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Monthly changes in the acetabular index according to age and sex: A large-scale analysis in healthy children aged 6 months to 5 years

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Abstract

This retrospective study aimed to evaluate age- and sex-related changes in the acetabular index (AI) and to provide age-specific reference values in healthy children aged 6 months to 5 years. A total of 1,640 children (841 females, 799 males) with radiographs obtained between January 2020 and December 2024 were included. Radiographs included both dedicated pelvic radiographs and imaging series in which the pelvis was incidentally visualized. AI measurements were performed digitally for both hips, and intraobserver and interobserver reliability were assessed using intraclass correlation coefficients (ICCs). AI values showed a strong inverse correlation with age ($r = -0.93$, $p < 0.001$), with a progressive decline throughout early childhood. Female children consistently exhibited higher AI values than male children across all age groups ($p = 0.013$). Measurement reliability was excellent, with ICC values ranging from 0.91 to 0.96. In conclusion, AI values show a progressive age-related decline during early childhood and remain consistently higher in female children. Age-specific reference values at monthly and three-month intervals may support the clinical assessment and follow-up of acetabular development, particularly in children with developmental dysplasia of the hip.

Keywords: Acetabular index; developmental dysplasia of the hip; early childhood; reference values; pelvic radiography

Introduction

Developmental dysplasia of the hip (DDH) is among the most common pediatric hip disorders [1]. Effective treatment has been available for many years, and the widespread implementation of screening programs has enabled early diagnosis, allowing many potential morbidities to be prevented through appropriate treatment [2]. Although hip ultrasonography is preferred for the diagnosis and treatment follow-up of DDH in early infancy, hip radiography is used as the primary imaging modality in infants older than six months and in older age groups [3,4].

Various radiographic parameters have been defined for the diagnosis and follow-up of DDH. Among these, the acetabular index (AI) is one of the most frequently used measurements. The AI is a globally accepted and widely used parameter not only for the diagnosis of DDH but also for monitoring acetabular development after treatment and for detecting residual acetabular dysplasia [5,6]. Reference values for the AI have been established in the literature for different age groups and sexes, and data from various countries and ethnic populations have been reported [7-9]. Studies reporting reference AI values for the Turkish population are also available [10,11].

Because the AI changes dynamically during early childhood, knowledge of the mean AI value appropriate for a child's chronological age is of substantial clinical importance during early follow-up after surgical interventions for DDH. The aim of this study was to determine age- and sex-specific AI reference values in healthy children aged 6 months to 5 years. AI measurements were evaluated at monthly intervals for children aged 6-36 months and at three-month intervals for those aged 36

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months to five years. Although based on single-center data, this study aims to provide a practical reference for clinical practice in Türkiye by presenting detailed age-specific AI values across the first five years of life.

Material and Methods

This retrospective study was approved by the Sincan Training and Research Hospital Scientific Research Ethics Committee (Approval No.: BAEK-2025-119; date: 18.11.2025) and adhered to the principles of the Declaration of Helsinki. The study was designed, conducted, and reported in accordance with the STROBE guidelines for observational studies.

Radiograph screening and patient selection are summarized in Figure 1. Only radiographs that had already been obtained for clinical indications between January 1, 2020, and December 31, 2024, were used; no radiographs were acquired specifically for this study. The initial screening team reviewed all imaging records to identify radiographic series that included the pelvis, including dedicated pelvic radiographs and abdominal, lumbar, and trauma series in which the pelvis was incidentally visualized. Because many of these radiographs were not primarily obtained for dedicated orthopedic pelvic assessment, all images underwent strict quality screening before AI measurement. Eligible radiographs required clear visualization of both hips, the triradiate cartilage, and the acetabular roofs, along with acceptable pelvic positioning, as assessed by visual and quantitative radiographic criteria, including obturator foramen symmetry and pubis-to-sacrococcygeal distance. Radiographs with incomplete pelvic visualization, excessive pelvic tilt or rotation, poor image quality, distorted pelvic contours, or obscured anatomical landmarks were excluded. Patients with pelvic trauma, congenital pelvic anomalies, neuromuscular disorders affecting hip development, or prior DDH surgery were also excluded. When multiple radiographs were available for the same patient, only one eligible radiograph was retained. Eligible radiographs were then categorized into monthly age groups for children aged 6-36 months and three-month age groups for those aged 36-60 months.

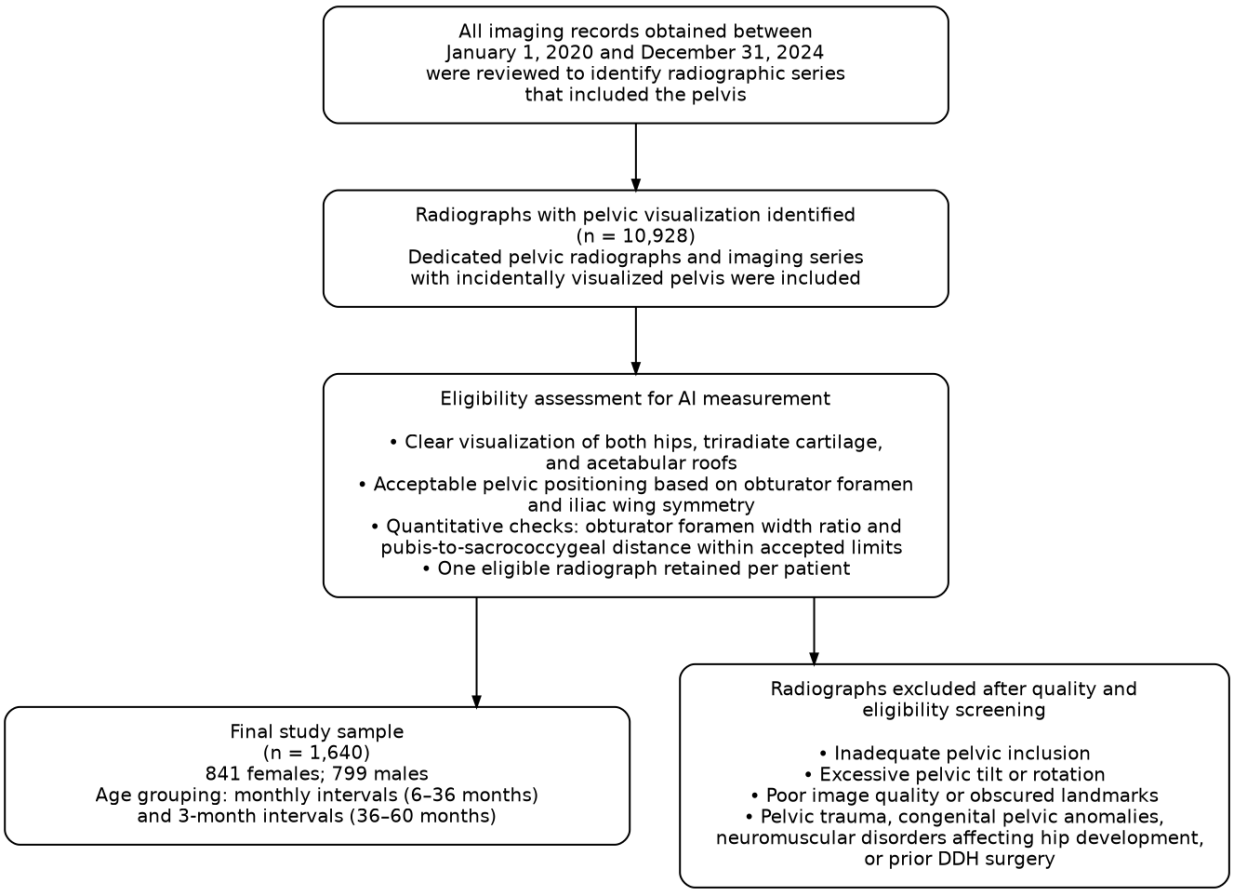


Figure 1. Flow diagram of radiograph screening and patient selection.

The AI was measured on standardized anteroposterior pelvic radiographs in accordance with established radiographic principles using the hospital's Picture Archiving and Communication System (SimplexBT RadX, version 2.2.2). Hilgenreiner's line was defined as a horizontal line connecting the inferior margins of both triradiate cartilages. The AI was

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defined as the angle formed between Hilgenreiner's line and a line drawn from the triradiate cartilage to the lateral osseous margin of the acetabular roof. The lateral edge of the acetabular sourcil was not used as a measurement reference point, based on previous evidence showing that its use, particularly at early ages, may lead to overestimation of residual acetabular dysplasia and reduced measurement reliability (Figure 2) [12]. All measurements were performed digitally using the integrated angle measurement tool of the PACS system; analog radiographs were not used. Measurements were performed independently by two orthopedic surgeons experienced in pediatric hip imaging, who were blinded to patient age, sex, and clinical information and were unaware of each other's measurements. Radiographs were reviewed in a randomized order, with all patient-identifying and demographic information concealed. Bilateral AI measurements were obtained for all included radiographs, as only images that met the predefined anteroposterior pelvic imaging criteria and provided complete visualization of both hips were included in the analysis.

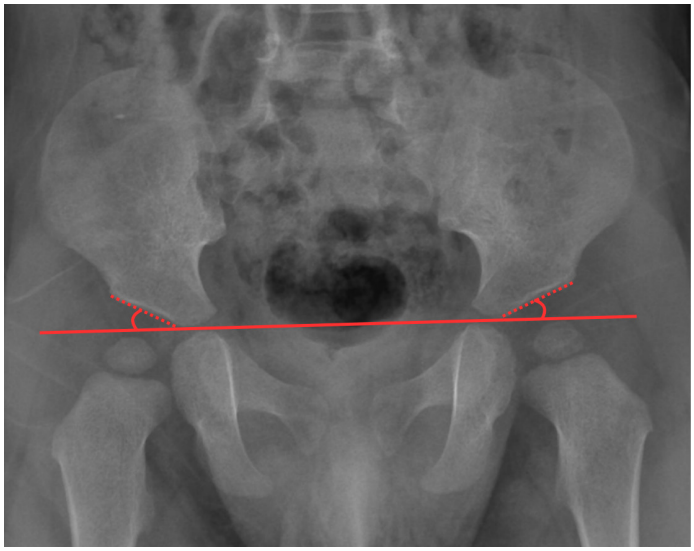


Figure 2. Representative anteroposterior pelvic radiograph demonstrating AI measurement. The AI was defined as the angle between Hilgenreiner's line and a line drawn from the triradiate cartilage to the lateral osseous margin of the acetabular roof.

To evaluate intraobserver and interobserver reliability, a subset of 41 radiographs was randomly selected from the study cohort to represent different age groups. Each observer measured these radiographs twice at a one-week interval to reduce recall bias. Intraclass correlation coefficient (ICC) analysis was performed to assess measurement reliability.

Statistical analyses were conducted using IBM SPSS Statistics (version 26.0.0.0). Continuous variables were expressed as the mean ± standard deviation (SD). The distribution of AI measurements was evaluated using visual methods (histograms and Q-Q plots) and analytical tests. The relationship between age and AI was examined using Pearson correlation analysis. Differences in AI values between female and male children were assessed using independent-samples t tests. Comparisons between the right and left hips within the same radiograph were assessed using paired-samples t tests, when applicable. All statistical tests were two-tailed, and a p value < 0.05 was considered statistically significant.

Results

Measurements were obtained from a total of 1,640 children (841 females and 799 males) aged 6 to 60 months. Mean AI values stratified by age, sex, and side are presented in Table 1 and illustrated in Figure 3.

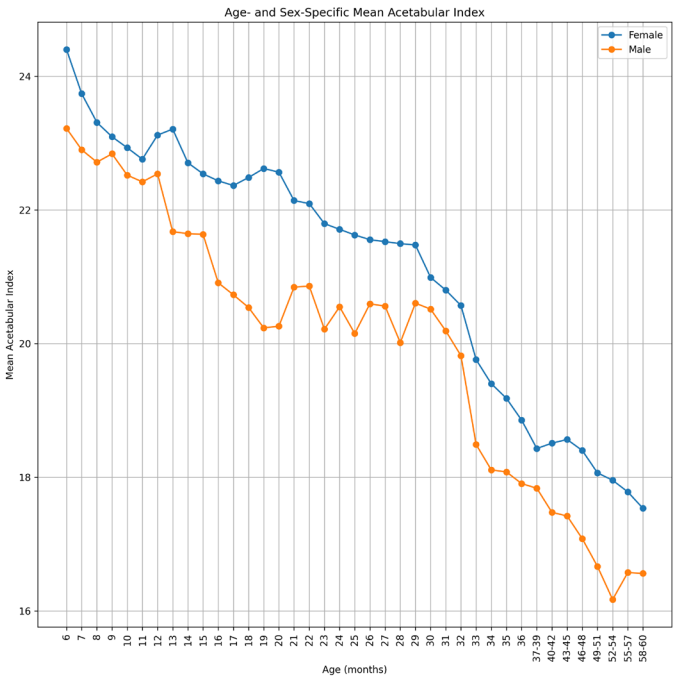


Figure 3. Sex-specific trends in acetabular index values across age groups.

In the overall study population, the AI demonstrated a strong and statistically significant decrease with increasing age (Pearson correlation, $r = -0.93$, $p < 0.001$). When stratified by sex, both female and male children exhibited a similar age-related downward trend. Female children generally showed higher AI values than male children, and this difference was statistically significant (independent-samples t test, $p = 0.013$).

Subgroup analyses indicated a gradual decline in AI values throughout early childhood. Although AI values were higher in younger children, the decrease was not strictly linear and showed mild fluctuations during the early months. With increasing age, a more consistent downward trend became evident, reflecting progressive acetabular maturation. No substantial side-to-side differences were observed between right and left hip measurements across age groups. Intraobserver reliability for AI measurements was excellent for both observers (ICC = 0.94 – 0.96). Interobserver agreement was also high for both right and left hip measurements (ICC = 0.91 – 0.93).

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Table 1. Age- and sex-specific mean acetabular index values in healthy children aged 6 months to 5 years

Age (months)	n	Females – right	Females – left	n	Males – right	Males – left
6	25	24.20 ± 3.02	24.60 ± 2.88	27	23.12 ± 3.53	23.32 ± 3.09
7	21	23.46 ± 2.59	24.02 ± 2.99	26	22.92 ± 2.49	22.88 ± 2.61
8	31	23.10 ± 2.74	23.52 ± 2.68	25	22.65 ± 2.41	22.78 ± 2.55
9	25	22.92 ± 2.39	23.27 ± 2.82	22	22.61 ± 3.23	23.07 ± 2.46
10	21	22.98 ± 2.63	22.88 ± 2.74	23	22.41 ± 2.51	22.63 ± 2.58
11	26	22.75 ± 2.30	22.77 ± 2.62	21	22.18 ± 3.13	22.66 ± 2.26
12	25	22.65 ± 3.97	23.59 ± 3.85	23	22.17 ± 2.75	22.91 ± 2.88
13	21	22.93 ± 2.17	23.49 ± 2.64	19	21.87 ± 2.09	21.48 ± 2.21
14	28	22.67 ± 2.61	22.74 ± 2.46	20	21.44 ± 2.48	21.85 ± 2.92
15	19	22.21 ± 2.44	22.87 ± 2.58	20	21.36 ± 2.39	21.91 ± 2.66
16	23	22.07 ± 3.20	22.80 ± 3.98	18	20.76 ± 3.07	21.06 ± 3.15
17	15	22.49 ± 3.63	22.24 ± 3.73	17	20.56 ± 3.21	20.90 ± 2.90
18	19	22.24 ± 2.63	22.73 ± 2.49	17	20.49 ± 2.55	20.59 ± 3.18
19	20	22.45 ± 4.52	22.79 ± 3.97	19	20.42 ± 2.19	20.05 ± 2.80
20	22	22.43 ± 4.09	22.70 ± 3.72	15	20.43 ± 2.37	20.09 ± 2.55
21	21	21.94 ± 3.21	22.34 ± 3.15	18	20.63 ± 2.59	21.06 ± 2.73
22	18	21.97 ± 3.41	22.22 ± 3.38	19	20.83 ± 3.04	20.89 ± 3.02
23	18	21.75 ± 3.08	21.84 ± 3.11	15	20.09 ± 3.16	20.34 ± 3.18
24	15	21.87 ± 3.33	21.55 ± 3.19	17	20.21 ± 3.24	20.89 ± 3.27
25	17	21.78 ± 3.28	21.47 ± 3.22	20	20.32 ± 3.31	19.98 ± 3.29
26	14	21.72 ± 3.35	21.39 ± 3.29	18	20.28 ± 3.36	20.91 ± 3.34
27	15	21.69 ± 3.30	21.36 ± 3.25	14	20.25 ± 3.35	20.87 ± 3.32
28	16	21.66 ± 3.34	21.33 ± 3.20	13	20.23 ± 3.36	19.80 ± 3.31
29	13	21.65 ± 3.32	21.30 ± 3.16	15	20.47 ± 3.37	20.74 ± 3.33
30	15	21.16 ± 3.23	20.82 ± 3.09	12	20.67 ± 3.33	20.36 ± 3.21
31	10	21.10 ± 2.31	20.50 ± 2.31	11	19.99 ± 2.41	20.39 ± 2.41
32	12	20.88 ± 2.57	20.26 ± 2.56	13	19.62 ± 2.81	20.02 ± 2.81
33	15	19.46 ± 1.27	20.06 ± 1.68	16	18.34 ± 1.96	18.64 ± 1.61
34	11	19.56 ± 2.01	19.24 ± 1.88	10	18.42 ± 1.66	17.80 ± 2.12
35	10	19.06 ± 1.54	19.30 ± 1.77	12	18.06 ± 2.03	18.10 ± 1.71
36	15	18.62 ± 1.98	19.09 ± 1.62	12	18.14 ± 1.85	17.67 ± 1.52
37-39	31	18.51 ± 1.75	18.35 ± 1.79	28	17.65 ± 1.45	18.02 ± 1.67
40-42	35	18.39 ± 1.75	18.63 ± 1.74	32	17.12 ± 1.81	17.83 ± 1.76
43-45	31	18.79 ± 1.54	18.34 ± 1.41	30	17.48 ± 1.72	17.36 ± 1.90
46-48	30	18.59 ± 1.72	18.21 ± 1.95	33	17.14 ± 1.34	17.02 ± 1.69
49-51	35	18.32 ± 1.58	17.81 ± 1.89	33	16.70 ± 2.09	16.63 ± 2.17
52-54	37	18.21 ± 1.82	17.70 ± 1.60	31	16.26 ± 1.56	16.08 ± 1.76
55-57	35	17.91 ± 2.07	17.65 ± 2.12	32	16.32 ± 1.97	16.83 ± 1.84
58-60	31	17.82 ± 1.45	17.25 ± 1.34	33	16.16 ± 1.53	16.96 ± 1.43
Total (n)	841			799		

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Discussion

In this study, we found that the AI in healthy Turkish children aged 6 months to 5 years decreased progressively with age and remained consistently higher in females than in males. In our cohort of healthy Turkish children, when both hips were considered together, mean AI values decreased from approximately 24.4° in females and 23.2° in males at 6 months of age to 17.5° and 16.6°, respectively, at 58-60 months, with the most pronounced decline occurring between 24 and 36 months (from 21.7° to 18.9° in females and from 20.6° to 17.9° in males). The study also provides detailed monthly and three-month interval reference values, allowing a more refined assessment of acetabular development during early childhood. This is particularly important because acetabular maturation is dynamic during the first years of life, and broader annual reference ranges may not fully reflect these short-term changes. Therefore, our findings provide population-specific reference data that may support more precise radiographic interpretation during clinical follow-up.

The age- and sex-specific AI reference values obtained in this study may serve as a complementary reference in clinical practice, particularly during the radiographic follow-up of children with DDH. Rather than representing diagnostic thresholds in isolation, these data may help clinicians interpret a measured AI value within the expected pattern of acetabular development according to the child's chronological age and sex. In particular, during post-treatment follow-up, assessing whether the AI follows the expected age-related downward trend may support the early identification of residual acetabular dysplasia or delayed improvement. In this regard, the presented reference values may contribute to clinical decision-making regarding the need for closer surveillance, further imaging, or additional treatment.

In the present study, the AI was found to decrease with increasing age and to be consistently higher in females than in males. These findings are consistent with previously reported results [8,13]. Carbonell et al. reported a significant reduction in AI values between two and three years of age [14]. Similarly, in our cohort, a more pronounced decrease was observed between 30 and 36 months of age, which is consistent with previous reports. Higher AI values in females than in males have also been reported in prior studies [8,14].

Previous studies have emphasized that AI values may vary across different populations [8,9]. For example, Kuong et al., in their evaluation of pelvic angular parameters in Chinese children, reported mean AI values that differed from those reported in European populations [8]. Our findings are generally consistent with previous reports demonstrating an age-related decline in AI and higher values in females. However, compared with earlier Turkish data presented in broader age categories, the values in our cohort were generally slightly higher across comparable age ranges [10,11]. Our results were also broadly comparable to those reported in other populations, including the series by Novais et al., particularly with respect to the overall age-related downward trend and the more pronounced decline observed between 2 and 3 years of age [7]. Taken together, these findings suggest that AI reference values may show population-related variation and support the use of age- and population-specific reference data in the radiographic evaluation of acetabular development. In the present study, both intraobserver and interobserver reliability for AI measurements were excellent. Previous studies have reported good to excellent reliability for AI measurements, and the high level of agreement observed in our study is consistent with these findings [6,15]. The use of digital measurement techniques and standardized anatomical landmarks may have contributed to the excellent reliability observed.

Furthermore, because previous studies have reported that secondary or late-onset acetabular dysplasia may occur after the age of two, the age-sensitive reference values presented in our study may be clinically useful in monitoring this patient group and evaluating the need for possible additional interventions [16]. In this context, these values may provide additional clinical value by facilitating closer radiographic surveillance during early and mid-childhood and supporting the timely identification of children who may require further follow-up or additional intervention.

Limitations

This study has several limitations that should be acknowledged. First, the retrospective and single-center design may limit the generalizability of the findings to other populations and clinical settings. Because the study was conducted in a specific geographical region, the reference values presented may not fully reflect variations across different ethnic groups. Second, although dedicated pelvic radiographs were included, most images were obtained from abdominal, lumbar, and trauma series in which the pelvis was incidentally visualized. However, this potential limitation was mitigated by the rigorous multistep image selection process, the exclusion of radiographs with apparent malposition or insufficient image quality, and the excellent intraobserver and interobserver reliability observed in the study. Finally, because the study population consisted exclusively of healthy children, caution should be exercised when directly extrapolating the presented reference values to patients with DDH or other pathological conditions affecting acetabular development.

Conclusion

This study describes age- and sex-related changes in the AI in healthy children aged 6 months to 5 years and presents age-specific reference values at monthly and three-month intervals. The findings may contribute to the clinical assessment of acetabular development during follow-up, particularly in children undergoing surgical or conservative treatment for DDH. These reference values may also assist clinicians in monitoring acetabular development over time, including the identification of residual or late-onset dysplasia.

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Ethical Approval
This retrospective study was approved by the Sincan Training and Research Hospital Scientific Research Ethics Committee (Approval No.: BAEK-2025-119; date: 18.11.2025) and adhered to the principles of the Declaration of Helsinki.

Patient Consent
The requirement for individual informed consent was waived due to the retrospective design.

Conflict of Interest
The authors confirm the absence of any conflicts associated with this work.

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