

What is the best treatment for displaced Salter–Harris II physeal fractures of the distal tibia?

Hoon PARK¹, Dong Hoon LEE², Seung Hwan HAN¹, Sungmin KIM², Nam Kyu EOM¹, and Hyun Woo KIM²

¹ Department of Orthopaedic Surgery, Gangnam Severance Hospital, Yonsei University College of Medicine, Seoul, Korea; ² Division of Orthopaedic Surgery, Severance Children's Hospital, Yonsei University College of Medicine, Seoul, Korea

Correspondence: pedhkim@yuhs.ac

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Background and purpose — The optimal treatment of displaced Salter–Harris (SH) II fractures of the distal tibia is controversial. We compared the outcomes of operative and nonoperative treatment of SH II distal tibial fractures with residual gap of > 3 mm. Factors that may be associated with the incidence of premature physeal closure (PPC) were analyzed.

Patients and methods — We retrospectively reviewed 95 patients who were treated for SH II distal tibial fractures with residual gap of > 3 mm after closed reduction. Patients were assigned to 1 of 2 groups: Group 1 included 25 patients with nonoperative treatment, irrespective of size of residual gap (patients treated primarily at other hospitals). Group 2 included 70 patients with operative treatment. All patients were followed for ≥ 12 months after surgery, with a mean follow-up time of 21 months. Logistic regression analyses were performed to identify risk factors for the occurrence of PPC.

Results — The incidence of PPC in patients who received nonoperative treatment was 13/52, whereas PPC incidence in patients who received operative treatment was 24/70 ($p = 0.1$). Multivariable logistic regression analysis determined that significant risk factors for the occurrence of PPC were age at injury, and injury mechanism. The method of treatment, sex, presence of fibular fracture, residual displacement after closed reduction, and implant type were not predictive factors for the occurrence of PPC.

Interpretation — Operative treatment for displaced SH II distal tibial fractures did not seem to reduce the incidence of PPC compared with nonoperative treatment. We cannot exclude that surgery may be of value in younger children with pronation–abduction or pronation–external rotation injuries.

et al. 1978, Kay and Matthys 2001). SH II fractures are considered low-risk fractures because the incidence of premature physeal closure (PPC) was reported as 2–5% in a previous study (Dugan et al. 1987). However, some studies indicate that PPC may be more common than previously realized in specifically SH II distal tibial fractures (Spiegel et al. 1978, Kling et al. 1984). Several recent studies reported that the incidence of PPC was 25–40% in SH II distal tibial fractures (Barmada et al. 2003, Rohmiller et al. 2006, Leary et al. 2009). Barmada et al. (2003) suggested that open reduction and removal of the entrapped periosteum in displaced SH II fractures with residual physeal gap of > 3 mm may be beneficial for reducing the incidence of PPC, and it seems to be a current trend that a surgical approach is the treatment of choice in displaced SH II fractures of the distal tibia. However, some authors insist that surgical management of these fractures does not reduce the incidence of PPC, and might increase the need for subsequent surgeries (Russo et al. 2013).

Most previous studies included patients with all types of physeal fractures and even transitional fractures (Barmada et al. 2003, Rohmiller et al. 2006, Leary et al. 2009, Schurz et al. 2010). Although some authors recently reported the results of surgical treatment only for displaced SH II distal tibial fractures, they included patients with residual gap of < 3 mm and performed surgical treatment in all patients with residual gap of > 4 mm after closed reduction (Russo et al. 2013). To our knowledge, there is no clinical study that directly compared operative treatment with nonoperative treatment for displaced SH II distal tibial fractures with a residual gap of > 3 mm to prove the superiority of surgical treatment as suggested by Barmada et al. (2003). Therefore, we compared the incidence of PPC after operative treatment with that after nonoperative treatment in displaced SH II distal tibial fractures with residual gap of > 3 mm, and aimed to analyze the factors that may be associated with PPC incidence. We hypothesized that anatomical reduction would reduce the incidence of PPC incidence compared with that of nonoperative management.

Physeal injuries of the distal tibia account for one-tenth of all physeal fractures (Peterson et al. 1994). Among these, Salter–Harris type II (SH II) fractures are the most common, accounting for 40% of all distal tibial fractures in children (Spiegel

Patients and methods

Our institution has treated patients with displaced SH II distal tibial fractures according to the protocol of Barmada et al. (2003). Initially, all acute displaced fractures were treated with closed reduction. Then, if the displacement was not reduced or believed to be > 3 mm, computed tomography (CT) scanning was performed to measure the residual gap. Patients received subsequent treatment based on the amount of residual fracture displacement. Those with residual gap > 3 mm were treated with open reduction and internal fixation.

We identified 150 patients with SH II distal tibial fractures between March 2006 and March 2015. The inclusion criteria were: (1) age younger than 15 years, (2) open distal tibial physis, (3) residual displacement after closed reduction > 3 mm on coronal or sagittal CT images, and (4) minimum follow-up time of 1 year. 46 patients with nondisplaced SH II distal tibial fractures were excluded from the study. A further 9 patients were excluded because they did not have post-reduction CT scans or follow-up radiographs available for review.

Thus, 95 ankles in 95 patients were included in this study. Demographic data are presented in Table 1. The mean follow-up period was 21 (12–100) months.

The patients were assigned to 1 of 2 groups based on the method of treatment. Group 1 included 25 patients who received nonoperative treatment. All patients in Group 1 were treated at other hospitals with cast immobilization after closed reduction and then referred to our tertiary care pediatric hospital. All patients brought their medical records and radiographs including CT scans to us. These patients could not be included in our treatment protocol as described above, because the mean interval from injury to the first visit at our hospital was 2.5 (2–4.5) weeks. Instead, they were treated with non-weight-bearing short-leg cast until 6 weeks after injury. Group 2 included 70 patients who received surgical treatment. All patients in Group 2 were initially diagnosed at our hospital and were treated according to our treatment protocol as described above. Two surgeons performed all surgeries in Group 2. Open reduction was performed under fluoroscopic control. In all cases, periosteum if interposed was removed. Fixation was either by K-wires, which crossed the physis, or with screws placed in the metaphysis according to the surgeon's preference. A non-weight-bearing short-leg cast was applied for 6 weeks after surgery for all patients. K-wires were removed 4 weeks after surgery. Screws were not routinely removed; if otherwise, this was done 6 months after surgery.

The mean residual displacement was 4.0 (3.4–5.5) mm in Group 1, and 5.5 (3.5–20) mm in Group 2. We thought that this discrepancy was due to potential bias arising from the surgeon's preference for fixation procedure. Therefore, we created Group 2A to match the range of residual displacement in Group 1. Group 2A consisted of 43 patients with residual displacement of 3.5–5.5 mm.

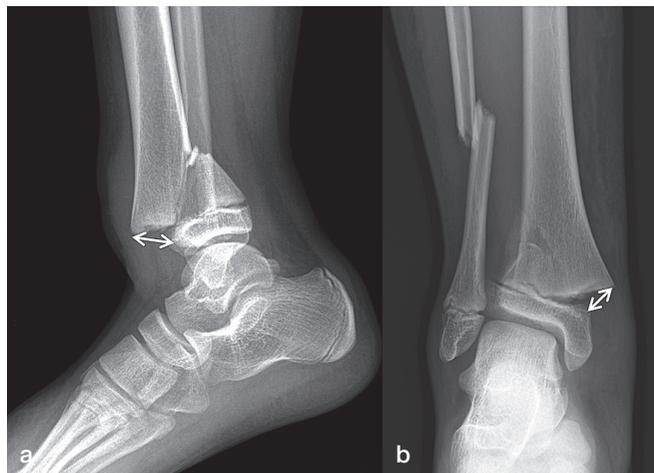


Figure 1. A SH II distal tibia fracture with (a) supination–external rotation (SER) injury, and (b) pronation–external rotation (PER) injury. The amount of initial displacement (white double-sided arrow) was measured as the largest displacement between the epiphysis and metaphysis on initial anteroposterior or lateral view.

Data included patient age at the time of injury, sex, mechanism of injury, presence of concurrent fibular fracture, amount of initial displacement before reduction, amount of residual displacement after reduction, the type of implant used, and occurrence of PPC. Initial displacement before reduction was measured from radiographs as the greatest amount of displacement (in millimeters) between the epiphysis and the metaphysis (Figure 1). Residual displacement after reduction was measured on coronal or sagittal CT images using the same method. Initial displacement was measured in 65/70 patients in Group 2. However, in Group 1, initial displacement was measured in only 6/25 patients. Some patients in Group 1 did not bring their initial radiographs before closed reduction, others brought only CT images, the remainder had inappropriate radiographs to measure the gaps. The mechanism of injury was classified as SER, ABD, or PER based on the Lauge-Hansen classification system (Lauge-Hansen 1950) (Figure 2). The physis was evaluated from bilateral anteroposterior or lateral radiographs during all follow-up appointments. If PPC was questionable, a CT scan was obtained to investigate the presence of a physeal bar. All radiological measurements were performed by 2 orthopedic surgeons (SK and NKE) who were blinded to the study.

Statistics

Comparisons were performed to determine whether the incidence of PPC differed statistically significantly between Groups 1 and 2. We also compared Group 1 with Group 2A with regard to the incidence of PPC. Several demographic and surgical variables were considered as possible factors that could be related to the occurrence of PPC. These factors included (1) age, (2) sex, (3) mechanism of injury, (4) presence of fibular fracture, (5) amount of residual displacement,

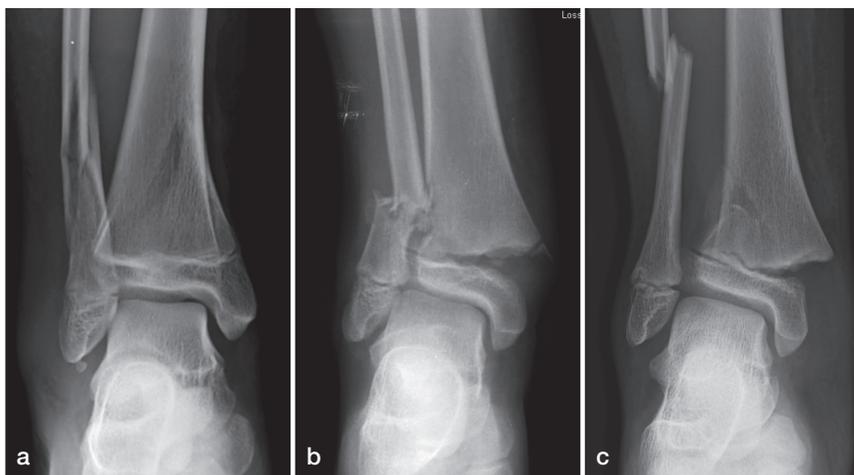


Figure 2. Types of injury: (a) supination-external rotation (SER) injury, (b) pronation-abduction (ABD) injury, and (c) pronation-external rotation (PER) injury.

(6) method of treatment, and (7) type of implant. These predictors were chosen a priori based on our own hypotheses and previous literature (Rohmiller et al. 2006, Leary et al. 2009, Russo et al. 2013). However, as mentioned earlier, we could not measure the amount of initial displacement in all patients, because most patients in Group 1 did not bring their initial radiograph at the time of injury. Therefore, the amount of initial displacement was excluded in all analyses. Correlation analyses were performed to determine whether the occurrence of PPC was significantly correlated with these demographic factors and surgical variables.

Statistical analyses were performed using SPSS® version 19.0 (SPSS, Chicago, IL, USA). Data were assessed for normality on plots and using the Shapiro–Wilk test. Student’s independent t-test for continuous variables and chi-square test for categorical variables were used to compare Group 1 and Group 2 with regard to demographic characteristics, pre-operative variables, and PPC rates. The same analytic tests were used to compare Group 1 and Group 2A. To identify the independent predictors of PPC, we used univariable and multivariable logistic regression with stepwise selection of candidate variables (see Table 1). Covariate selection was checked by visual inspection of directed acyclic graphs (Shrier and Platt 2008). Age and mechanism of injury were retained in all models. Additionally, the effect of method of treatment on incidence of PPC was analyzed in all patients and the effect of the type of implant on incidence of PPC was analyzed in patients who received surgical treatment (Group 2). All tests were 2-tailed, and $p < 0.05$ was considered statistically significant and $0.05 \leq p < 0.1$ was considered a trend toward significance to increase the sensitivity to detect potential selection bias (Altman and Bland 1996).

Ethics, funding, and potential conflicts of interest

Our Institutional Review Board approved this retrospective study (date of approval September 6, 2016; IRB number 4-2016-0650). Each author certifies that his institution approved the human protocol for this investigation, and that all investigations were conducted in conformity with ethical principles of research. No financial support has been received relating to this research. All authors have no conflicts of interests or financial disclosures to declare.

Results

There were no statistically significant differences between Group 1 and Group 2 with respect to age, sex, mechanism of injury, or the presence of fibular fracture (see Table 1). The residual displacement was significantly different ($p < 0.001$) between the 2 groups. The incidence of PPC (13/25) in Group 1 was higher than that (24/70) in Group 2, but the difference was not statistically significant ($p = 0.1$).

We created Group 2A to match the range of the residual displacement of Group 1 and compared these 2 groups with regard to same variables and still found no statistically significant difference in PPC incidence between Group 1 (13/25) and Group 2A (14/43) ($p = 0.1$).

The incidence of PPC was evaluated with multivariable logistic regression analysis of all included patients. The occurrence of PPC was associated with older age at injury (OR = 1.5), ABD-type injury (OR = 4.0), and PER-type injury (OR = 6.6). The method of treatment had no effect on the incidence of PPC (Table 2). Multivariable logistic regression analysis of Group 2 revealed two significant risk factors for the incidence of PPC, which were older age at injury (OR = 1.4) and injury mechanism: PER injury (OR = 7.2) (Table 3). ABD injury and type of implant were not predictive factors for the occurrence of PPC.

There was no nonunion and no implant failures. Superficial skin infection developed after surgery in 2 patients, who were treated with intravenous antibiotics. The mean time after surgery for PPC diagnosis was 8 (4–12) months. The mean age of patients who developed PPC was 12.3 (8.2–15) years. 37 patients had PPC, 13 in Group 1 and 24 in Group 2 (Table 4). Shortening and angular deformity were similar between groups. 2 patients underwent correctional osteotomy for angular deformity and one patient underwent permanent epiphysiodesis of the proximal tibia on the contralateral side for leg-length discrepancy in Group 1. In Group 2, we performed correctional osteotomy in 1 patient and temporary epiphysiodesis with tension band plate in 1 patient. Although we

Table 1. Comparisons between groups by treatment method

| Variables | Group 1 Cast (n = 25) | Group 2 Surgery (n = 70) | p-value (1 versus 2) | Group 2A Matched subgroup (n = 43) ^a | p-value (1 versus 2A) |
|--|-----------------------------|--------------------------------|-------------------------|---|--------------------------|
| Age, mean (range), years | 12.0 (8.2–14.8) | 11.6 (5.1–15.0) | 0.4 | 11.3 (5.1–14.5) | 0.2 |
| Sex, n | | | 0.9 | | 0.9 |
| Male | 17 | 49 | | 29 | |
| Female | 8 | 21 | | 14 | |
| Mechanism of injury, n | 0.7 | | | | |
| Supination–external rotation | 16 | 45 | | 31 | |
| Pronation–abduction | 7 | 16 | | 9 | |
| Pronation–external rotation | 2 | 9 | | 3 | |
| Fibular fracture, n | 15 | 46 | 0.6 | 22 | 0.5 |
| Residual displacement, mean (SD) (mm) | 4.0 (0.7) | 5.5 (2.7) | < 0.001 | 4.1 (0.7) | 0.6 |
| Total number of premature physal closure | 13 | 24 | 0.1 | 14 | 0.1 |

^a A matched subgroup (Group 2A) consisted of patients with residual displacement of 3.5–5.5 mm to match the range of residual displacement of Group 1.

Table 2. Univariable and multivariable logistic regression analysis of premature physal closure

| Factor | Univariable | | Multivariable | |
|----------------------------------|-------------------------|---------|-------------------------|---------|
| | Odds ratio ^a | p-value | Odds ratio ^a | p-value |
| Age at time of injury | 1.3 (1.0–1.7) | 0.02 | 1.5 (1.1–2.0) | 0.01 |
| Female versus male | 0.6 (0.2–1.5) | 0.3 | | |
| Mechanism of injury ^b | | | | |
| ABD type | 2.2 (0.8–5.9) | 0.1 | 4.0 (1.2–13) | 0.02 |
| PER type | 6.4 (1.5–27) | 0.01 | 6.6 (1.5–29) | 0.01 |
| Fibular fracture | 1.6 (0.6–3.7) | 0.3 | | |
| Residual displacement | 1.0 (0.9–1.2) | 0.8 | | |
| Surgery versus cast | 0.5 (0.2–1.2) | 0.1 | 0.5 (0.2–1.3) | 0.1 |

^a Values are odds ratio (95% confidence interval).

^b SER type is the reference group. SER: supination–external rotation; ABD: pronation–abduction; PER: pronation–external rotation.

Table 3. Univariable and multivariable logistic regression analysis of premature physal closure in patients treated with surgery (Group 2)

| Factor | Univariable | | Multivariable | |
|----------------------------------|-------------------------|---------|-------------------------|---------|
| | Odds ratio ^a | p-value | Odds ratio ^a | p-value |
| Age at time of injury | 1.3 (0.9–1.8) | 0.06 | 1.4 (1.0–2.0) | 0.06 |
| Female versus male | 0.9 (0.3–2.8) | 0.9 | | |
| Mechanism of injury ^b | | | | |
| ABD type | 1.2 (0.4–4.3) | 0.7 | 1.4 (0.3–6.2) | 0.6 |
| PER type | 9.6 (1.8–53) | 0.01 | 7.2 (1.2–42) | 0.03 |
| Fibular fracture | 1.1 (0.4–3.0) | 0.9 | | |
| Residual displacement | 1.0 (0.9–1.3) | 0.7 | | |
| Screw versus K-wire | 1.9 (0.6–5.8) | 0.2 | 2.4 (0.6–8.9) | 0.2 |

^a and ^b See Table 2

recommended permanent epiphysodesis of the contralateral proximal tibia for 2 patients showing shortening > 10 mm in Group 2, they refused subsequent surgery. The remaining 30 patients who had mild angular deformity or shortening did not undergo correctional surgery as of the last follow-up.

Table 4. Comparisons of complications between groups by treatment method. Values are number of patients

| Variables | Group 1 Cast (n = 25) | Group 2 Surgery (n = 70) | p-value |
|----------------------------------|-----------------------------|--------------------------------|---------|
| Total number of PPC ^a | 13 | 24 | 0.2 |
| Shortening < 10mm | 8 | 15 | 0.3 |
| Shortening > 10mm | 1 | 2 | 0.8 |
| Angulation < 10 degrees | 2 | 5 | 0.9 |
| Angulation > 10 degrees | 2 | 2 | 0.3 |
| Required correctional surgery | 3 | 4 | 0.3 |

^a PPC: premature physal closure.

Discussion

We found that anatomical reduction using surgical treatment was not more effective for reducing the incidence of PPC than non-operative management for displaced SH II fractures. Although the PPC incidence in Group 1 patients was higher than that in Group 2 patients, there was no statistically significant difference between groups. Our results showed that the surgical treatment for displaced SH II fractures with residual physal gap of > 3 mm was not superior to nonoperative treatment.

Although SH II fractures in general have been reported to have a low incidence of growth disturbance, our results indicate that the overall incidence of PPC was 0.4 (37/95) in displaced SH II distal tibial fractures, similar to previously reported incidences (Barmada et al. 2003, Rohmiller et al. 2006, Leary et al. 2009). Thus, the presence of a residual gap (> 3 mm) in these injuries may predict a higher incidence of PPC. Although Dugan et al. (1987) considered SH II distal tibial fractures to be low-risk fractures based on the rate of complications (2–5%), we believe that displaced SH II distal tibial fractures should be considered high-risk fractures based on the incidence of PPC.

Previous studies report that initial and residual displacements are risk factors for PPC (Barmada et al. 2003, Rohmiller et al. 2006). We could not prove the effect of the amount of initial and residual displacement on the incidence of PPC using multivariable logistic regression, because these factors were not suitable for multivariable logistic regression using visual inspection of directed acyclic graphs (Shrier and Platt 2008). However, residual displacement was not a significant predictor of PPC using univariable logistic regression and the rate of PPC of Group 2 was similar to that of Group 2A.

ABD and PER injuries were associated with the occurrence of PPC, and these associations are consistent with those reported by recent studies (Rohmiller et al. 2006, Russo et al. 2013). Some authors presume that trauma involved in these types of injuries might be greater than that of SER injury, or that the direction of force during these injuries might damage Kump's bump, which could occur during initial physiological closure of the distal tibial physis (Kump 1966, Chung and Jaramillo 1995, Rohmiller et al. 2006). We agree: the medial side of the physis was more commonly injured in ABD or PER injuries than in SER injury.

PPC occurred in 37 of our patients. Of these, 7 patients developed deformity which motivated correctional surgery (performed in 5 of these). The remaining 30 patients did not undergo a second surgery, and these rates were similar to those of previous reports (Leary et al. 2009, Russo et al. 2013). Although these patients had clinical sequelae such as leg-length discrepancy of < 10 mm or angular deformity of < 10 degrees, they did not complain of any discomfort in their daily lives. Thus, not all patients with PPC have clinical sequelae that required surgical correction.

Adolescent patients close to skeletal maturity are unlikely to have significant deformity due to PPC; however, younger patients need to be followed up closely for development of significant deformities of the distal tibia.

Although surgical treatment for displaced SH II distal tibial physeal fractures with a residual gap of > 3 mm did not statistically significantly reduce the rate of PPC, surgery may be necessary in some selected patients. We think that surgical treatment may be considered in younger patients with a high possibility of PPC such as ABD or PER type injury. Additionally, older patients with a large residual displacement may require anatomical reduction to improve joint alignment due to lower remodeling potential. Therefore, the choice of treatment for displaced SH II distal tibial physeal fractures should be individualized.

This study had several limitations. First, it was a retrospective study without randomization and the relatively small number of patients with PER injury reduces the power of the statistical analysis. Second, 2 surgeons were involved, and the operative techniques and number of reduction attempts were not standardized. Third, because the patients in Group 1 did not come from our own institution, we did not know

the number of fracture reductions and the degrees of initial displacement. Moreover, the amount of initial displacement could not be analyzed as a risk factor on the incidence of PPC. Fourth, we focused on radiological results without clinical or subjective outcome.

In summary, we suggest that the treatment of displaced SH II distal tibial physeal fractures with a residual gap of > 3 mm should be individualized, with consideration of the patient's age and injury mechanism.

HP: Data analysis and interpretation, statistical analysis, writing of the manuscript. DHL: treatment concepts, revision of the manuscript. SHH: Study design. SK: data collection. NKE: data collection. HWK: treatment concepts, critical revision of the manuscript.

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