the center of the femoral head in the presence of a posterior acetabular deficit [28]. (j) Ischial spine sign: A positive ischial spine sign is present when the triangular projection of the ischial tuberosity is visible medial to the iliopectineal line [29].

Table I. ***Patient characteristics*** [a]

	Total ($n = 126$)	*PART negative ($n = 90$)*	*PART positive ($n = 36$)*	*P-value* [b]
Laterality, *n* (%)				
Right	66 (52)	45 (50)	21 (58)	0.005
Left	60 (48)	45 (50)	15 (42)	
Sex, *n* (%)				
Male	69 (55)	60 (67)	9 (25)	0.003
Female	57 (45)	30 (33)	27 (75)	
Age, y	29.6 ± 6.4 (18–39)	30.1 ± 6.4 (18–39)	28.2 ± 6.2 (18–38)	0.996
BMI, kg/m^2	24.5 ± 2.1 (18.4–28.1)	24.9 ± 2.0 (20.8–28.1)	23.3 ± 2.1 (18.4–25.6)	0.017

[a] Data are presented as mean ± SD (range) unless otherwise noted.
[b] Displayed is the statistical comparison between the two PART groups.
Significant differences are presented in bold.

scores for both inter- and intrarater reliability with respect to the individual radiological parameters (ICC, 0.91–0.94).

The correlation analysis showed a high linear association between LCEA ($P < 0.0001$), FEAR index ($P < 0.0001$), GAA ($P < 0.0001$) and the PART, and a moderate linear association between AWI ($P < 0.0001$), ULS ($P < 0.0001$) and the PART (Table III). Consequently, signs of borderline dysplasia with low LCEA, AWI and higher FEAR, GAA, occurrence of UCL were positively associated with PART-positive hips, whereas signs of acetabular retroversion were negatively associated with PART-positive hips. The correlations between the other instability tests and the radiological parameters are shown in Table III. A correlation between the HEER test and the prone instability test and the LCEA as well as a moderate association with the FEAR index and GAA were observed.

The CHAID algorithm revealed that the strongest predictor of positive PART was the GAA, with 90° as the threshold. Patients with a GAA greater than 90° had a positive PART result (Fig. 3). No other radiological parameters were identified with respect to PART prediction.

DISCUSSION

The main finding of the present study is a high correlation between the recently described PART as a clinical instability

Table II. ***Radiographic measurements***[a]

	Total (n = 126)	*PART negative (n = 90)*	*PART positive (n = 36)*	*P-value*[b]
Tönnis Grade				
0, *n* (%)	90 (71)	60 (67)	30 (83)	0.897
1, *n* (%)	36 (29)	30 (33)	6 (17)	
LCEA	27.5 ± 6.8 (12–38)	31.2 ± 3.6 (26–38)	18.2 ± 3.5 (12–23)	<0.0001
AWI	0.34 ± 0.07 (0.2–0.5)	0.38 ± 0.05 (0.29–0.5)	0.26 ± 0.04 (0.2–0.32)	<0.0001
PWI	0.96 ± 0.13 (0.75–1.2)	1.0 ± 0.1 (0.75–1.2)	0.95 ± 0.1 (0.8–1.2)	0.996
Alpha angle	68.6 ± 9.6 (50–80)	69 ± 9.8 (55–80)	70 ± 8.9 (55–80)	0.923
FEAR index	−2.7 ± 4.9 (−10–8)	−5.4 ± 2.2 (−10–−1)	4.3 ± 1.9 (2–8)	<0.0001
GAA	87.3 ± 5.1 (80–99)	84.4 ± 2.5 (80–89)	94.4 ±2.1 (92–99)	<0.0001
ULS, *n* (%)	33 (26)	2 (2)	31 (86)	<0.0001
COS, *n* (%)	19 (15)	19 (21)	0 (0)	<0.0001
PWS, *n* (%)	15 (12)	13 (14)	2 (7)	<0.0001
Ischial spine, *n* (%)	15 (12)	15 (17)	0 (0)	<0.0001

[a]Data are presented as mean ± SD (range) unless otherwise noted.
[b]Displayed is the statistical comparison between the two PART groups.

Table III. Correlation analysis of radiographic parameters and instability tests

	PART	*P-value*	*HEER*	*P-value*	*Prone instability*	*P-value*
LCEA	−0.855	<0.0001	−0.632	<0.0001	−0.635	<0.0001
AWI	−0.738	<0.0001	0.638	<0.0001	0.637	<0.0001
PWI	−0.149	0.097	−0.115	0.087	−0.112	0.087
Alpha angle	0.092	0.32	0.096	0.33	0.095	0.33
FEAR index	0.884	<0.0001	0.675	<0.0001	0.678	<0.0001
GAA	0.897	<0.0001	0.678	<0.0001	0.684	<0.0001
ULS	0.765	<0.0001	0.568	<0.001	0.675	<0.001
COS	−0.232	0.009	−0.166	0.011	−0.176	0.011
PWS	−0.275	0.002	−0.164	0.01	−0.174	0.01
Ischial spine sign	−0.275	0.002	−0.175	0.012	−0.175	0.012

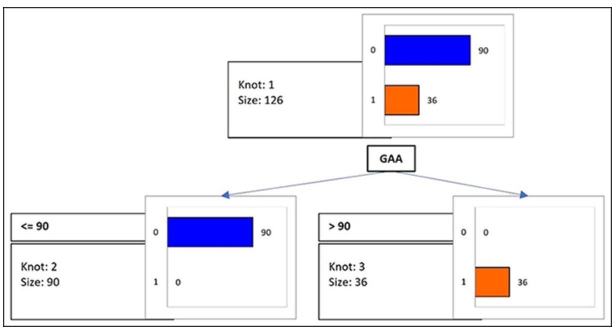

Fig. 3. A chi-squared automatic interaction detection classification tree analysis to identify the radiographic parameters related to a positive PART.

test and radiological instability parameters. Thus, there was an excellent linear correlation between the GAA, the FEAR index and the LCEA and a very good correlation between the AWI, ULS and the PART.

In recent years, there has been increasing controversy about whether so-called borderline hips with an LCEA between 18° and 25° can be treated arthroscopically or should undergo bony acetabular correction. Several groups have suggested that these borderline hips should be categorized into stable and unstable hips and consequently the stable hips may be treated arthroscopically and the unstable hips may undergo acetabular correction [12–14].

In order to achieve this differentiation, various radiological parameters have been defined and described in recent years, which should enable a distinction between stable and unstable hips. Wyatt *et al.* described the FEAR index, whereby a laterally opened angle >2° indicates an unstable hip [13, 32]. A related score, the GAA, was described by Zimmerer *et al.* in 2021, which includes the so-called Gothic arch of the pelvis [12]. A GAA > 90° indicates an unstable hip. Another radiographic parameter, the ULS, was described by Wong *et al.* in 2018 [14]. Patients with a positive ULS were associated with the clinical instability of the hip.

Another element of the stability assessment comprises the clinical examination. In 2020, a new instability parameter was described in the form of the PART by Spiker *et al.* [18]. The PART corresponds to a provocative examination that may be helpful in replicating the symptoms of hip instability. In this context, Spiker *et al.* demonstrated that PART-positive patients had significantly more acetabular anteversion in the 3 o'clock position as measured by CT. Thus, PART-positive patients appear to have an anterior deficient acetabulum. There was no association between PART and previously described anterior apprehension tests. However, Spiker *et al.*'s study did not capture and correlate the relationship between PART and the recent radiographic instability criteria mentioned above. In order to meet this concern, we conducted the present study. Thereby, we were able to demonstrate an excellent correlation between FEAR index, GAA, LCEA and the PART. However, in contrast to Spiker *et al.*'s study, we found a significant difference regarding LCEA between PART groups. In Spiker *et al.*'s study, the mean LCEA was 23.1 ± 7.3° in the PART-negative group and 21.1 ± 8.1° in the PART-positive group ($P > 0.05$) [18]. Thus, the mean LCEA of the PART-negative group is also within the range of borderline dysplasia. In our patient cohort, a positive PART was predominantly present in dysplastic hips (LCEA < 25°). The PART-negative patients demonstrated a mean LCEA of 31.2°, which corresponds to a normative lateral rim [33, 34]. Similarly, significantly more females in our cohort had a positive PART, which is likely due to the fact that the female gender is a predisposing risk factor for the occurrence of hip dysplasia [35].

An additional point noted by Spiker *et al.* included that a positive PART was associated with increased anteversion at 3 o'clock position on CT. However, an analysis of the anterior rim was not evaluated using the existing AWI radiographic score on an AP pelvis radiograph [26]. In this regard, we demonstrated that the PART-positive group had a significantly lower AWI than the PART-negative group. Similarly, a positive PART was correlated with a decreased AWI. Thus, we can confirm Spiker *et al.*'s results namely a correlation between a positive PART and a radiologically proven anterior deficient acetabulum. Another significant correlation in our analysis was between the ULS and the PART. Patients who had a positive ULS displayed a high proportion of a positive PART. Consequently, it can be concluded that the known radiological instability scores demonstrate a significant correlation with the PART as a clinical instability test. In the CHAID analysis, however, the GAA was shown to be the strongest predictor of a positive PART, revealing a threshold of 90°. As a next step, studies are needed to analyze the potential impact of the results, i.e. reliable classification into stable and unstable hips based on these clinical and radiographic parameters and consequently referral for hip arthroscopy or bony realignment of the acetabulum, and to demonstrate that reliable and excellent results can be achieved with this approach. The goal should be to develop consensus-based criteria to standardize definitions, diagnostic criteria and treatments for hip instability.

The study is limited by the fact that the clinical examination was performed by only one investigator, the senior author. Thus, there is a bias with regard of the interpretation and assessability of the PART result. However, a recent study demonstrated a high inter- and intraobserver reliability regarding the PART interpretation [19], so that we consider this bias as low. It should also be noted that the study was performed in a high-volume center, so that a high number of dysplastic hips were included in the patient population. Therefore, it may be difficult to generalize the data. General instability criteria, such as the Beighton score, were not recorded, so the influence cannot be assessed, although the primary aim of the present study was correlation analysis between PART and radiological parameters.

In conclusion, a high correlation between the PART and known radiological instability parameters was found. In particular, a high correlation was found between the newly described parameters of the FEAR index and GAA. Moreover, in the case of a deficient anterior acetabulum, there was also a significant correlation with a positive PART. Consequently, a combination of clinical instability testing and radiological instability parameters should be applied to detect unstable hips.

ACKNOWLEDGEMENTS

We acknowledge the support of the Article Processing Charge by the German Research Foundation and the Open Access Publication Fund of the University of Greifswald.

FUNDING

There was no external funding for this study.

CONFLICT OF INTEREST STATEMENT

None declared.

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