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ORIGINAL PAPER

Incidence of delayed union one year after peri-acetabular osteotomy based on computed tomography

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Abstract
Background Pubic bone nonunion and delayed union are reported as post-operative complications after peri-acetabular osteotomy (PAO). However, few studies have determined the incidence of delayed union using computed tomography (CT) scans. This study aimed to determine the incidence of delayed union at one year after PAO using X-ray and CT scans.
Methods We performed a retrospective review of 150 hips in 132 consecutive patients with acetabular dysplasia who underwent PAO between January 2012 and June 2016 and evaluated 107 hips for which pelvic CT scans taken at one year after PAO were available. Clinical evaluations included age at surgery, weight, body mass index (BMI) and history. Radiographic evaluations were to assess pubic, ischial and iliac delayed union at one year post-operatively.
Results Based on X-ray analysis, the incidence of delayed union in the pubic, ischial and iliac bones was 11.2% (12 hips), 5.6% (6 hips) and 0% (0 hips), respectively, and20.6% (22 hips), 8.4% (9 hips) and 0% (0 hips), respectively, based on CT scans.
Conclusion The incidence of delayed union of the pubis and ischium at one year after PAO according to CT scans was higher than that based on X-ray imaging. CT scans are useful in patients with some symptoms at the osteotomy site.

Level of Evidence: Level III.

Keywords Peri-acetabular osteotomy · Nonunion · Delayed union · Computed tomography scans

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Introduction

Peri-acetabular osteotomy (PAO) [1] is one of the treatment options for patients with symptomatic hip dysplasia [2–5], for which the survival rate is approximately 84–88% at the ten year follow-up [6, 7]. Several potential complications that could arise from PAO have been reported, including injury to lateral femoral cutaneous or sciatic nerve [8–10], nonunion of the pubic or ischial bones [11, 12] and stress fractures in the inferior pubic ramus [13, 14]. Among these complications, nonunion causes pain and requires subsequent re-operation. As such, nonunion as a complication for PAO needs to be avoided [12, 15]. The reported incidence of pubic nonunion is 6–21% [8, 11–14], and that of ischial nonunion is 1–6% [15–17]. However, these reports were based on X-ray confirmation of union; few reports have employed computed tomography (CT) [18] scans to ascertain the incidence of delayed union. This study aimed to determine the incidence of post-operative delayed union at one year after PAO, comparing the incidence rates determined by X-ray and CT scans.

Materials and methods

This study was approved by our institutional review board, and all patients provided informed consent. We performed a retrospective review of 150 hips in 132 consecutive patients with acetabular dysplasia who underwent PAO between January 2012 and June 2016. To evaluate the post-operative progress, pelvic X-rays were routinely performed at one year post-operatively. At the same time, pelvic CT scans was performed with the consent of the patient. Of the 150 hips, 43 were excluded because of an inability to conduct a CT scan at one year post-operatively. We examined the remaining 107 hips in 93 patients. The follow-up rate was 71.3%.

In our department, the indications for PAO include pain and limitation of daily activities for >five months; a lateral centre-edge angle (LCEA) of <25° on anteroposterior radiographs, with improved congruency of the hip in abduction; and age at surgery of <65 years [4, 19]. All surgical procedures were performed by three surgeons (MN, YN, KK). In our PAO, modified Bernese PAO and ischial, pubic and iliac osteotomies were performed via a direct anterior approach with patients in the supine position. The iliac osteotomy line was from the proximal part of the anterior inferior iliac spine to the distal part of the quadrilateral surface. Active exercises were initiated on the first post-operative day. Partial weight bearing with two crutches or a walker started on the third post-operative day. Full weight bearing was allowed at eight weeks postoperatively.

Clinical evaluations comprised age at surgery, height, weight, body mass index (BMI), and history of cigarette smoking defined as currently or some history of smoking. The Harris Hip Sscore [20] (HHS) was used for the clinical outcome, for a total of 100 points: 44 points for pain items, 47 for function items and nine for range of motion (ROM)/transformation items. In radiographic assessments, we evaluated anteroposterior pelvic radiographs for pubic, ischial and/or iliac delayed union at one year post-operatively (Fig. 1). We also used images to ascertain pre-operative and post-operative LCEA, head lateralisation index (HLI) [21] and Tönnis grade [22] (Fig. 2).

We further measured delayed union for the pubic, ischial, and iliac bones on CT scans at one year post-operatively. For CT scans, all patients were placed in the supine position with the hip in a neutral position. We used a 64-channel multidetector CT system (Aquilion TSX-101A/HA; Toshiba Medical Systems), and the scanning protocol had a slice distance of 0.5 mm from the anterior superior iliac spine to below the knee. All images were digitally acquired using the Picture Archiving and Communication System (PACS).

Fig. 1 Anteroposterior radiograph at 1 year post-operatively showing delayed union of the pubis and ischium

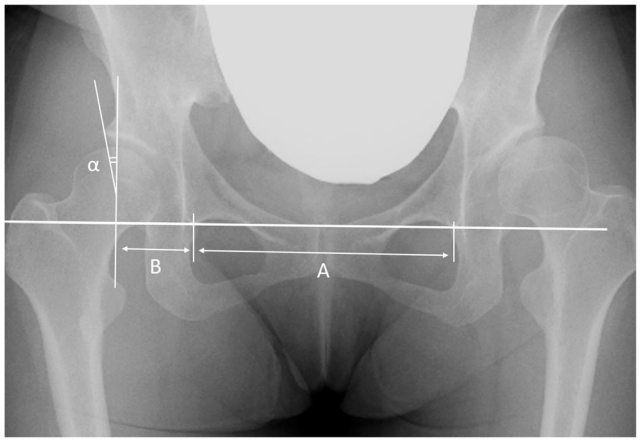

Fig. 2 Radiological indices of the hip: **a** lateral centre-edge angle (LCEA); **b** head lateralisation index (HLI)

Definition of delayed union

Bone union using X-ray was assessed on standardised anteroposterior radiographs of the pelvis and hip at one year (range 11–14 months) post-operatively. Delayed union was defined based on radiographic evidence of an absence of continuity at the osteotomy site. Using CT scans, bone union was assessed on pelvic images and all coronal slices of the PAO at one year post-operatively. Delayed union for this method was also defined based on radiographic evidence of an absence of continuity in the osteotomy site.

Assessment of reliability

Delayed union was assessed by three authors (SA, AM, SI) who were blinded to clinical outcomes. The same observers reviewed the radiographs three times on different days, and the mean values were calculated. The measurements were analysed for intra- and inter-observer reliability. Intraclass correlation coefficients were 0.92–0.97 (intra-observer variance) and 0.89–0.95 (inter-observer variance).

Results

Clinical data for the 107 hips in 93 patients are shown in Table 1. Patients comprised four men and 103 women with a mean age of 37.6 years (range 14–65). Mean BMI was 22.4 kg/m^2 (range 15.6–33.3 kg/m^2) at the time of surgery. Pre-operatively, 49 hips had no signs of osteoarthritis (grade 0 according to Tönnis classification), 51 had early joint space narrowing or early osteophyte formation (grade 1), seven had moderate joint-space narrowing and moderate loss of articular cartilage (grade 2) and no hip had complete loss of articular cartilage (grade 3). Mean pre-operative HHS was 74.9 (range 47–96), and the mean post-operative HHS was 91.9 (range 65–100).

Table 1 Clinical data for the 107 hips in 93 patients

	Average	Range
Age at surgery (years)	37.6	14–65
Height (cm)	158	143–179
Weight (kg)	55.9	38–89
Body mass index (kg/m^2)	22.4	15.6–33.3
Pre-operative HHS (points)	74.9	47–96
Pain	25.1	10–40
Function	41.6	23–47
ROM / deformity	8.6	7–9
Post-operative HHS	91.9	65–100
Pain	39.1	20–44
Function	44.7	32–47
ROM / deformity	8.7	7–9
Pre-operative LCEA (°)	10.2	−10–23
Post-operative LCEA	30.0	15–44
Change in LCEA	19.9	6–38
Pre-operative HLI	0.56	0.46–0.73
Post-operative HLI	0.54	0.44–0.75
Smoking status (*n* %)	24 (22%)	
Pre-operative Tönnis grade 0, 1, 2, 3 (*n* hips)	49, 51, 7, 0	
Sex, male:female (*n*hips)	4:103	

HHS Harris Hip Score, *ROM* range of motion, *LCEA* lateral centre-edge angle, *HLI* head lateralisation index

The incidence of pubic delayed union on X-rays at one year post-operatively was 11.2% (12 of 107 hips) and on CT scans was 20.6% (22 of 107 hips). The incidence of ischial delayed union on X-rays was 5.6% (6 of 107 hips) and 8.4% (9 of 107 hips) on CT scans. No patient showed delayed union for the iliac bone in either modality (Table 2).

Comparisons between patients with delayed union and union clinical outcomes are shown in Table 3. In patients with both pubic and ischial delayed union, the post-operative pain score (p = 0.032) differed significantly between groups, but there were no significant differences in function and range of motion/transformation scores. There were also no significant differences in patients with pubic or ischial delayed union only.

Table 2 Incidence of delayed union in the 107 hips

	No. hips	Rate (%)
Pubic delayed union (X-ray)	12	11.2
Pubic delayed union (CT)	22	20.6
Ischial delayed union (X-ray)	6	5.6
Ischial delayed union (CT)	9	8.4
Iliac delayed union (X-ray)	0	0
Iliac delayed union (CT)	0	0

CT computed tomography

Table 3 Comparisons between patients with delayed union and union clinical outcomes

	Delayed union (*n*)	Union (*n*)	*P* value
Pubic bones	22	85	
Post-operative HHS (points)	90.3	92.6	0.252
Pain	38.0	39.6	0.187
Function	44.2	44.9	0.459
ROM / deformity	8.7	8.8	0.550
Ischial bones	9	98	
Post-operative HHS (points)	90.3	92.3	0.496
Pain	36.4	39.5	0.072
Function	44.6	44.7	0.871
ROM / deformity	8.8	8.7	0.811
Pubic and ischial bones	7	100	
Post-operative HHS (points)	88.1	92.5	0.190
Pain	35.4	39.6	0.032*
Function	43.9	44.8	0.509
ROM / deformity	8.8	8.7	0.493

HHS Harris Hip Score, *ROM* range of motion

*p<0.05: significant difference

Case presentations

Case 1

Case 1 was a 22-year-old woman with right-sided PAO. In pelvic anteroposterior radiographs, the LCEA varied from pre-operative 9° to post-operative 22°. The lateral covering of the acetabular roof improved post-operatively. X-ray and CT scans were performed at one year post-operatively. Pubic, ischial and iliac bone union appeared to be complete on both X-ray and CT scans (Fig. 3a–c). HHS at one year was 100 points; item scores for pain, function and ROM/transformation were 44, 47 and 9, respectively. There was no pubic or ischial pain during follow-up examinations.

Case 2

Case 2 was a 51-year-old woman with right-sided PAO. In pelvic anteroposterior radiographs, the LCEA varied from pre-operative 0° to post-operative 22°. X-ray and CT scans were performed at one year post-operatively. In X-ray images, union appeared to be complete for all three bones (iliac, pubic and ischial) (Fig. 4a). However, CT scans indicated delayed union in the pubic bone (Fig. 4b, c). HHS at one year after PAO was 92 points; item scores for pain, function and ROM/transformation were 40, 43 and 9, respectively. There was mild tenderness in the pubic region, with discomfort of the pubic region during hip flexion. A cane was occasionally needed during long walks. There was no need for analgesic medication.

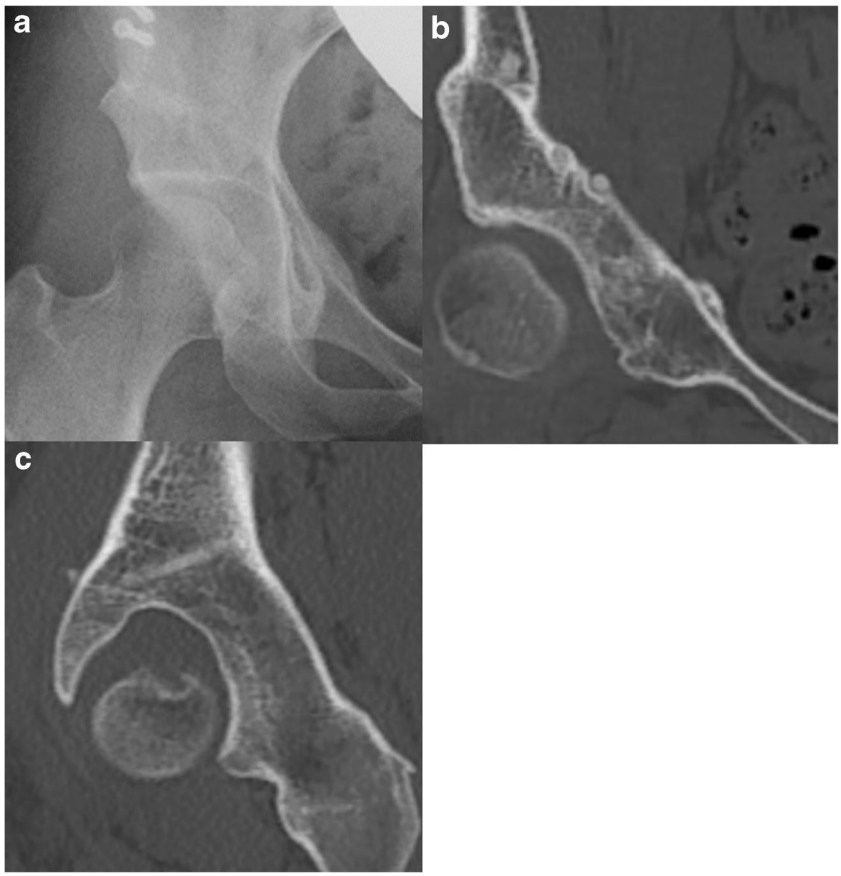

Fig. 3 Case 1. A 22-year-old woman who underwent right-sided peri-acetabular osteotomy (PAO): Both X-ray and computed tomography (CT) scans indicated bone union in the osteotomy at one year after surgery. **a** Anteroposterior radiographs at one year post-operatively; ilium, pubis and ischium show good bone union. **b** Computed tomography (CT) scan at one year post-operatively; pubis bone union appears to be complete. **c** CT scan at one year post-operatively; bone union appears to be complete for both the ilium and ischium

Case 3

Case 3 was a 51-year-old woman with left-sided PAO. In pelvic anteroposterior radiographs, the LCEA varied from preoperative 6° to post-operative 30°. X-ray and CT scans were performed at one year post-operatively. In X-ray images, union appeared to be complete for all three bones (iliac, pubic and ischial) (Fig. 5a). However, CT scans indicated delayed union for both pubic and ischial bones (Fig. 5b–d). HHS at one year after PAO was 84 points; item scores for pain, function and ROM/transformation were 30, 45 and 9, respectively. Pubic and ischial pain occurred on a lengthy sitting position and walking.

Discussion

Previous studies have reported the incidence of pubic nonunion after PAO as 12% (10:83 hips) [15] and 17.2% (60:348 hips) [13]. Similarly, the incidence of ischial nonunion after PAO is reported at 1.2% (1:83 hips) [15] and 6% (1:16 hips) [16]. These reports were evaluated based on X-rays. In the study reported here, X-ray findings indicated similar incidences of pubic and ischial delayed union at one year after PAO. Few studies have determined the incidence of delayed union using CT scans. We determined the incidence of delayed union at one year after PAO using both X-ray and CT scans, with an incidence of pubic, ischial and iliac delayed union being 20.6%, 8.4% and 0%, respectively. Compared with X-ray findings, CT scans identified a higher incidence of delayed union, indicating that even when bone union is confirmed on X-ray, there remain cases where an absence of bone continuity can only be seen on CT images, as observed in our case studies 2 and 3. For case 2, although bone union was confirmed on pelvic anteroposterior radiographs, the absence of bone continuity could be seen on 3D–CT oblique images. We propose that this limitation might stem from the 2D nature of X-ray images. For case 3, an opaque, callus-like tissue on the osteotomy site was observed in X-ray images but not on CT scans; we are unsure of the cause of this callus-like tissue. In both cases, the patient was accompanied by some symptoms at the osteotomy site.

In regards to the ilium, Trumble et al. [23] reported that only 1:123 hips had impeding iliac nonunion after PAO, bone grafting re-operation was required for that patient. Similarly, Christoph et al. [15] showed union for all 83 hips after PAO; we observed union for all iliac bones in our study. Thus, it appears there is a low chance of delayed union of the iliac bone after PAO.

We investigated clinical outcomes to evaluate painful symptoms of delayed union. Ischial pain occurred following a lengthy sitting position and walking. There was tenderness in the pubic region, with discomfort during hip flexion.

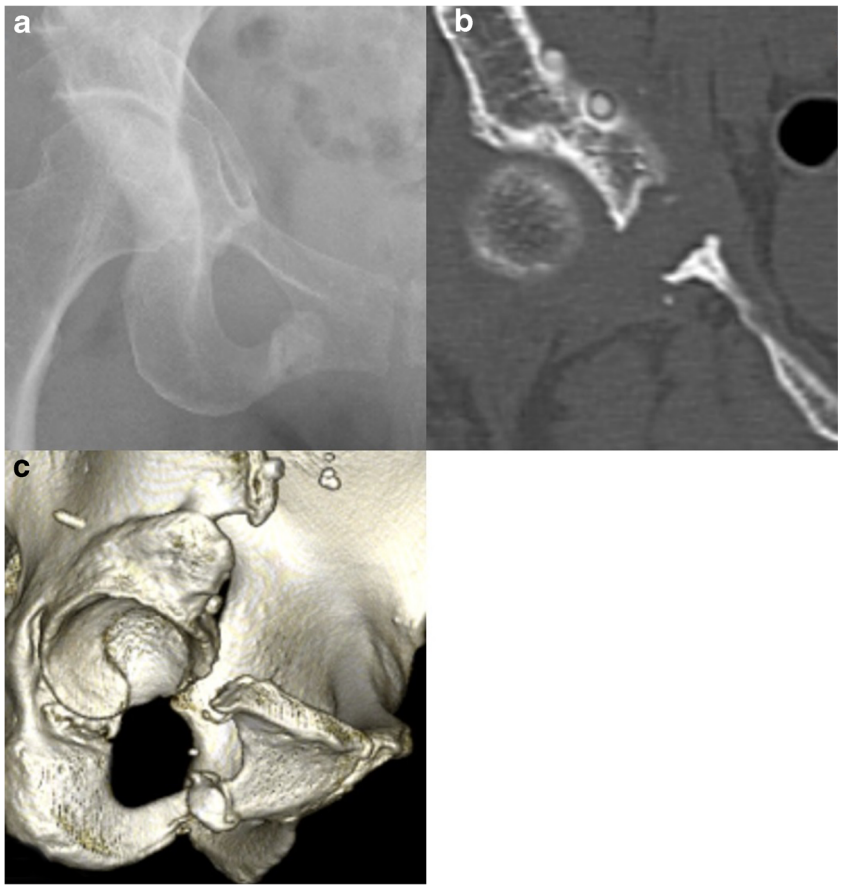

Fig. 4 Case 2. A 51-year-old woman who underwent right-sided peri-acetabular osteotomy (PAO): Conflicting results seen with X-ray and computed tomography (CT) scans at one year after surgery. **a** Anteroposterior radiographs at one year post-operatively; osseous continuity was confirmed. **b** CT coronal slice of the pubic osteotomy section at one year post-operatively; no continuity of the pubis in coronal slices, suggesting delayed pubic union. **c** Three-dimensional CT oblique image at one year post-operatively; gap is present in the pubis osteotomy section showing delayed union of the pubic bone

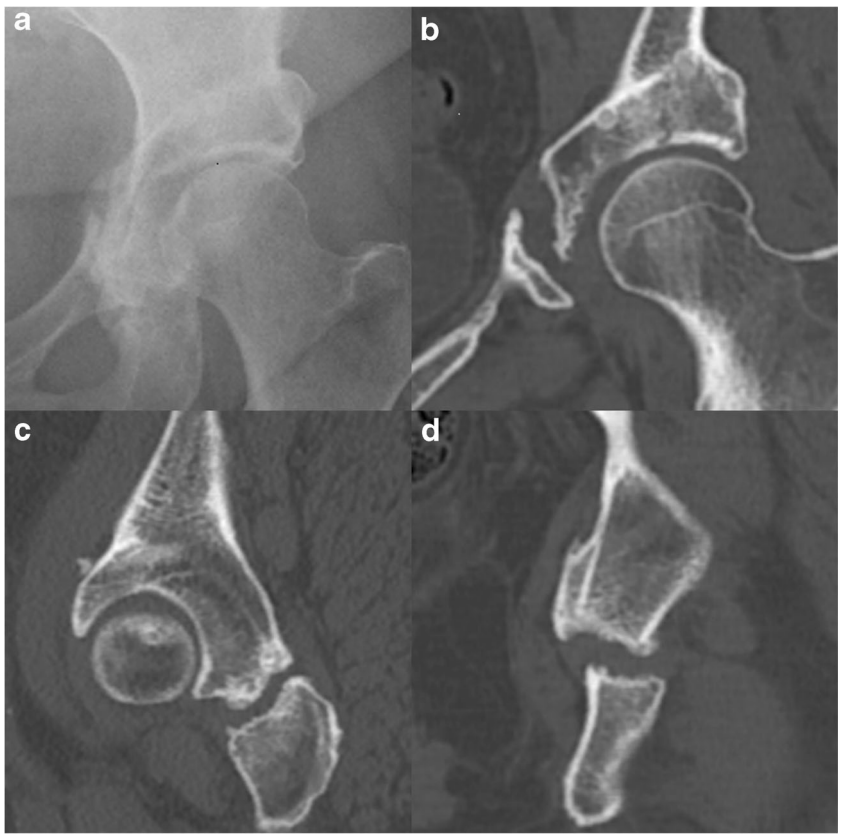

Fig. 5 Case 3. A 51-year-old woman who underwent left-sided peri-acetabular osteotomy (PAO): Conflicting results were seen with X-ray and CT scans at one year after surgery. **a** Anteroposterior radiographs at one year post-operatively; all three bones (ilium, pubis and ischium) appear to be healed on X-ray images. **b** Computed tomography (CT) coronal slice of the pubic osteotomy section at one year post-operatively; no continuity of the pubis in coronal slices is visible, suggesting delayed pubic union. **c** CT sagittal slice of the iliac and ischial osteotomy section at one year post-operatively; iliac bone union was good, but there was no continuity of the ischium in sagittal slices. **d** CT coronal slice of the ischial osteotomy section at one year post-operatively; no continuity of the ischium was seen in the coronal slice, indicating delayed union of the ischium and pubis

Compared with the union group, the post-operative pain score was lower in the delayed union group. In patients with both pubic and ischial delayed union, post-operative pain score differed significantly (Table 3). Thus, delayed union may have an effect on post-operative pain.

This study had several limitations. First, although we confirmed cases with delayed union at one year post-operatively, it is unknown whether these bones fail to unite or eventually heal. Second, we could only evaluate a small number of cases and did not achieve an 80% follow-up rate. A loss to follow-up increases bias, and this may have affected our results. Third, comparison of clinical scores between patients with union and nonunion was not available due to the small number of cases. The incidence of symptomatic delayed union of the pubis is reported to be ~10% [12]; Finally, in terms of radiation exposure, we do not believe that pelvic CT scans one year after PAO should be performed routinely. In the future, it will be desirable to devise a radiographic method, such as multidirectional X-ray, that has a higher sensitivity than anteroposterior X-ray but a lower radiation exposure than CT scans.

In conclusion, CT scans were superior for detecting delayed union of the pubis and ischium at 1 year after PAO compared with X-ray imaging in cases with some symptoms at the osteotomy site.

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Compliance with ethical standards

Conflict of interest The authors declare that they have 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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