



The prevalence and risk factors for delayed union of the superior pubic ramus at one year after curved periacetabular osteotomy: its risk factor and outcome

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Abstract

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

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

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

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

Keywords Periacetabular osteotomy · Complication · Delayed union and nonunion · Superior pubic ramus · Risk factor

Introduction

Acetabular dysplasia of the hip is known to cause of osteoarthritis of the hip [1], which accounts for more than 70% of hip osteoarthritis cases in Japan [2]. Periacetabular osteotomy (PAO) has been developed as a surgical treatment for symptomatic acetabular dysplasia, and good clinical results have been reported [3–9]. However, the complications of PAO include superior pubic ramus nonunion, inferior pubic ramus stress fracture, posterior column fracture, and lateral cutaneous nerve

injuries [3–15]. Several studies have reported the prevalence of delayed union and nonunion of the superior pubic ramus after PAO to be around 1.0 to 17.0% [7–9, 11–14]. However, all these reports did not mention the evaluation time. In addition, to our knowledge, no reports have described the risk factors for this complication. The purpose of this study was to assess the prevalence of delayed union of the superior pubic ramus on radiographs at one year after CPO, and also to investigate the risk factors correlated with delayed union.

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Materials and methods

Between the period of April 2008 and January 2012, CPO was performed in consecutive 128 hips in 120 patients for the treatment of acetabular dysplasia of the hip. To assess the

osteotomy sites, pelvic computed tomography (CT) scans were routinely performed at one week post-operatively, and anteroposterior (AP) and false-profile radiographs of the hip were assessed at pre-operative and one year post-operatively. CT scans could not be performed in seven hips in seven patients, and an additional eight hips in eight patients were lost to follow-up. Finally, 113 hips in 105 patients were included in this study (follow-up rate 88.3%). The mean age of the patients at the time of surgery was 38.3 (range, 15–68) years, and the 113 hips comprised ten hips in male patients and 103 hips in female patients. The mean follow-up duration was 51.2 (range, 12.0–81.0) months. The mean period until radiographic follow-up at one year post-operatively was 12.3 (range, 10.7–13.4) months. The mean body mass index (BMI) was 22.1 (range, 10.7–13.4) kg/m². The pre-operative Tönnis grades [16] were grade 0 in 72 hips, grade 1 in 40 hips, and grade 2 in one hip.

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

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

Radiographic evaluations included pre- and post-operative LCEA, acetabular roof obliquity (ARO) [19], and head lateralization index (HLI) [20]. The anterior centre-edge angle (ACEA) [21] was assessed on false-profile radiographs. The amounts of change of transfer of the acetabular fragment were assessed by differences in the pre- and post-operative measurements of the LCEA, ARO and ACEA. At one week

post-operatively, a pelvic CT scan was routinely performed to examine the osteotomy area (TSX-101A/HA; Toshiba Medical Systems, Tochigi, Japan). CT coronal imaging was used to measure the gap at the pubic ramus osteotomy site, and the narrowest gap on all the slices was taken as the smallest gap (Fig. 1).

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

Statistical analysis

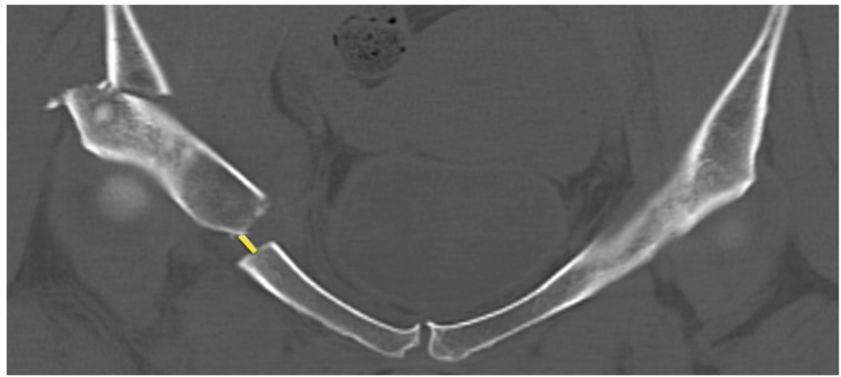
The Mann–Whitney U test was used to compare the demographic data, clinical scores, and radiographic data between the D and U groups. The chi-squared test was used to assess differences in clinical factors such as sex, lifestyle habits, and comorbidities. A cut-off value for the gap distance at the superior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

Results

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

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

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



The radiographic evaluations are shown in Table 3. Delayed union was observed in 19 hips (16.8%) at one year post-operatively. Among these 19 hips with delayed union, five hips obtained bone union at an average of 24 months post-operatively (Fig. 2). However, the remaining 14 hips showed nonunion of the pubis even at the final follow-up, and mean follow up duration was 48.7 (range 24.0–62.9) months (Fig. 3). Posterior column fracture rate did not show a significant difference between the two groups ($p=0.174$). Compared with the U group, the D group had a significantly smaller post-operative ARO ($p=0.009$), and a significantly greater amount of correction of the ARO ($p=0.007$). The gap at the pubic osteotomy site on CT coronal images was significantly larger in the D group ($p<0.001$), and the cut-

off value for the risk of nonunion was larger than 5.1 mm, with a sensitivity of 78.9% and a specificity of 76.6%.

The results of the multivariate regression analysis are shown in Table 4. The multivariate regression analysis indicated that smoking (odds ratio (OR) 10.701, 95% confidence interval (CI) 2.06–55.44) and a gap at the superior pubic ramus >5.1 mm (OR 16.5, 95% CI 3.7–73.7) were significantly associated with delayed union as independent risk factors.

Discussion

PAO has been performed as a surgical treatment for symptomatic acetabular dysplasia, and good short- and mid-term outcomes have been reported [3–9]. However, some reports have described that the incidence of superior pubic ramus nonunion is reportedly 1.0 to 17.0% [7–9, 11–14], although these reports did not mention the evaluation time. In this study, the incidence of delayed union of the superior pubic ramus was 16.8% at one year post-operatively. Among these cases of delayed union, five of 19 patients obtained bone fusion at an average of 24 months post-operatively. As a result, the

Table 1 Demographic data in the delayed union group and the union group

Characteristic	Delayed union group ($n=19$)	Union group ($n=94$)	<i>P</i> -value
Sex, M:F (no. of hips)	0:19	0.475	0.138
Age at surgery (y)	41.0 (20–66)	37.7 (14–68)	0.184
Follow-up duration (mo)	49.2 (12.1–72.0)	51.6 (12.0–81.0)	0.673
Time to radiographic follow-up (mo)	12.3 (10.7–13.2)	12.2 (10.8–13.4)	0.686
Body mass index (kg/m^2)	21.7 (19.1–25.9)	22.2 (16.8–31.7)	0.416
HHS (points)			
Preoperative	77.0 \pm 8.2	75.8 \pm 11.1	0.160
Postoperative	91.2 \pm 8.3	93.8 \pm 5.5	0.251
Pain component of the HHS (points)			
Preoperative	25.3 \pm 5.1	15.6 \pm 7.3	0.394
Postoperative	36.2 \pm 7.3	39.9 \pm 6.2	0.005
Tönnis grade ^a			
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 \pm standard deviation (range)

HHS Harris hip score, F female, M male

^a Number 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

Variable	Delayed union group ($n=19$)	Union group ($n=94$)	<i>P</i> -value ^a
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

BMI body mass index

^a 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

Table 3 Radiographic evaluations in the delayed union group and the union group

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

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

nonunion rate was 12.4% at the final follow up. This rate was almost equivalent to the previously reported incidence.

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

Pubic delayed union might be related to several factors such as severe hip dysplasia, large acetabular correction, posterior column fracture, patient age, presence of bone grafting, and early rehabilitation. In our study, there were a significantly greater proportion of smokers in the D group. Regarding the effects of smoking on the musculoskeletal system, nicotine and carbon monoxide are known to reduce oxygen supply and peripheral blood flow to tissues, and to reduce bone metabolic activity [22]. Brown et al. [23] reported that smoking reduces oxygen levels in the blood and increases the rate of nonunion. Andersen et al. [24] reported that smoking has negative effects on fusion and patient satisfaction after spinal fusion procedures. A smoking

Fig. 2 Radiographs of a 35-year-old female who underwent curved periacetabular osteotomy for hip dysplasia. **a** Pre-operative anteroposterior radiograph. **b** Post-operative anteroposterior radiograph. **c** There was no bone continuity of the superior pubic ramus on anteroposterior radiographs taken one year post-operatively. **d** Bone union was obtained at 24 months post-operatively

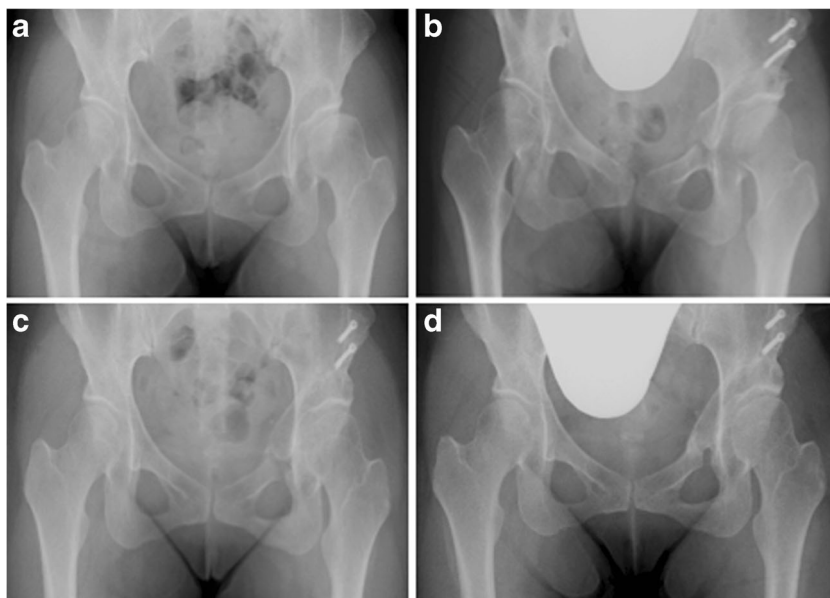
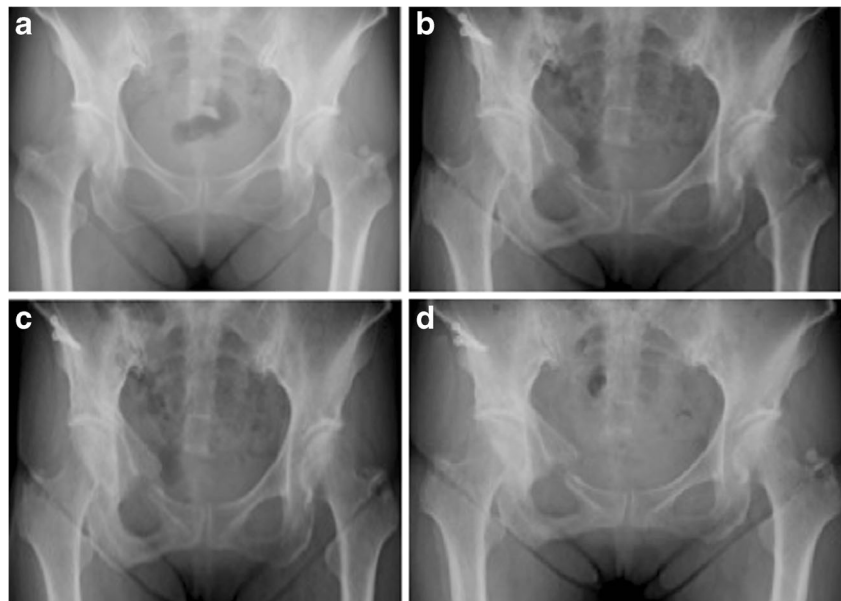


Fig. 3 Radiographs of a 66-year-old female patient who underwent curved periacetabular osteotomy for hip dysplasia. **a** Pre-operative anteroposterior radiograph. **b** Post-operative anteroposterior radiograph. **c** There was no bone continuity of the superior pubic ramus on anteroposterior radiographs taken one year post-operatively. **d** There was nonunion of the superior pubic ramus at final follow-up (5.2 years post-operatively)



cessation program prior to surgery is reportedly effective in decreasing the incidence of post-operative complications caused by smoking [25]. In the present study, the OR for delayed union of the superior pubic ramus was 10.7 times higher in smokers, indicating that guidance on quitting smoking prior to surgery is necessary to decrease the risk of delayed union.

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

To further evaluate the transfer of the acetabular fragment, the gap at the superior pubic ramus osteotomy site

Table 4 Multivariate regression analysis for risk factors predicting delayed union of the superior pubic ramus

Risk factors	OR	95% CI	P-value
Post-operative 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 >5.1 mm	16.466	3.67–73.72	0.001

OR odds ratio, CI confidence interval, ARO acetabular roof obliquity

was measured on CT images. The mean gap at the osteotomy site was 6.9 mm in the D group, was significantly larger than that in the U group, and the cut-off value for the risk of delayed union was 5.1 mm, while the OR was 16.4 times higher. Thus, to prevent delayed union of the superior pubic ramus, the osteotomy site must have a large contact area. Osteotomy of the superior pubic ramus was made at the location just medial to the iliopubic eminence in the present study, and so it will be displaced further with rotation of the acetabular fragment. Performing the pubic osteotomy at the medial aspect, where the bone is narrower and the contact area is smaller, may make it more difficult to heal compared with osteotomy performed at the more lateral aspect of the pubis. In our hospital, we have performed superior pubic osteotomy using a flap form since 2013, and have transplanted a bone graft into the superior pubic osteotomy site to promote bone union.

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

Conclusions

In summary, surgeons must be aware that delayed union and nonunion of the osteotomy site at the pubic ramus can sometimes occur after CPO. The rate of delayed union of the superior pubic ramus on AP radiographs at one year after CPO was 16.8%. Smoking and a gap larger than 5.1 mm at the pubis osteotomy site are risk factors for delayed union after CPO.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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

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