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The Incidence and Risk Factors of Pelvic Stress Fracture, Delayed-healing and Non-union Following Periacetabular Osteotomy in Adolescents

Daniel Lazar[1,#,*], Daniel Bomark[1,#], Ole Ovesen[2], Morten Bøgehøj[3], Søren Overgaard[4]

[1]University of Southern Denmark, Denmark

[2]Orthopaedic research unit, Department of Orthopaedic Surgery and Traumatology, Odense University Hospital Department of Clinical Research, University of Southern Denmark, Denmark

[3]Department of Orthopaedic Surgery, Aarhus University Hospital, Aarhus, Denmark

[4]Department of Orthopaedic Surgery and Traumatology, Copenhagen University Hospital, Bispebjerg, University of Copenhagen, Denmark

[#]These authors have contributed equally to the paper

[*]Correspondence should be addressed to Daniel Lazar, daniel-lazar@hotmail.com

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Abstract

Background: Periacetabular Osteotomy (PAO) is a well-established procedure, however more prospective cohort studies are required to assess all clinical factors related to this invasive intervention. The aims of this study are as follows 1) quantifying stress fractures, delayed-healing and non-union post PAO and 2) to correlate possible risk factors for developing symptomatic stress fracture, delayed-healing or non-union.

Methods: We retrospectively collected radiologic and baseline data of the patient cohort and prospectively evaluated radiologic images for stress fractures, delayed-healing and non-union. A total of 621 hips (537 patients with a mean age 31.8, ranging 18 to 58 years) between January 2004 and December 2017 were included of which females composed the majority (78%). Compiled data were analyzed by utilizing chi-square and t-test for stress fracture, delayed-healing and non-union for risk factor determination.

Results: In this cohort comprising 621 hips, this study determined the prevalence rates of stress fractures, delayed healing, and non-union following PAO surgery to be 4.0%, 2.3%, and 5.6%, respectively. A detailed analysis of the data pertaining to patients who experienced stress fractures revealed three significant variables associated with their occurrence: higher body mass index (BMI), lower Wiberg's Center Edge (CE) angle, and higher AA angle. Furthermore, the incidence of delayed healing was also significantly related to higher BMI, lower CE angle, and higher Acetabular Index (AA) angle. While the risk of non-union was found to be significantly associated with both higher BMI and a history of smoking.

Conclusions: This study has quantified the prevalence of stress fracture, delayed-healing and non-union for patients that have undergone PAO and suggested an increased risk of aforementioned adverse events for certain baseline values.

Keywords: Periacetabular osteotomy, Pelvic stress fracture, Hip dysplasia, Risk factor

List of Abbreviations: PAO: Periacetabular Osteotomy; BMI: Body Mass Index; BMD: Bone Mass Density; CE-angle: Wiberg's Center Edge Angle; AA-angle: Acetabular Index Angle; HD: Hip Dysplasia; OUH: Odense University Hospital

Introduction

Hip dysplasia (HD) affects approximately 2-5% of both genders[1-3], characterized by an abnormal steep and shallow acetabular socket that compromises femoral head coverage. This condition can lead to pain, impaired function, and a significant decrease in quality of life due to increased mechanical stress and dynamic instability [4,5].

The Bernese Periacetabular Osteotomy (PAO) is a recognized and validated surgical intervention utilized in adults diagnosed with HD. This procedure aims to alleviate pain, enhance physical function, and improve overall quality of life by reorienting the acetabulum to restore appropriate anatomic coverage of the femoral head [6-8]. For experienced surgeons, the procedure generally demonstrates a favorable safety profile; however, it is not without potential complications. These may include nerve and vascular dysfunctions, and some patients may experience stress fractures, delayed healing, or non-union of the surgical site [9].

Existing literature on the association between PAO and pelvic stress fractures presents a variable prevalence, ranging from 2% (n = 17) [10] to 18.4% (n = 359) [11]. Given this disparity, there is a pressing need to identify risk factors that contribute to these complications to enhance patient safety and improve treatment efficiency.

Accurately defining risk factors for complications in hip dysplasia surgeries is crucial for enhancing patient safety and optimizing cost-effectiveness. Identifying these risk factors allows for a more precise stratification of patients, enabling the implementation of preventive strategies and tailored interventions that reduce the likelihood of adverse outcomes. Understanding these factors is essential for minimizing complications and improving overall care in hip dysplasia treatment.

Our study aims to quantify the incidence of stress fractures, delayed-healing, and non-union after PAO and subsequently identify risk factors associated with these outcomes.

Materials and Methods

Patient selection

This retrospective cohort study was approved by the Danish Patient Safety Authority on June 12, 2019, Region of South Denmark (Fortegnelsen) on May 5, 2019 and our institutional review board, November 21, 2019. The study is reported according to STROBE guidelines [12].

We had conducted a comprehensive review of radiographic images and collected baseline data from a cohort of 955 hips, involving 812 consecutive patients who underwent PAO for HD between January 2004 and December 2017. The surgical procedures were performed by three experienced orthopedic surgeons. Patient records were meticulously extracted from the patient files at Odense University Hospital (OUH) using each patient's unique personal identification number to ensure accurate data retrieval and analysis.

The inclusion criteria consisted of patients between ≥ 18 and ≤ 60 of age who have undergone PAO. Hips were excluded if underwent ipsilateral PAO reoperation (n = 2), incomplete data recording (n = 5), operation outside the time frame (n = 80) or lack of postoperative imaging (n = 110). In the end 621 (65%) of the total 955 hips were included in the study with a minimum 1/2-year follow-up (mean follow-up, 1.1 years, range 0.52 to 2.1 years) for stress fracture and delayed-healing, while 2 to 5 years for non-union determination **(Figure 1)**.

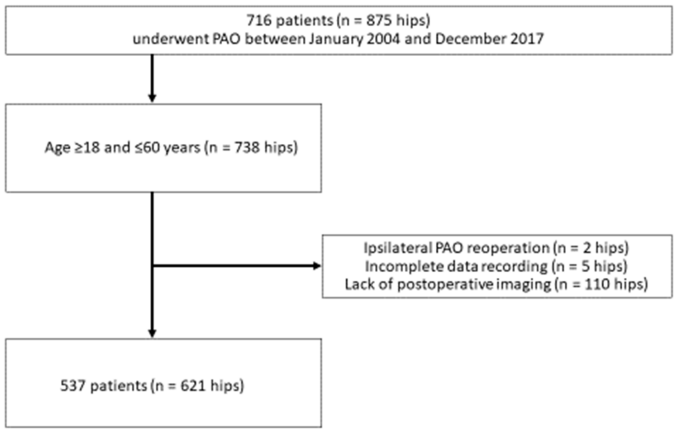

Figure 1. Flow diagram of included and excluded patients.

The surgical procedure

The procedure was carried out in supine position using a modified ilio-femoral approach [13]. In brief, all bones were exposed sub-periosteally. First the pubic bone was exposed and osteotomized medial to acetabulum. Secondly, the ischium was approached through blind dissection anteriorly and osteotomized using a curved osteotome preserving the posterior column. From the medial side the osteotomy was continued around the acetabulum. Thirdly the iliac bone was divided using an oscillating saw. Finally, the osteotomy was completed by using a straight osteotome from above. Thereafter, reorientation of acetabulum was done aiming to increase coverage of the femoral head keeping the roof horizontal and the opening of acetabulum anterior. All osteotomies were fixed with two cortical screws from the iliac crest in the acetabular bone **(Figure 2)**. Identical fixation implants and procedures included in this study, were conducted by the following authors and experienced consultants; OO, MB, and SO (**Figure 2)**.

Study size

A total of 537 patients, representing 621 hips, were enrolled in the study. The study predominantly comprised females, accounting for 420 individuals (78%). Of the 621 surgical procedures performed, 344 hips (55%) were operated on the right side, while the remaining 277 hips (45%) were on the left side. The mean age of the patients at the time of surgery was 31.8 years, with an age range spanning from 18 to 58.1 years. Smoking history amongst the participants indicated that 255 patients (47%) were nonsmokers, 139 patients (26%) were either current or former smokers, and there was no smoking status information available for 143 patients (27%). The average body mass index (BMI) was 28.6 kg/m^2 (range, 16.7 to 43.9 kg/m2). Of the total patient pool 14 were underweight (BMI <18.5 kg/m^2), 268 of normal weight (BMI ≥18.5 to <25 kg/m^2), 183 were overweight (BMI ≥25 to <30 kg/m^2) and 72 were obese (BMI ≥30 kg/m^2). In summary we categorized BMI in 2 patient groups; BMI <25 kg/m^2 with 282 (53%) patients and BMI ≥25 kg/m^2 with 255 (47%) patients.

The baseline data variables collected included age, BMI, gender, smoking history, and the CE and AA angles.

Radiographic definitions and measurements

Patients were systematically reviewed in terms of anteroposterior and in false profile in which the pelvis was rotated 65° anteriorly [14] in pelvic- and hip view. Radiographic images for 536 patients (621 hips) were evaluated after approximately 8 weeks and 12 months for stress fracture, delayed-healing after 12 months and a minimum of 2 years for non-union. All images were prospectively assessed individually by the lead authors. Senior author (SO) was consulted when no consensus was achieved and to confirm stress fracture, delayed-healing or non-union.

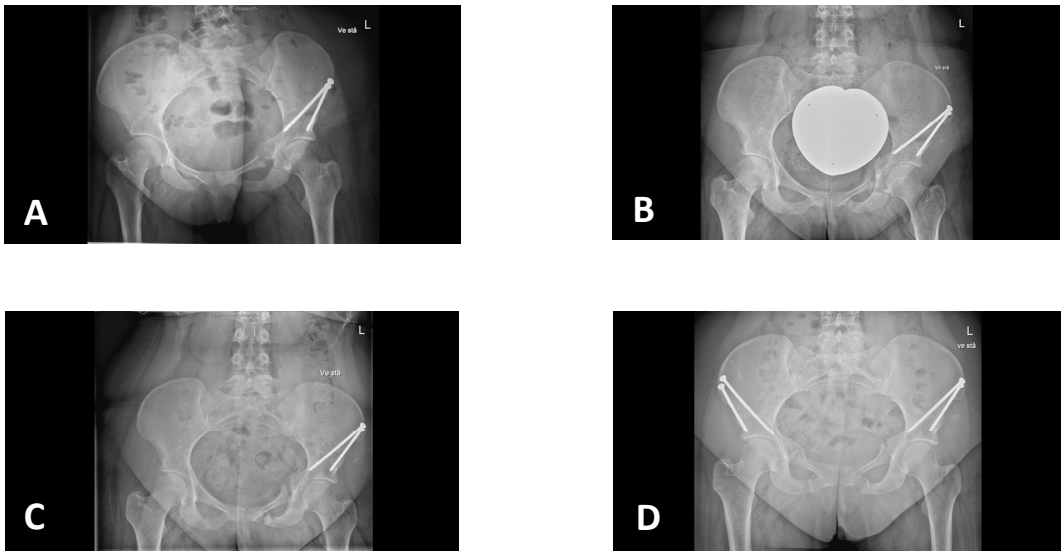

Figure 2. A 20-year-old woman with symptomatic acetabular dysplasia who underwent PAO on left hip on June 04, 2014, through a modified ilio-femoral approach. **A.** Immediate postoperative radiograph anterior posterior (AP) projection of pelvis. **B.** 8 weeks postoperative radiograph AP projection of left hip showing progress of all osteotomies. **C.** 1- year postoperative radiograph AP projection illustrating a prominent stress fracture on the left inferior pubic bone. **D.** Respectively 5- and 4 years postoperative AP projection, following left and right PAO. Both hips exhibit a stress fracture in the inferior pubic bone, while left osteotomy of superior pubic ramus demonstrates a non-union.

Healing was defined as a contiguous osseous union across with a visible trabecular pattern in superior pubic ramus, ischium or ilium [15]. Stress fracture was defined in consensus by the authors as a non-contiguous osseous structure or a condensed zone like impression fracture localized in the inferior pubic ramus or sacrum, which was not present at postoperative control radiograph on day of surgery. The fracture line may be with callus formation and some resorption. Delayed-healing (n = 35) was likewise defined in consensus by the authors as lack of healing with no bridging bone 12 months postoperatively in superior pubic ramus, ischium or ilium. Non-union (n = 14) localized in the aforementioned 3 areas was permanent no-bridging bone 2 to 5 years post PAO.

Radiographic hip dysplasia measurements were evaluated pre- and postoperative to determine the acetabular morphology and by utilizing Wiberg's center-edge (CE) angle [16, 17] (cut-off value set at > 25°) and Acetabular Index Angle (AA) [18] (cut-off value set at > 10°). Assessors were not affiliated with the surgical teams at the date of the procedures.

Statistical analysis

The study's statistical analysis focused on evaluating potential risk and protective factors for stress fractures, delayed healing, and non-union following PAO. We analyzed factors including age, BMI, gender, smoking status, and radiographic parameters such as the CE angle and AA angle.

Association tests were performed for stress fracture, delayed-healing and non-union as dependent variables, proposed risk and protective factors as independent variables. Chi-square and t-test were used to compare categorical and continuous variables respectively, between patients who sustained a stress fracture, delayed-healing and non-union respectively, and those who did not. For association models, the null hypothesis of no association was rejected at $\alpha = 0.05$. As we had no preconceived hypothesis of the relationships between the predictors and the outcomes, a two-tailed test was used to reject the null hypothesis for continuous variables. Statistical models were performed using STATA 15.0 (StataCorp. 2017. Stata Statistical Software: Release 15. College Station, TX: StataCorp LLC).

No additional examinations or interventions were conducted beyond the standard clinical assessments related to the patients' hip procedures. We obtained ethical approval prior to the investigation of patient files, ensuring full compliance with institutional guidelines.

Results

A total of 955 hips from 812 consecutive patients underwent PAO, of which 621 hips from 537 consecutive patients were found to meet the eligibility criteria for inclusion **(Figure 1)**. The specifics regarding the localization of stress fractures, as well as instances of delayed healing and non-union, are outlined **(Table 1)**.

At the eight-week postoperative mark, no stress fractures were identified; however, by the twelve-month follow-up, 25 hips (4%) exhibited stress fractures. Notably, these fractures occurred exclusively in female patients and were localized to the inferior pubic bone. Among these cases, nine stress fractures (36%) were correlated with instances of delayed healing, non-union, or both. The average age (Mean and

Table 1. Locations of stress fracture, delayed-healing and non-union.

	Right hip	Left hip	Total hips*
Surgeries, total:	**344 (55%)**	**277 (45%)**	**621 (100%)**
Stress fracture, sum:	**17 (68%)†**	**8 (32%)†**	**25 (4%)**
Inferior pubic ramus	17 (68%)	8 (32%)	
Sacrum	0	0	
Delayed-healing, sum:	**20 (57%)**	**15 (43%)†**	**35 (6%)**
Superior pubic ramus	15 (75%)	13 (87%)	
Ilium	0	0	
Ischium	5 (25%)	2 (13%)	
Non-union, sum:	**8 (57%)†**	**6 (43%)†**	**14 (2%)**
Superior pubic ramus	7 (88%)	5 (83%)	
Ilium	0	0	
Ischium	1 (12%)	1 (17%)	

*Values are listed as total hips with events followed by percentage of affected hips for total operated hips. †Values are listed as events for affected hips followed by percentage of events in hips in parentheses.

SD) of patients with stress fractures (46.4 ± 11.7 years) was significantly higher compared to those with delayed healing (40.5 ± 9.9 years) and non-union (39.4 ± 10.9 years).

Stress fractures were significantly associated with increasing age ($p < 0.001$), higher BMI ($p = 0.006$), female gender ($p = 0.008$), and a history of smoking ($p = 0.013$), with 61.9% of patients with stress fractures being smokers as opposed to 35.1% of those without.

At the twelve-month follow-up, 35 patients (5.6%) were found to experience delayed healing, with a substantial majority of 30 patients (86%) being women. This subgroup exhibited a significantly higher BMI ($p = 0.005$), a lower PreCE angle ($p = 0.006$), and a larger PreAA ($p = 0.009$).

Additionally, a total of 14 instances of non-union (2%) were diagnosed, with 71% of these cases occurring in female patients. A higher BMI ($p < 0.001$) and a history of smoking ($p = 0.002$) with 76.9% of non-union cases being smokers compared to 35.2% of those with normal union, were also statistically related to non-union outcomes.

A summary of the findings regarding all three adverse events—stress fractures, delayed healing, and non-union—is presented **(Table 2)**.

Discussion

This study reported the occurrence of 25 (4%) stress fractures, 35 (5.6%) cases of delayed healing, and 14 (2%) instances of non-union. These findings align with previous research that has indicated a range of stress fracture prevalence between 2% and 18.4% across both genders [1-3]. No instances of stress fractures were reported among male participants, thereby precluding the development of a prediction model. A chi-squared test indicated a significance level of $\alpha = 0.008$, suggesting that the observed discrepancy between genders is unlikely to be attributable to chance. This notable finding, which identified an absence of stress fractures among male participants, may be elucidated by anatomical differences inherent to each gender. Existing literature has demonstrated that women generally exhibit lower BMD and bone size in comparison to men, which could contribute to a greater susceptibility to stress fractures in females [19,20]. Women generally have decreased trabecular density than men, which further declines through time from a specific age, as shown by the bone peak mass difference [21], which corresponds with a higher mean age of 46.4 ± 11.7 (Mean and SD) for those with stress fracture. Additionally, patients who experienced stress fractures demonstrated a higher BMI, suggesting a correlation between a BMI of 25 or greater and the incidence of stress fractures. The increased risk associated with advancing age and elevated BMI may consequently explain the higher prevalence of stress fractures observed in women.

Our study indicated that patients exhibiting the most severe form of dysplasia are at a heightened risk of adverse outcomes. This observation can be rationalized by the fact that greater degrees of reorientation are required in cases with more substantial anatomical discrepancies, particularly in the superior pubic bone. This increased reorientation necessitates a wider gap, which may contribute to the elevated risk observed in this patient population [22]. The pelvis undergoes substantial changes after a PAO. Specifically, the disruption of bony continuity in the superior pubic ramus and the following extensive correction procedures, resulting in abnormal load distribution through the ischium and inferior pubis. This increased level of stress on these anatomical structures may exceed its ability to cope, and if the superior pubic ramus does not heal correctly, the likelihood of failure increases [23].

A notable limitation of this study is that the dataset was collected over a span of 14 years, which allowed for the inclusion of a larger sample size. However, the follow-up period was restricted to only one year, potentially leading to an underestimation of the incidence rates. The operating techniques and equipment utilized may have exhibited some variations, and it is also possible that the postoperative protocols have evolved over time. Depending exclusively on

Table 2. Baseline data associations with stress fracture, delayed-healing and non-union*.

	Stress fracture	*P* value	delayed-healing	*P* value	Non-union	*P* value
Age†	46.4 ± 11.7 (25, 41.6 to 51.2)	**<0.001**	40.5 ± 9.9 (35, 37.1 to 43.9)	0.169	39.4 ± 10.9 (14, 33.2 to 45.7)	0.636
BMI†	27.6 ± 3.5 (25, 26.2 to 29.1)	**0.006**	27.3 ± 4.4 (35, 25.8 to 28.8)	**0.005**	29.7 ± 2.9 (14, 28.0 to 31.3)	**<0.001**
Gender: Female‡	25 (100%)	**0.008**	30 (85.7%)	0.299	10 (71.4%)	0.499
Smoking history‡	13 (61.9%)	**0.013**	9 (39.1%)	0.776	10 (76.9%)	**0.002**
CE angle†	20.3 ± 5.0 (8, 16.1 to 24.4)	0.392	17.7 ± 10.4 (21, 13.0 to 22.4)	**0.006**	23.6 ± 3.5 (7, 20.4 to 26.8)	0.866
AA angle†	12.8 ± 3.3 (8, 10.0 to 15.5)	0.602	15.7 ± 8.0 (21, 12.0 to 19.3)	**0.009**	15.1 ± 6.7 (7, 9.0 to 21.3)	0.199

*Preoperative data for 537 patients (621 hips). †Values are listed as follows: mean and standard deviation followed by the number of patients with available data and a 95% confidence interval in parentheses. ‡Values are listed as follows: number of patients and the percentage of patients with available data in parentheses.

radiographic images for assessment, without the inclusion of computed tomography (CT) scans, may pose a significant risk of misdiagnosis. Although radiographic images provide valuable information, their lower resolution may not adequately capture all pathological conditions when compared to CT scans [24]. Consequently, exclusive reliance on radiographs could result in erroneous conclusions regarding patient diagnosis. To address this potential issue, consultations with the senior author (SO) were conducted in cases of diagnostic discrepancies.

A significant strength of this study lies in its substantial sample size, which encompassed the radiographic images of 537 patients, representing a total of 621 hips. This comprehensive evaluation enabled the quantification of the prevalence of stress fractures, delayed healing, and non-union among patients who underwent PAO. It is important to acknowledge that inaccuracies in imaging interpretation may arise due to various factors [25]. To mitigate the risk of erroneous radiographic assessments, all cases exhibiting potential signs of stress fractures, delayed healing, or non-union were meticulously reviewed and deliberated upon with the Senior author (SO).

Conclusion

This study found that stress fractures occurred in the inferior pubes and exclusively in women. Higher age, smoking, and BMI were identified as risk factors. The findings suggest a need for targeted patient education, especially for women and more focus should be done to minimize a gap between osteotomy ends during surgery. Closer monitoring postoperative may be beneficial for this group.

Declaration

Ethics approval and consent to participate

The study was approved by the Danish Patient Safety Authority (Reference number: 3-3013-3001/1), Region of South Denmark (Reference number: 19:20322) and our institutional review board (Reference number:2019_17).

Consent for publication

Informed consent was obtained from all patients prior to undertaking this research.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

Not applicable.

Authors' contributions

Study design was done by SO, DL, and DB. Patient recruitment, data collection, and surgical procedures done by OO, MB, and SO. Data analysis and data interpretation by DL and DB, which have equally contributed to the paper. Drafting of the manuscript by DL, DB, and SO. Manuscript review by OO and MB. All authors have read and approved the final manuscript.

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