

1 **The Prevalence and Risk Factors for Delayed Union of the Superior Pubic Ramus at 1 Year After**
2 **Curved Periacetabular Osteotomy: its risk factor and outcome**

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32 **Abstract**

33 *Purpose:* Curved periacetabular osteotomy (CPO) has been developed for the treatment of acetabular
34 dysplasia. While several studies have reported its good clinical results, the complications of CPO
35 include delayed union and nonunion of the superior pubic ramus. The purpose of this study is to
36 investigate the prevalence of delayed union of the pubis 1 year after CPO, and to determine the risk
37 factors for this complication.

38 *Methods:* The study examined 113 hips that underwent CPO between 2008 and 2012. Delayed union
39 was assessed based on the anteroposterior radiography 1 year after CPO. A superior pubic ramus union
40 group (U group) and a delayed union group (D group) were retrospectively compared regarding patient
41 characteristics, clinical evaluations, and radiographic parameters.

42 *Results:* Delayed union rate was 16.8%. The D group contained a significantly greater proportion of
43 smokers ($p < 0.001$). The gap at the pubic osteotomy site on CT coronal images was significantly larger
44 in the D group ($p < 0.001$), and the cut-off value for the risk of nonunion was a larger than 5.1 mm.
45 Multivariate regression analysis indicated that smoking (OR 10.7, 95% CI 2.1–55.4) and a gap at the
46 superior pubic ramus > 5.1 mm (OR 16.5, 95% CI 3.7–73.7) were significantly associated with delayed
47 union as independent risk factors.

48 *Conclusion:* The prevalence of delayed union 1 year after CPO was 16.8%. Smoking and a gap larger
49 than 5.1 mm at the pubic osteotomy site are risk factors for delayed union after CPO.

50

51 **Key words**

52 periacetabular osteotomy; complication; delayed union and nonunion; superior pubic ramus; risk factor

53

54

55 **Introduction**

56 Acetabular dysplasia of the hip is known to cause of osteoarthritis of the hip [1], which accounts for
57 more than 70% of hip osteoarthritis cases in Japan [2]. Periacetabular osteotomy (PAO) has been
58 developed as a surgical treatment for symptomatic acetabular dysplasia, and good clinical results have
59 been reported [3–9]. However, the complications of PAO include superior pubic ramus nonunion, inferior
60 pubic ramus stress fracture, posterior column fracture, and lateral cutaneous nerve injuries [3–15]. Several
61 studies have reported the prevalence of delayed union and nonunion of the superior pubic ramus after
62 PAO to be around 1.0 to 17.0% [7-9,11-14]. However, all these reports did not mention the evaluation
63 time. In addition, to our knowledge, no reports have described the risk factors for this complication. The
64 purpose of this study was to assess the prevalence of delayed union of the superior pubic ramus on
65 radiographs at 1 year after CPO, and also to investigate the risk factors correlated with delayed union.

66
67 **Materials and Methods**

68 Between the period of April 2008 and January 2012, CPO was performed in consecutive 128 hips in
69 120 patients for the treatment of acetabular dysplasia of the hip. To assess the osteotomy sites, pelvic
70 computed tomography (CT) scans were routinely performed at 1 week postoperatively, and
71 anteroposterior (AP) and false-profile radiographs of the hip were assessed at preoperative and 1 year
72 postoperatively. CT scans could not be performed in seven hips in seven patients, and an additional eight
73 hips in eight patients were lost to follow-up. Finally, 113 hips in 105 patients were included in this study
74 (follow-up rate 88.3%). The mean age of the patients at the time of surgery was 38.3 (range, 15–68)
75 years, and the 113 hips comprised 10 hips in male patients and 103 hips in female patients. The mean
76 follow-up duration was 51.2 (range, 12.0–81.0) months. The mean period until radiographic follow-up at

77 1 year postoperatively was 12.3 (range, 10.7–13.4) months. The mean body mass index (BMI) was 22.1
78 (range, 16.8–31.7) kg/m². The preoperative Tönnis grades [16] were grade 0 in 72 hips, grade 1 in 40
79 hips, and grade 2 in 1 hip.

80 CPO, which is a modified Bernese PAO developed by Ganz et al. [3,4] has been performed at our
81 hospital since 1995. The surgical indications for CPO included acetabular dysplasia associated with hip
82 pain and discomfort that caused some limitation of daily activities, lateral center-edge angle (LCEA) [17]
83 of less than 20° on AP radiographs, and improvement in joint congruency in the abducted position on AP
84 radiographs. All surgical procedures were performed by three surgeons. CPO was undertaken using the
85 modified Smith–Peterson approach. The c-shaped osteotomy was performed from the proximal part of the
86 anterior inferior iliac spine to the distal part of the quadrilateral surface. Osteotomy of the superior pubic
87 ramus was carried out just medial to the iliopubic eminence, and was performed at an inclination of 30° to
88 the horizontal line for medialization of the femoral head [18]. Bone grafting was not performed at the
89 osteotomy area of the superior pubic ramus. Active motion exercises were initiated on the first
90 postoperative day. Partial weight-bearing (10 kg) was allowed on the third postoperative day, and full
91 weight-bearing was allowed from 8 weeks postoperatively.

92 Clinical evaluations were performed using the Harris hip score (HHS) both preoperatively and at 1 year
93 postoperatively. The pain component of the HHS was also investigated. The lifestyle habits and
94 comorbidities of the patients were examined by reading their electronic charts retrospectively. Patients
95 who were smokers at the time of CPO or had a history of smoking were grouped as smokers. Patients
96 with a daily alcohol drinking habit were grouped as alcohol drinkers.

97 Radiographic evaluations included pre- and postoperative LCEA, acetabular roof obliquity (ARO) [19],
98 and head lateralization index (HLI) [20]. The anterior center-edge angle (ACEA) [21] was assessed on

99 false-profile radiographs. The amounts of change of transfer of the acetabular fragment were assessed by
100 differences in the pre- and postoperative measurements of the LCEA, ARO and ACEA. At 1 week
101 postoperatively, a pelvic CT scan was routinely performed to examine the osteotomy area
102 (TSX-101A/HA; Toshiba Medical Systems, Tochigi, Japan). CT coronal imaging was used to measure the
103 gap at the pubic ramus osteotomy site, and the narrowest gap on all the slices was taken as the smallest
104 gap (Fig. 1).

105 Patients showing no bone continuity on AP radiographs at 1 year postoperatively were assigned to the
106 delayed union group (D group), while patients showing bone continuity were assigned to the union
107 group (U group). Bone continuity on AP radiographs was determined by two investigators (A.M. and
108 S.A.). Among the cases judged to have delayed union, cases in which bone union was not obtained even
109 at the time of the final follow-up were regarded as a nonunion. In the case of delayed union, the
110 presence of pubic tenderness was investigated by reading their electronic charts retrospectively.

111

112 **Statistical Analysis**

113 The Mann–Whitney U test was used to compare the demographic data, clinical scores, and radiographic
114 data between the D and U groups. The chi-squared test was used to assess differences in clinical factors
115 such as sex, lifestyle habits, and comorbidities. A cut-off value for the gap distance at the superior pubic
116 ramus osteotomy site that optimized sensitivity and specificity was identified using a receiver-operating
117 characteristic curve. A multivariate regression analysis was performed to identify factors related to
118 delayed union of the superior pubic ramus. Statistical analyses were performed using SPSS ver. 20.0
119 (IBM Inc., Armonk, New York, USA). Statistical significance was defined as $p < 0.05$.

120

121 **Results**

122 Delayed union was observed in 19 hips (16.8%; D group). The clinical data for the D and U groups are
123 shown in Table 1. There were no significant differences between the two groups in mean age at the time
124 of surgery, sex, mean follow-up duration, mean time to radiographic follow-up, and mean BMI. The mean
125 score for the pain component of the HHS at 1 year postoperatively was significantly greater in the U
126 group than the D group ($p = 0.005$). Pubic tenderness was present in 21.0% (four of 19 hips) in the D
127 group. Hip osteoarthritis had not progressed at 1 year postoperatively in any of the D group patients,
128 whereas it had progressed from Tönnis Grade 1 to Grade 2 in one hip and from Tönnis Grade 2 to Grade 3
129 in another hip in the U group.

130 The lifestyle habits and comorbidities in the two groups are shown in Table 2. Smokers were present at a
131 significantly higher rate in the D group ($p = 0.025$).

132 The radiographic evaluations are shown in Table 3. Delayed union was observed in 19 hips (16.8%) at 1
133 year postoperatively. Among these 19 hips with delayed union, five hips obtained bone union at an
134 average of 24 months postoperatively (Fig. 2). However, the remaining 14 hips showed nonunion of the
135 pubis even at the final follow-up, and mean follow up duration was 48.7 (range 24.0 to 62.9) months (Fig.
136 3). Posterior column fracture rate did not show a significant difference between the two groups ($p =$
137 0.174). Compared with the U group, the D group had a significantly smaller postoperative ARO ($p =$
138 0.009), and a significantly greater amount of correction of the ARO ($p = 0.007$). The gap at the pubic
139 osteotomy site on CT coronal images was significantly larger in the D group ($p < 0.001$), and the cut-off
140 value for the risk of nonunion was a larger than 5.1 mm, with a sensitivity of 78.9% and a specificity of
141 76.6%.

142 The results of the multivariate regression analysis are shown in Table 4. The multivariate regression

143 analysis indicated that smoking (odds ratio (OR) 10.701, 95% confidence interval (CI) 2.06–55.44) and
144 a gap at the superior pubic ramus > 5.1 mm (OR 16.5, 95% CI 3.7–73.7) were significantly associated
145 with delayed union as independent risk factors.

146

147 **Discussion**

148 PAO has been performed as a surgical treatment for symptomatic acetabular dysplasia, and good short-
149 and mid-term outcomes have been reported [3-9]. However, some reports have described that the
150 incidence of superior pubic ramus nonunion is reportedly 1.0 to 17.0% [7-9,11-14], although these
151 reports did not mention the evaluation time. In this study, the incidence of delayed union of the superior
152 pubic ramus was 16.8% at 1 year postoperatively. Among these cases of delayed union, five of 19
153 patients obtained bone fusion at an average of 24 months postoperatively. As a result, the nonunion rate
154 was 12.4% at the final follow up. This rate was almost equivalent to the previously reported incidence.

155 Several studies have reported that pubic ramus nonunion is asymptomatic in most patients and has no
156 effect on the clinical outcome [7,13]. However, symptomatic pubic ramus nonunion rates were reported
157 to be 1% and 4% by Peters et al. [11] and Clohisy et al. [9], respectively. Furthermore, Siebenrock et al.
158 [12] and Clohisy et al. [9] reported that surgery was necessary for nonunion in 1% and 4% of patients,
159 respectively. In the present study, the mean score for the pain component of the postoperative HHS was
160 significantly lower in the D group. Since hip osteoarthritis had not progressed at 1 year postoperatively
161 in any of the hips in the D group, the lower score for the pain component in the D group seems to be
162 related to the delayed union itself rather than the hip osteoarthritis. The present results indicate that
163 although bone fusion may be obtained in the long-term in cases of delayed union, delayed union may
164 cause early postoperative pain and lead to a decrease in the activities of daily living.

165 Pubic delayed union might be related to several factors such as severe hip dysplasia, large acetabular
166 correction, posterior column fracture, patient age, presence of bone grafting, and early rehabilitation. In
167 our study, there were a significantly greater proportion of smokers in the D group. Regarding the effects
168 of smoking on the musculoskeletal system, nicotine and carbon monoxide are known to reduce oxygen
169 supply and peripheral blood flow to tissues, and to reduce bone metabolic activity [22]. Brown et al. [23]
170 reported that smoking reduces oxygen levels in the blood and increases the rate of nonunion. Andersen
171 et al. [24] reported that smoking has negative effects on fusion and patient satisfaction after spinal fusion
172 procedures. A smoking cessation program prior to surgery is reportedly effective in decreasing the
173 incidence of postoperative complications caused by smoking [25]. In the present study, the OR for
174 delayed union of the superior pubic ramus was 10.7 times higher in smokers, indicating that guidance on
175 quitting smoking prior to surgery is necessary to decrease the risk of delayed union.

176 Some studies have reported on the relationship between severity of acetabular dysplasia and pubic
177 ramus nonunion. Clohisy et al. [8] reported a pubic ramus nonunion rate of 12.0% hips with severe
178 dysplasia that underwent Bernese PAO. Peters et al. [11] reported a pubic ramus nonunion rate of 12.0%
179 treated by PAO, and most of these cases involved hips with large acetabular corrections. In our study, the
180 factors associated with the preoperative severity of acetabular dysplasia did not significantly differ
181 between the two groups. However, the amounts of correction of the ARO was significantly greater in the
182 D group, indicating that a large amount of acetabular correction may have been involved in delayed
183 union.

184 To further evaluate the transfer of the acetabular fragment, the gap at the superior pubic ramus
185 osteotomy site was measured on CT images. The mean gap at the osteotomy site was 6.9 mm in the D
186 group, was significantly larger than that in the U group, and the cut-off value for the risk of delayed

187 union was 5.1 mm, the OR was 16.4 times higher. Thus, to prevent delayed union of the superior pubic
188 ramus, the osteotomy site must have a large contact area. Osteotomy of the superior pubic ramus was
189 made at the location just medial to the iliopubic eminence in the present study, and so it will be
190 displaced further with rotation of the acetabular fragment. Performing the pubic osteotomy at the medial
191 aspect, where the bone is narrower and the contact area is smaller, may make it more difficult to heal
192 compared with osteotomy performed at the more lateral aspect of the pubis. In our hospital, we have
193 performed superior pubic osteotomy using a flap form since 2013, and have transplanted a bone graft
194 into the superior pubic osteotomy site to promote bone union.

195 This study had several limitations. The first limitation was the low follow up rate of 88.3%. As a result,
196 the sample size was insufficient, and there was a large difference in the number of patients in the two
197 groups. The second limitation was that delayed union of the pubis was assessed only based on
198 radiographic evaluation. The actual rate of delayed union of the superior pubic ramus may show higher
199 percentage if CT scans were used for the evaluation. Third, the correlation between the pack-year history
200 of smoking and delayed union was not examined. An increasing pack-year history of smoking may have
201 resulted in an increased risk of delayed union. Fourth, the radiographic evaluation of transfer of the
202 acetabular fragment was assessed in two dimensions only. It may be difficult to measure the amount of
203 acetabular fragment transfer on pelvic radiography; this measurement requires a three-dimensional
204 assessment.

205

206 **Conclusions**

207 In summary, surgeons must be aware that delayed union and nonunion of the osteotomy site at the pubic
208 ramus can sometimes occur after CPO. The rate of delayed union of the superior pubic ramus on AP

209 radiographs at 1 year after CPO was 16.8%. Smoking and a gap larger than 5.1 mm at the pubis

210 osteotomy site are risk factors for delayed union after CPO.

211

212 **Conflict of Interest:** On behalf of all authors, the corresponding author states that there is no conflict of

213 interest.

214 **Ethical approval:** All procedures performed in studies involving human participants were in

215 accordance with the ethical standards of the institutional and/or national research committee and with

216 the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

217 **Informed consent:** Informed consent was obtained from all individual participants included in the study.

218

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Figure captions

Fig. 1. Measurement of the smallest gap (yellow line) at the superior pubic ramus osteotomy site on a coronal computed tomography image.

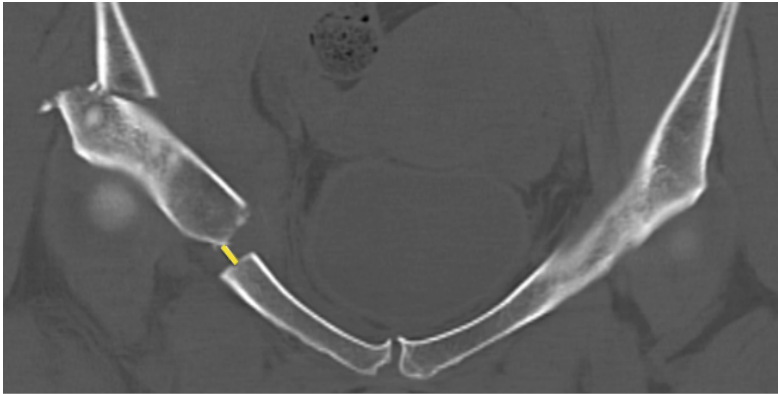


Fig. 2. Radiographs of a 35-year-old female who underwent curved periacetabular osteotomy for hip dysplasia. a: Preoperative anteroposterior radiograph; b: Postoperative anteroposterior radiograph; c: There was no bone continuity of the superior pubic ramus on anteroposterior radiographs taken 1 year postoperatively; d: Bone union was obtained at 24 months postoperatively.

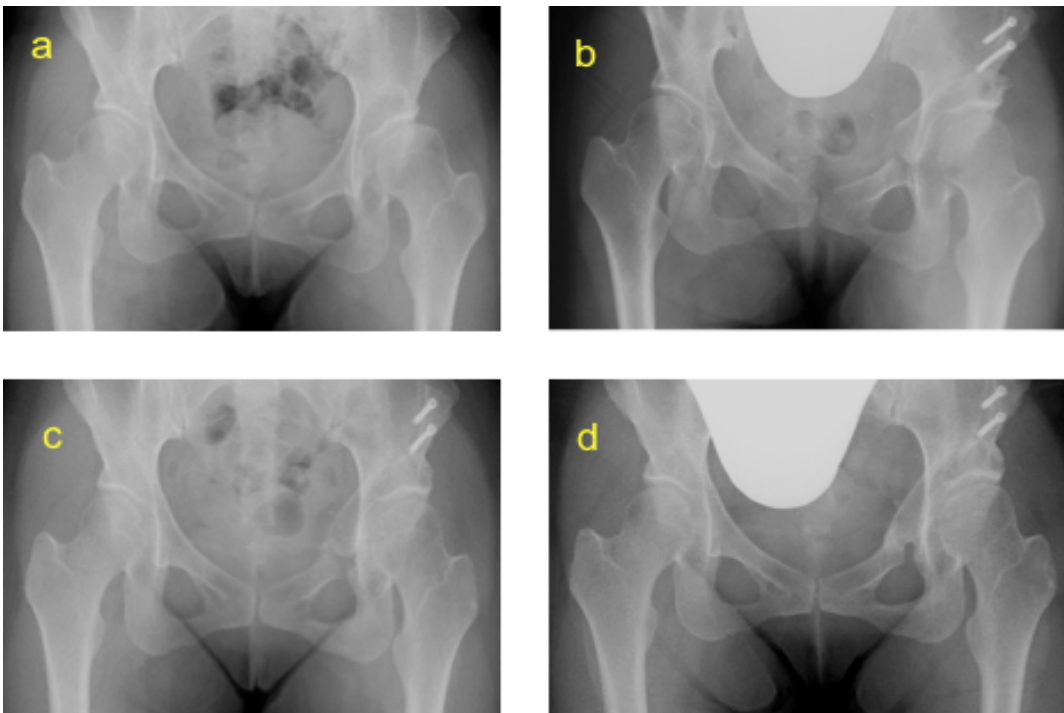
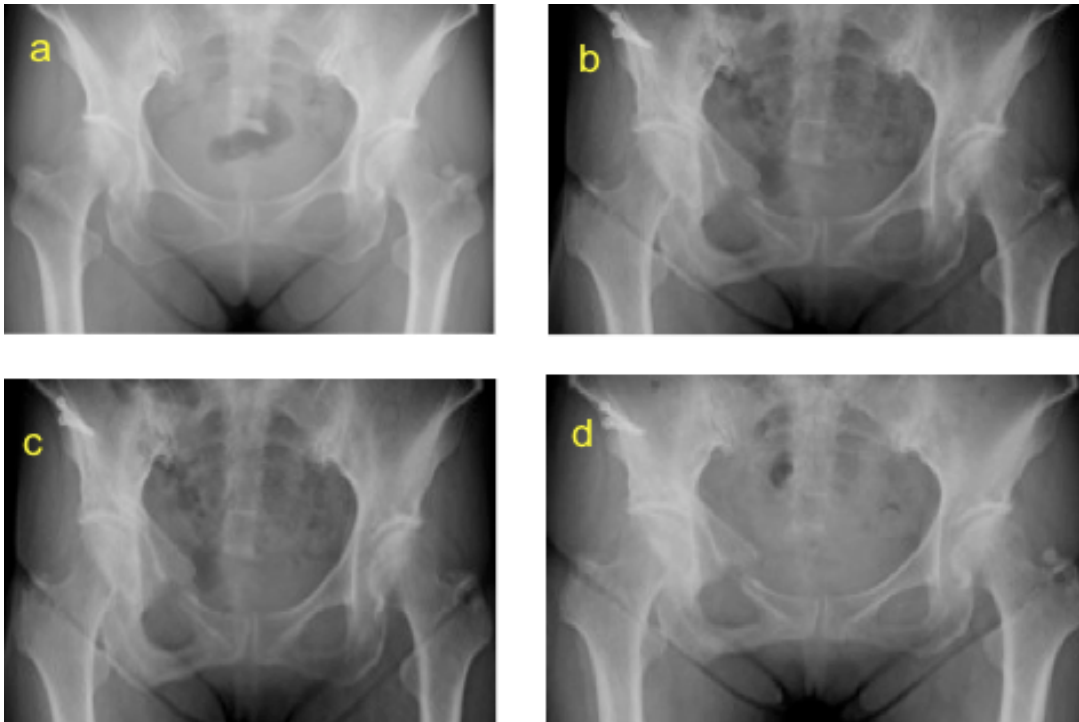


Fig. 3. Radiographs of a 66-year-old female patient who underwent curved periacetabular osteotomy for hip dysplasia. a: Preoperative anteroposterior radiograph; b: Postoperative anteroposterior radiograph; c: There was no bone continuity of the superior pubic ramus on anteroposterior radiographs taken 1 year postoperatively; d: There was nonunion of the superior pubic ramus at final follow-up (5.2 years postoperatively)



Table

Table 1. Demographic Data in the Delayed Union Group and the Union Group

	Delayed union group (n = 19)	Union group (n = 94)	P value
Sex, M:F (no. of hips)	0:19	10:84	0.138
Age at surgery (y)	41.0 (20 to 66)	37.7 (14 to 68)	0.184
Follow-up duration (mo)	49.2 (12.1 to 72.0)	51.6 (12.0 to 81.0)	0.673
Time to radiographic follow-up (mo)	12.3 (10.7 to 13.2)	12.2 (10.8 to 13.4)	0.686
Body mass index (kg/m ²)	21.7 (19.1 to 25.9)	22.2 (16.8 to 31.7)	0.416
HHS (points)			
Preoperative	77.0 ± 8.2	75.8 ± 11.1	0.160
Postoperative	91.2 ± 8.3	93.8 ± 5.5	0.251
Pain component of the HHS (points)			
Preoperative	25.3 ± 5.1	15.6 ± 7.3	0.394
Postoperative	36.2 ± 7.3	39.9 ± 6.2	0.005
Tönnis grade†			
Preoperative	10/ 9/ 0/ 0	62/ 31 /1/ 0	
Postoperative	10/ 9/ 0/ 0	62/ 30/ 1/ 1	

The values are given as the mean ± standard deviation (range).

HHS: Harris Hip Score. F: female, M: male.

† no. of hips with Tönnis grade 0/ grade1/ grade2/ grade3

Table 2. Preoperative Patient-Reported Lifestyle Habits and Comorbidities in the Delayed Union Group and the Union Group

	Delayed union group (n = 19)	Union group (n = 94)	P value†
Smokers	7 (36.8%)	12 (12.7%)	0.025
Alcohol drinker	3 (15.7%)	7 (7.4%)	0.370
BMI > 25 kg/m ²	2 (10.5%)	16 (17.0%)	0.338
Liver disease	0 (0%)	3 (3.1%)	0.554
Heart disease	0 (0%)	4 (4.2%)	0.453
Diabetes	0 (0%)	2 (2.1%)	0.676
Depression	0 (0%)	2 (2.1%)	0.676

† Calculated using chi-squared tests. Smokers included those who were smokers at the time of surgery and those with a prior history of smoking. Alcohol drinkers included those who drank alcohol daily. BMI: body mass index.

Table 3. Radiographic Evaluations in the Delayed Union Group and the Union Group

	Delayed union group (n = 19)	Union group (n = 94)	P value
Lateral center-edge angle (°)			
Preoperative	9.1 ± 7.4 (-5 to 17)	9.6 ± 5.6 (-6 to 26)	0.362
Postoperative	32.9 ± 5.4 (25 to 44)	32.4 ± 5.4 (20 to 48)	0.521
Correction	23.9 ± 8.4 (13 to 39)	22.7 ± 6.4 (1 to 38)	0.127
Acetabular roof obliquity (°)			
Preoperative	19.6 ± 6.0 (10 to 29.4)	17.3 ± 5.8 (2 to 34)	0.152
Postoperative	1.4 ± 1.9 (-1.7 to 6.7)	3.1 ± 2.8 (-4 to 12)	0.009
Correction	18.1 ± 5.8 (9 to 29.9)	14.1 ± 5.3 (-1.3 to 30.3)	0.007
Anterior center-edge angle (°)			
Preoperative	20.5 ± 12.6 (-4.7 to 49.7)	18.5 ± 10.2 (-5.8 to 36.2)	0.651
Postoperative	36.3 ± 8.9 (29 to 59.1)	35.1 ± 8.2 (20 to 57.2)	0.499
Correction	15.5 ± 6.9 (7.2 to 34.6)	16.3 ± 8.3 (0.9 to 40)	0.525
Head lateralization index			
Preoperative	0.55 ± 0.05 (0.47 to 0.67)	0.57 ± 0.06 (0.47 to 0.73)	0.196
Postoperative	0.50 ± 0.06 (0.39 to 0.62)	0.53 ± 0.07 (0.40 to 0.72)	0.057
Distance of the pubic ramus osteotomy site (mm)	6.9 ± 3.2 (2.5 to 15.9)	4.0 ± 2.3 (0 to 15.6)	< 0.001
Posterior column fracture (n, %)	3 (15.8 %)	6 (6.4 %)	0.174

The values are given as the mean ± standard deviation (range).

Table 4. Multivariate Regression Analysis for Risk Factors Predicting Delayed Union of the Superior Pubic Ramus

Risk factors	OR	95% CI	P value
Postoperative ARO	0.689	0.51-0.94	0.017
Correction of the ARO	1.165	1.04-1.31	0.009
Smoking	10.701	2.06–55.44	0.005
Distance at the pubic ramus osteotomy site > 5.1mm	16.466	3.67–73.72	0.001

OR: odds ratio, CI: confidence interval.