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Original article

Preoperative prognosis score is a useful tool regarding eccentric rotational acetabular osteotomy in patients with acetabular dysplasia

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ABSTRACT

Background: It is unknown how possible preoperative factors influence the postoperative outcome of eccentric rotational acetabular osteotomy (ERAO). We aimed to determine these factors and to develop a scoring system for predicting the prognosis after ERAO in patients with symptomatic hip dysplasia.
Patients: We included 700 patients (54 men, 646 women) who underwent ERAO during September 1989 to March 2013. The patients' clinical background, preoperative clinical findings, and preoperative imaging findings were examined retrospectively. Univariate and multivariate Cox regression were performed using the time from the day of surgery to a Harris hip score (HHS) <80 as an endpoint. A failure score was defined to predict the prognosis for an HHS <80, and its predictive capacity was assessed.
Results: Ninety patients had an HHS <80. Forty-two patients underwent conversion to total hip arthroplasty (THA) after their HHS decreased to <80. Five factors were identified in relation to an HHS <80: a history of congenital dislocation of the hip, joint congruity, body mass index, the preoperative minimum joint space width, and the preoperative abduction range of motion. We estimated the weight of each factor using the results of multivariate Cox regression, and the outcome prediction scoring was obtained (0–17 points). For three groups of patients (total points of each factors: 0–5, 6–9, and ≥10 points), the Kaplan–Meier event-free survival rates at 15 years postoperatively for an HHS <80 were 97%, 81%, and 55%, respectively; the survival rates for THA conversion using this prediction scoring were 99%, 96%, and 85%, respectively.
Conclusions: Five preoperative factors can easily and clearly predict the prognosis following ERAO. The prognosis score may be a useful tool when making a decision regarding operative treatments in adult patients with acetabular dysplasia.

There are various procedures for performing acetabular osteotomy in acetabular dysplasia or early osteoarthritis of the hip, including periacetabular osteotomy (PAO) [1], rotational acetabular osteotomy (RAO) [2], eccentric rotational acetabular osteotomy (ERAO) [3], and curved periacetabular osteotomy [4]. By rotating the acetabular fragment, changing the load direction, and expanding the load area, these operative procedures aim to reduce burden on the cartilage and stabilize the joint. Recently, favorable clinical outcomes and mid-to long-term outcomes have been reported for acetabular osteotomy procedures [5,6]. Under appropriate indications and surgical procedures, favorable prognoses are expected for all of these operative procedures. Since 1989, we have performed a type of PAO called eccentric rotational acetabular osteotomy, and we have reported favorable clinical outcomes and long-term outcomes similar to those aforementioned [3,7,8].

Various risk factors relating to the postoperative outcome of acetabular osteotomy have been reported [8–11], including age [12–15], sex [16,17], joint congruity [18,19], preoperative minimum joint space width [20,21], obesity [8,22], and postoperative acetabular coverage [9,23]. However, in individual cases, it is likely that these factors exert complex effects. The degree to which a given factor affects the prognosis is still unclear. Consequently, the expected prognosis is also unclear. In addition, there are no reports

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on preoperative predictions of prognosis for making individualized decisions in patients with acetabular dysplasia.

We created a simple method for predicting the postoperative prognosis after ERAO by referring to patients' preoperative clinical backgrounds, clinical findings, and imaging findings. Using these preoperative parameters, our objective was to predict the optimal period at which joint function can be preserved following ERAO before patients undergo surgery.

1. Materials and methods

We included 711 individuals who consecutively underwent ERAO from September 1989 until March 2013 and for whom follow-up for at least 1 year was possible. Surgery was performed by a single surgeon (H. Y.). Inclusion criteria were mainly symptomatic pre/early-stage hip osteoarthritis. In advanced stage osteoarthritis, we decided on surgery because of the patient's age (≤60 years) and joint congruity (i.e., improvement in maximum abduction). Patients with end-stage hip osteoarthritis, hip contracture or <1 year of follow-up were excluded. Finally, 11 individuals were excluded.

Of the remaining 700 individuals, 54 hips were in men, and 646 were in women. The mean age at the time of ERAO was 40 ± 11 years. The mean duration of follow-up was 9.5 years (range, 1–24 years). Patients' background characteristics are shown in Table 1.

All patients' preoperative clinical background characteristics, clinical findings, and imaging findings were retrospectively examined from the medical charts, hospital records, and surgical records. The preoperative patients' clinical background factors included age, height, weight, body mass index (BMI), bilateral or unilateral dysplasia, the operative side, a history of developmental dysplasia of the hip (DDH), a history of hip surgery, and preoperative sports participation. A history of DDH was defined by the existence of closed reduction (i.e., cast treatment or traction or Pavlik harness). A history of hip surgery was defined by open reduction or osteotomy (e.g., Salter osteotomy and triple osteotomy). The absence and presence were scored as yes or no, whereas the measured values were assessed as continuous variables when possible. Current preoperative sports participation was assessed as follows: regular exercise at least once per week was recorded as yes, and anything less was recorded as no.

Preoperative clinical findings included the preoperative Harris hip score (HHS) and preoperative range of motion (ROM). Hip joint ROM was measured by outpatient clinic physicians (A. T. and H. Y.).

Imaging findings included the preoperative stage of osteoarthritis of the hip (Ninomiya and Tagawa [2]: stage 1 indicates no osteoarthritic change; stage 2 indicates slight narrowing of the joint space (early stage osteoarthritis); stage 3 indicates narrowing of the joint space associated with cystic lucencies and small osteophytes in the acetabulum and femoral head (advanced osteoarthritis). This classification is very similar to Tőnnis grades.), preoperative minimum joint space width, preoperative center-edge (CE) angle, preoperative acetabular head index (AHI), and joint congruity. Joint congruity was assessed and modified from the classification of Yasunaga [23] as follows: cases with no worsening of joint congruity in abduction and cases in which the margins of the acetabular roof and epiphysis were parallel were considered good, whereas all other cases were considered poor.

Radiographic measurements were obtained using a medical computer system (NeoChart Hospital Information System; Fujitsu, Tokyo, Japan). Imaging findings were independently recorded three times by two authors (A. T. and H. Y.) with an interval of 1 month between each measurement. Intraclass correlation coefficients between the two authors for the preoperative disease stage, preoperative joint space width, preoperative CE angle, preoperative AHI, and joint congruity were 0.789, 0.965, 0.963, 0.967, and 0.847, respectively.

Table 1
Patients background.

	Total	Non occurrence of event	HHS <80	THA conversion
No. of patients (hips)	700	610	90	42
Males	54	49	5	2
Females	646	561	85	40
Left	356	306	50	22
Right	344	304	40	20
Mean age (yr)	40 ± 11	40 ± 11	42 ± 9	47 ± 7
Mean height (cm)	157 ± 6	157 ± 6	156 ± 5	156 ± 5
Mean weight (kg)	54 ± 9	54 ± 8	56 ± 11	56 ± 8
Body mass index (kg/m^2)	22 ± 3	22 ± 3	23 ± 4	23 ± 3
Duration of follow-up				
Mean (yr)	9.5	10	5.7	10.4
Median (yr)	8.3	9.2	5	9.6
IGR (Q1–Q3) (yr)	4–15	5–16	1–8	6–15
Preoperative CE[a] angle (°)	3.2 ± 9.3	3.4 ± 8.9	2.0 ± 11.3	2.8 ± 9.8
Preoperative AHI[b] (%)	52.9 ± 9.3	52.9 ± 8.9	52.8 ± 11.5	53.1 ± 10.5
Postoperative CE[a] angle (°)	35.2 ± 8.7	35.7 ± 8.3	31.9 ± 10.3	34.2 ± 9.4
Postoperative AHI[b] (%)	93.7 ± 8.3	94.4 ± 7.5	89.6 ± 11.3	90.2 ± 10.5

[a] CE: center edge.
[b] AHI: acetabular head index.

2. Process of extracting the predictive factors

To extract the predictive factors, the process involved four phases from a previous scoring modeling method [24] supervised by the biostatistician (M. K.).

In phase 1, the endpoint was the length of time from the day of surgery to an HHS <80 for the first time; univariate Cox regression was performed for this endpoint. Factors with a $p < 0.05$ were considered candidate factors. Then, multivariate Cox analysis was performed using a stepwise method. By using a stepwise method, it was possible to properly adjust prognosis-related factors and confounding factors. Postoperative predictive factors for an HHS <80 were extracted respectively.

In phase 2, continuous variables for the predictive factors extracted in phase 1 were categorized. Multivariate Cox regression was performed again for the categorized variables. Based on the estimated coefficient, the prognosis score was defined.

In phase 3, the predictive ability of the scored prediction formula was assessed using Harrell's C-index [24]. The C-index is defined as the probability that the results predicted by the model agree with the actual prognosis.

In phase 4, cutoff scores were established to enable the efficient determination of the prognosis. Event-free survival rates were confirmed for the endpoint (an HHS <80), and Kaplan–Meier survival curves were created. We also evaluated total hip arthroplasty (THA) conversion as an endpoint using this prognosis score and created a Kaplan–Meier curve.

All statistical analyses were performed with SAS, version 9.3 (SAS Institute, Cary, NC, USA) by aforementioned biostatistician. The present study received approval from our hospital's institutional ethical review board. No external funding was received for this study.

3. Results

3.1. Phase 1

Regarding the endpoints, 90 patients demonstrated an HHS <80, whereas 42 were converted to THA. Conversions to THA were performed after the patients' HHS decreased to <80, and the mean duration until THA conversion was 4.5 years.

Univariate Cox regression was obtained, as shown in Table 2. According to multivariate Cox regression analyses after univariate Cox regression, the following five factors were abstracted when defining an HHS <80 as an endpoint: a history of DDH, joint congruity, BMI, the preoperative minimum joint space width, and the preoperative abduction ROM (Table 3). The five factors were similarly accorded with forward and backward methods and the robustness of the five factors were statistically probable as prognosis factors.

3.2. Phase 2

According to the Cox proportional hazards analysis, continuous variables were categorized, and a hazard ratio for each factor was determined. We classified each factor by referencing previously published literature and international criteria. We estimated the weight of each factor using the results of multivariate Cox regression, and the final scores were obtained, as shown in Table 4.

Table 2
Univariate Cox analysis.

Variable	Hazard ratio	95% CI		p value
Sex	1.472	0.597	3.628	0.4011
Unilateral or bilateral dysplasia	1.034	0.679	1.576	0.8755
Operative side	1.148	0.757	1.74	0.5155
Past history of developmental dysplasia of the hip	2.443	1.523	3.919	0.0002*
Joint congruity	7.817	4.551	13.429	<0.0001*
Age	1.029	1.009	1.05	0.0042*
Body weight	1.031	1.007	1.055	0.011*
Body height	0.978	0.945	1.013	0.2125
Body mass index	1.116	1.054	1.182	0.0002*
Minimum joint space width	0.52	0.448	0.605	<0.0001*
Past history of previous surgery	3.903	2.164	7.041	<0.0001*
Preoperative CE angle[a]	0.994	0.97	1.019	0.642
Preoperative AHI[b]	1.017	0.989	1.045	0.2336
Preoperative stage (Tagawa and Ninomiya)	3.273	2.43	4.41	<0.0001*
Preoperative HHS[c]	0.902	0.88	0.924	<0.0001*
Preoperative range of motion				
(flexion)	0.965	0.957	0.972	<0.0001*
(abduction)	0.873	0.844	0.903	<0.0001*
(adduction)	0.901	0.854	0.951	0.0002*
(internal rotation)	0.945	0.929	0.962	<0.0001*
(external rotation)	0.943	0.915	0.972	0.0001*
(extension)	0.885	0.855	0.916	<0.0001*
Presence of preoperative sports participation	0.917	0.497	1.694	0.7824
Postoperative CE angle	0.950	0.297	0.974	<0.0001*
Postoperative AHI	0.946	0.927	0.966	<0.0001*

*: $p < 0.05$.
[a] CE: center edge.
[b] AHI: acetabular head index.
[c] HHS: Harris hip score.

Table 3
Multivariate Cox analysis.

	Hazard ratio	95% CI		p value
History of DDH[a]	1.655	1.011	2.711	0.0452
Joint congruity	2.961	1.550	5.660	0.0010
Body mass index	2.316	1.362	3.937	0.0019
Minimum joint space width	1.672	1.362	2.053	<0.0001
Abduction	1.781	1.049	3.025	0.0327

[a] DDH: developmental dysplasia of the hip.

3.3. Phase 3

For an HHS <80, the C-index of the prediction formula was 0.750 (95% confidence interval: 0.714–0.787). In this case, it can be interpreted that the scores of the predictive model reflected the prognoses for 75.0% of the analysis set. Fig. 1 shows the change in the 5-, 10-, and 15-year event-free survival rates for each score, and it shows a correspondence between the scores and prognoses.

3.4. Phase 4

Based on data from our 700 subjects, we determined a cutoff value that would enable us to efficiently separate the possible prognoses into three grades. For an HHS <80, three prediction score grades were established: 0–5, 6–9, and ≥10 points. Since the performance of the predictive model was evaluated using the C-index, the method of division is not related to the performance of the predictive model; thus, we would like to focus on the fact that the division into three grades was done for convenience. Kaplan–Meier curves were created for these grades (Fig. 2). The 15-year survival rates for the three aforementioned grades were 97%, 81%, and 55%, respectively. Using this prediction scoring, Kaplan–Meier curves were created for the endpoint of THA conversion (Fig. 3). The 15-year survival rates for the three aforementioned grades were 99%, 96%, and 85%, respectively.

4. Discussion

We abstracted five factors (a history of DDH, joint congruity, BMI, the preoperative minimum joint space width, and the preoperative abduction ROM) from the preoperative parameters. With this prognosis score, we were able to clarify the expected prognosis after ERAO for patients with acetabular dysplasia before they underwent surgery. This scoring system included the factors in patients' clinical background characteristics, clinical findings, and imaging findings, and each factor can be easily assessed by hip specialists and general orthopedists.

Table 4
Scores for the categories of each prognosis factor.

Factor	Category	Estimate	Score
History of DDH[a]	No		0
	Yes	0.5100	2
Joint congruity	Good		0
	Poor	1.0767	4
Body mass index	<25 kg/m^2		0
	≧25 kg/m^2	0.8470	3
Minimum joint space width	≧4 mm		0
	2 mm ≦ <4 mm	0.6035	2
	<2 mm	1.6528	6
Abduction	≧30°		0
	<30°	0.5783	2

[a] DDH: developmental dysplasia of the hip.

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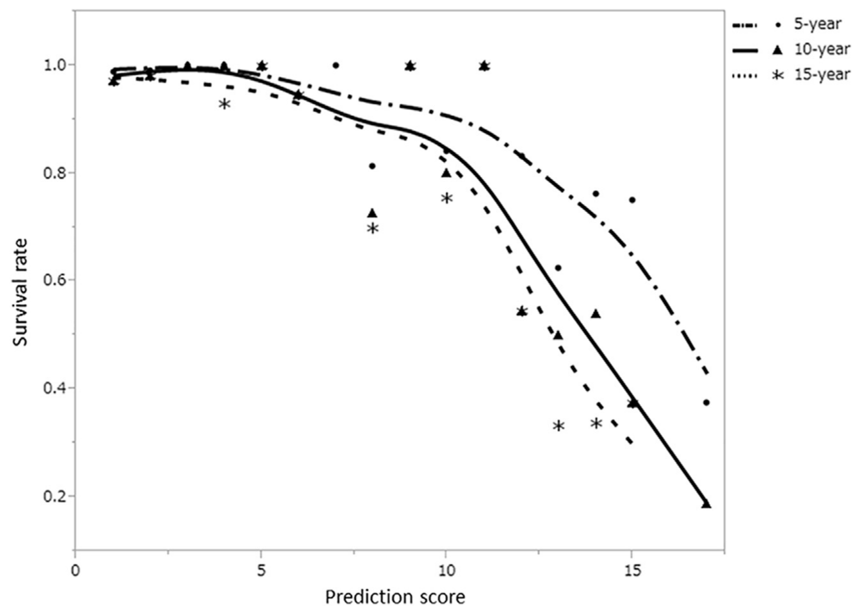

Fig. 1. Survival rate of each prediction score (●: 5-year survival rate, ▲: 10-year survival rate, *: 15-year survival rate, each line means approximate curves of each survival rate.).

In the present study, the minimum joint space width and joint abduction ROM were abstracted as predictors of the prognosis. Affected joint conformity and joint space width have been reported as postoperative risk factors [18–21]. Regarding the joint space width, Yasunaga [20] and Hasegawa [21] defined a cutoff value of 2 mm. Similarly, in our scoring system, a joint space width of <2 mm was assigned a high score of 6 points; thus, the joint space width was confirmed as a crucial factor for prognosis. Although the hip abduction ROM was a predictor of the prognosis, there are no previous reports on hip ROM and prognosis prediction of peri-acetabular osteotomy. We performed multivariate Cox analysis using not only a stepwise method but also forward and backward methods, the abduction ROM was extracted by all the methods. So we were unable to disregard the factor. Only some previous have reported on prognosis prediction of osteoarthritis of the hip [25,26]. Arokoski [25] reported that the lower ROM of the hip was in abduction and in both internal and external rotations when osteoarthritis of the hip deteriorated. Our result might suggest the preoperative slight contracture predict the postoperative progression of osteoarthritis. We classified abduction as ≥30° or <30°. By consulting the Merle d'Aubigne-Postel hip score, full points for mobility is flexion of >90° and abduction up to 30°. In our study, the

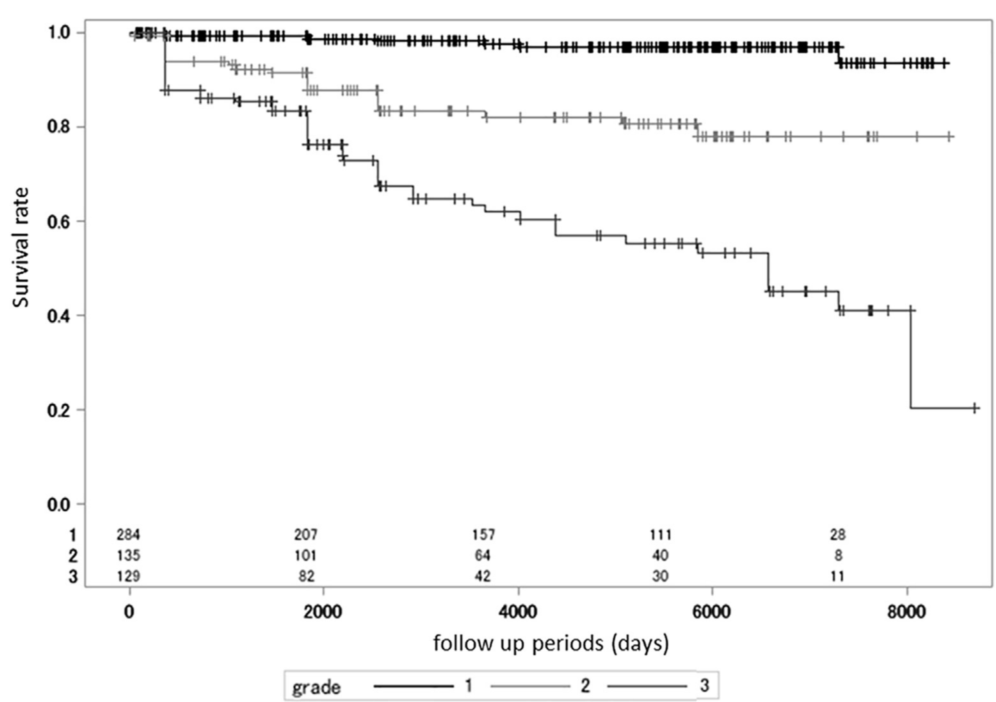

Fig. 2. Event-free survival of each grade (0–5, 6–9, and ≥10 points) for the endpoint of an HHS <80.

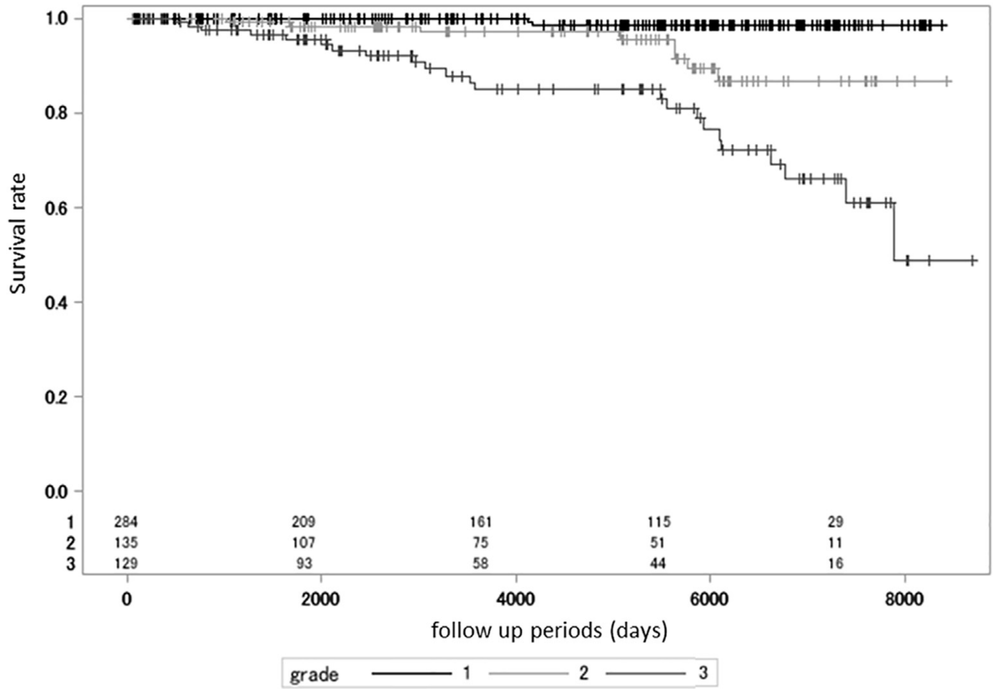

Fig. 3. Event-free survival of each grade (0–5, 6–9, and ≥10 points) for the endpoint of THA conversion.

overall median abduction was also 30° so we considered 30° as the normal and adequate range.

Joint congruity is a well-known risk factor [8,18,19]. Yasunaga [18] and Okano [19] divided joint congruity into four groups (excellent, good, fair, and poor); however, the borderline of each group was vague, and the assessment was difficult for anyone other than hip specialists to perform. We simply classified excellent and good in the aforementioned classification as good, and fair and poor as poor [8,12]. The inter-rater reliability for joint congruity was 0.847, proving that this classification was more useful and consistent. Joint congruity was also assigned a high score of 4 points, which was a proven risk factor.

Age was not abstracted as a predictor of prognosis for those with an HHS <80. Several studies have examined age as a predictor of prognosis [12–15,27], and two have demonstrated that 30–40 years is a significant risk factor [9,10]. However, the rest of these studies have reported favorable prognoses even for patients aged 40–59 years if the indication of osteotomy was suitable [12,14,15,27]. The mean age of patients who underwent surgery at our department was 40 years, and the oldest patient was 62 years. For patients aged ≥50 years, we chose not to perform osteotomy if it would be too difficult on the patient. Therefore, among patients aged ≥50 years, the percentage of patients converted to THA may increase.

There are various indicators of acetabular coverage such as the CE angle and AHI. In the present study, these were not predictors of prognosis with regard to the severity of preoperative dysplasia. Koga [23] also reported that preoperative acetabular coverage did not affect the progression of osteoarthritis. With ERAO, a spherical osteotomy, you can rotate the acetabulum to achieve coverage of an acetabular roof angle of 0°. Thus, pubic discontinuity is less likely to occur in ERAO than in PAO [28]. Therefore, if congruity is favorable, the likelihood of a favorable outcome is high. This may be why the CE angle and AHI were not identified as preoperative predictors of prognosis in the present study.

There were significant factors in terms of the postoperative CE angle and AHI in univariate Cox analysis. The aim of our study was to predict the prognosis after ERAO when patients decided to undergo the operation, and we created a prognosis score based on only the preoperative factors. However, it is important to obtain optimal acetabular coverage to achieve a favorable postoperative clinical outcome. Some authors have identified significant risk factors associated with a postoperative CE angle <25° and a postoperative AHI <80% [9,23]. Our results for the postoperative CE angle were almost between 30° and 40°, and our results for the postoperative AHI were nearly 90%; thus, most patients obtained optimal acetabular coverage. Hence, we considered that our individuals were impartial for predicting the score.

There were some limitations to the present study. First, it was a retrospective trial that only examined outcomes for a single operative procedure (i.e., ERAO) by a single surgeon on a single race. There are reports of favorable outcomes for PAO [10,11,22] as well as favorable medium to long-term outcomes for RAO [7,29,30]. In terms of medium to long-term outcomes, the 15-year event-free survival rate for patients in our department was 83.4% (range, 79.7–86.5%), which is nearly equivalent; thus, the same predictors of prognostication may be important factors even for a different operative procedure or in subjects of a different race. Second, we did not examine some postoperative risk factors in the prognosis prediction, so we do not know whether the progression of a deformity can be affected by a postoperative activity or a body weight increase. Depending on the postoperative status, outcomes can consequently be worse than those predicted in the present study. Furthermore, since the current study assessed the prognosis of 700 patients, many kinds of postoperative changes were included. Thus, if the same treatment is performed for all patients, the results should resemble the prognoses predicted in the present study. Being particular about the preoperative parameters may make it possible to present patients with a clear preoperative prognostic prediction. Third, we did not evaluate preoperative intraarticular conditions such as the cartilage status by using magnetic resonance imaging (MRI). From the viewpoint of screening, MRI is fairly costly and difficult for patients to undergo at general clinics. If we use routine MRI examination to evaluate the cartilage status, we may precisely predict the prognosis of ERAO.

We created a prognosis score for the postoperative outcome prediction after ERAO by referring to five preoperative factors, and we were able to clarify the expected prognosis for patients with acetabular dysplasia. Outcome prediction scoring may be a useful tool for making decisions regarding operative treatments in adult patients with acetabular dysplasia.

Conflict of interest

The authors declare that they have no conflict of interest.

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