

A Single Retrograde Intramedullary Nail Technique for Treatment of Displaced Proximal Humeral Fractures in Children

Case Series and Review of the Literature

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Background: Displaced proximal humeral fractures in older children with low remodeling potential need to be reduced and fixed. There are many options for stabilization, including external fixation, rigid internal fixation with screws and plates, percutaneous pinning, and flexible intramedullary nailing. The use of 2 flexible retrograde nails, originated at the University of Nancy, France, became the most popular technique in Europe. The aim of this study was to describe and assess a modified, single retrograde nail technique to treat fractures of the proximal part of the humerus.

Methods: We performed a retrospective monocentric study. From June 2016 to May 2019, a modified retrograde nail technique with 1 prebent nail was used for the management of 21 consecutive children with a closed displaced proximal humeral fracture. Demographic and surgical data were collected. The surgical technique is similar to the classic elastic stable intramedullary nailing, but only 1 nail is used. The average surgical time and perioperative complications were used as criteria for the feasibility of this technique. Radiographs were obtained preoperatively; at 1, 4, and 6 weeks postoperatively; and after implant removal at an average of 4.2 months postoperatively. The clinical outcomes were assessed on the basis of the shoulder range of motion documented in the medical records and by using the French edition of the QuickDASH (shortened version of the Disabilities of the Arm, Shoulder and Hand [DASH] questionnaire) evaluation scale at the time of implant removal.

Results: Nineteen patients with a mean age of 12.6 years and a mean follow-up of 6 months were included in the study. The mean surgical time was 49 minutes. The single intramedullary nail technique provided a satisfactory reduction of all fractures. No perioperative complication occurred. In 1 case, partial loss of reduction was observed on the first-week control radiograph. All patients had a healed fracture, no deficits, excellent results according to the QuickDASH score, a normal range of motion, and excellent strength of the shoulder joint at the time of implant removal (at a mean of 4.2 months).

Conclusions: The current study confirms the feasibility and efficacy of the single retrograde intramedullary nail technique to treat displaced proximal humeral fractures in children.

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

Proximal humeral fractures in children represent about 2% of all pediatric fractures, with a peak incidence between 11 and 15 years of age^{1,2}. Most of these injuries can be treated nonoperatively with good clinical outcomes because of the enormous remodeling potential of the proximal part of the humerus in younger children. However, in older children with low remodeling potential, severely displaced fractures may

be treated operatively to restore anatomic alignment and maximize shoulder motion^{1,3,4}. When reduction is performed for these patients, internal fixation is required to maintain reduction and avoid subsequent displacement⁴. Several techniques can be used to stabilize operatively treated proximal humeral fractures in children, including screws, plates, external fixation, percutaneous pinning, and intramedullary nailing^{2,3,5,6}. The latter

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2 techniques are the most frequently used for closed fractures and are both effective. Intramedullary nail techniques are associated with fewer complications but require longer operations. Patients treated with this technique are also expected to have higher estimated blood loss and need for surgical implant removal compared with those who undergo percutaneous pinning. The use of 2 flexible retrograde nails, which was described in the 1970s by the team of Jean Prévot and Paul Metaizeau at the University of Nancy, France^{7,8}, became the most popular method in Europe.

The aim of this study was to describe a modified single retrograde intramedullary nail technique and discuss the outcomes in a group of skeletally immature patients with a closed displaced proximal humeral fracture.

Materials and Methods

Between June 2016 and May 2019, 43 consecutive children with a proximal humeral fracture were referred from the Emergency Department to the Pediatric Orthopedic Department of the University Hospital of Lausanne in Switzerland as potential surgical candidates and their cases were reviewed for inclusion in this retrospective study. The inclusion criteria were (1) skeletal immaturity as determined by the presence of open physes, (2) a displaced proximal humeral physeal or metaphyseal fracture deemed to be in unacceptable malalignment given the patient's age and remodeling potential, and (3) treatment with closed reduction and single intramedullary nailing.

Twenty-one children met the criteria and formed the basis of this study. Two patients who resided permanently in other countries were lost in the follow-up period, leaving 19 patients with adequate radiographic and clinical data. Records were reviewed for information regarding sex, mechanism of injury, fracture type, surgical time, complications, timing of surgical implant removal, duration of the implant removal procedure, and final shoulder range of motion and function. Preoperative, immediate postoperative, 6-week, and final post-implant-removal follow-up radiographs were assessed for maximum angular deformity and the Neer-Horowitz classification.

The indication for surgical treatment was a low remodeling potential estimated on the basis of bone age. All children were ≥ 11 years of age and had a Neer-Horowitz grade-4 fracture or a Neer-Horowitz grade-3 fracture with angulation of $>40^\circ$. The surgical indication was always validated by a chief specialized pediatric orthopaedic surgeon. Fellowship-trained pediatric orthopaedic surgeons treated all patients in this study, according to the surgical technique described below.

We undertook a retrospective review that included radiographic and clinical assessments after approval by the Swiss Ethics Committee (2019-01812). A single independent observer evaluated standard anteroposterior and Neer shoulder radiographic views of the operatively treated side retrospectively. The radiographs were evaluated for apposition, angulation, fracture union, and implant-related complications.

Clinical evaluation was both objective and subjective. The French edition of the QuickDASH (shortened version of the Disabilities of the Arm, Shoulder and Hand [DASH]

questionnaire) score was used for objective assessment at the time of implant removal (at a mean of 4.2 months postoperatively). The DASH score is a 100-point patient-completed 30-item questionnaire measuring physical and social function together with symptoms in any or all joints in the upper extremity⁹. The lower the DASH score, the more favorable the outcome.

As part of a subjective assessment, patients were asked if they were very satisfied, satisfied, or not satisfied with the outcome of treatment at the final follow-up.

Surgical Technique

All patients received antibiotics 30 minutes prior to the procedure. The surgery is performed with the patient under general anesthesia. The patient is positioned supine on the operating table with the affected upper limb placed on a radiolucent arm-table. The arm is draped free above the humeral head to allow a full range of motion. After draping, the image intensifier is placed at the level of the humeral head, over the axilla, parallel to the operating table, and perpendicular to the arm-table. In this position, there is no risk of interference with nail insertion and reduction maneuvers. A 1-cm incision is made 10 to 20 mm proximal to the lateral epicondyle. Following fascial incision and separation of muscle fibers, dissection continues to the bone. The entry hole in the distal portion of the lateral column is made with an awl, 10 to 20 mm above the lateral epicondyle.

A 3-mm sharp titanium nail that is slightly prebent at its leading end is inserted into the medullary canal using a T-handle. Reduction is achieved by gentle traction and usually requires abduction and internal rotation to counter the displacement. One must keep in mind that the rotation center, a capsuloperiosteal flap, is located posteromedially. Anteroposterior and Neer fluoroscopic views allow the quality of reduction to be checked. If reduction is satisfactory, the nail is hammered into the proximal epiphysis. In cases of unsatisfactory reduction due to substantial soft-tissue interposition in the fracture site, we suggest an external exacerbation of the deformity in both planes advancement of the nail until the fracture site is reached, and rotation of the nail in the fracture site while traction is applied in order to retrieve the interposed tissue. Then the prebent nail engages the proximal fragment and is turned accordingly to correct the reduction. Once the reduction is satisfactory, the wire can be advanced into the subchondral bone by crossing the physis to achieve maximal stability and to prevent proximal migration. The stability of fracture fixation is checked under fluoroscopic imaging by rotating the humeral head in different directions. The nail is then trimmed and is buried under the skin.

Postoperatively, the arm was supported in a simple sling for 2 weeks. Pendulum exercises were initiated on the day after surgery. Patients were asked to perform active range-of-motion exercises for 4 weeks postoperatively. Anteroposterior and Neer radiographs of the shoulder were obtained at 1, 4, and 6 weeks postoperatively (Figs. 1-A through 1-J). Routine removal of the implant was performed as an ambulatory procedure with the patient under general anesthesia after 3 to 6 months of implantation.

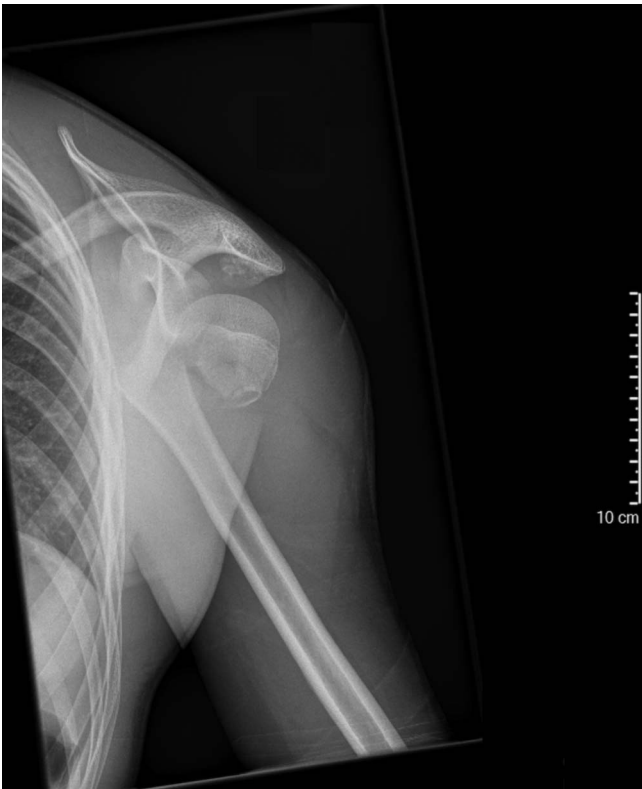


Fig. 1-A



Fig. 1-B



Fig. 1-C



Fig. 1-D

Figs. 1-A through 1-J Radiographs of a 14-year-old boy with a displaced proximal humeral fracture. **Figs. 1-A and 1-B** Preoperative radiographs. **Figs. 1-C and 1-D** One-week control radiographs following closed reduction and internal fixation with the single retrograde intramedullary nail technique.



Fig. 1-E



Fig. 1-F



Fig. 1-G



Fig. 1-H

Figs. 1-E and 1-F Four-week postoperative radiographs. **Figs. 1-G and 1-H** Four-week full-length anteroposterior and lateral humeral radiographs demonstrating the entry point of the nail.

Results

Nineteen patients were included in our retrospective analysis. There were 10 boys and 9 girls with a mean age of 12.6 years (standard deviation = 2.74 years). The mechanism of injury was a pedestrian-vehicular accident (3 patients) or a fall during a sports-related activity (16 patients). Four patients had a Neer-Horowitz grade-3 fracture and 15, a Neer-Horowitz

grade-4 fracture. Eleven fractures were metaphyseal, 7 were physeal Salter-Harris type-II fractures, and 1 was a Salter-Harris type-I fracture. All fractures were reduced in a closed fashion and were fixed according to the surgical technique described above. The nail size used throughout the study was 3 mm. The average operating time was 49 minutes. The mean postoperative follow-up in the clinic was 6 months. One patient



Fig. 1-I

Figs. 1-I and 1-J Six-week postoperative radiographs.



Fig. 1-J

presented with a brachial plexus apraxia that had occurred at the time of fracture; the symptoms had partially resolved at the last postoperative follow-up (12 months).

Neither superficial skin irritation nor elbow stiffness occurred as a result of the protruding distal end of the nail. No cases of infection or neurological damage were encountered.

Radiographic analysis showed a maximum residual coronal and sagittal angulation of 10° postoperatively, which remained stable during the follow-up. In 1 case, partial loss of reduction was observed on the first-week control radiograph. Critical review of the postoperative radiographs of this patient showed inadequate advancement of the nail in the proximal fragment. This patient did not undergo a reoperation because the displacement was acceptable for his age and potential for remodeling (equivalent of Neer-Horowitz grade 2). All fractures appeared united on the radiographs at a median of 6 weeks.

The implants were removed without difficulty from all 19 patients at a mean of 4.2 months (range, 1.5 to 6 months) after the index operation. The average operating time for the removal was 26 minutes. There were no complications related to implant removal.

The QuickDASH shoulder scores on the day of implant removal averaged 0.84 (range, 0 to 4.54), which is an excellent outcome. The score was 0 for the 1 patient with displacement. All children were very satisfied with the outcome of treatment at the final follow-up.

The recorded shoulder range of motion in the medical records was normal for all patients, and the strength of the shoulder joint was excellent.

Discussion

Although most proximal humeral fractures in children are treated nonoperatively and the mainstay of treatment is immobilization with a sling, multiple authors have recommended reduction and internal fixation of highly displaced fractures in older children^{3,4,10}. Recent studies have shown an increase in the surgical treatment of pediatric proximal humeral fractures¹¹⁻¹³.

Kasser and Beaty recommended reduction and often internal fixation of Neer-Horowitz grade-3 and 4 proximal humeral fractures in patients 11 years of age and older¹⁴. These indications were applied in our case series. Once the surgical indication was established, closed reduction was first attempted by all surgeons. Potential reasons for a failed closed reduction have previously been described as interposed periosteum, deltoid, capsule, or long head of the biceps tendon¹⁵. In the current case series, no open reduction was performed; this is in contrast to the literature, in which soft-tissue entrapment and irreducible fractures are occasionally mentioned¹⁵⁻¹⁷.

Maintaining the reduction is critical because the nature of the fracture is often unstable, and surgeons must choose a technique of internal fixation according to their familiarity and experience.

Several techniques are used for fixation of proximal humeral fractures. Percutaneous pinning techniques and intramedullary nailing techniques are the most common, and they usually result in comparable and satisfactory results. Overall, the decision is based on surgeon and patient-specific factors. Intramedullary techniques generally require longer operations, greater blood loss, and higher rates of surgical implant removal^{3,5,9}.

Our study shows that the described single retrograde intramedullary nail technique is a method of fixation of proximal humeral fractures that provides sufficient stability. All children obtained radiographic union, at a median of 6 weeks, and pain-free complete movement after implant removal. The use of 2 nails seems to be biomechanically superior as the divergent ends of the nails exert equal forces on both the tension and compression sides of the fracture, whereas a single nail seems to apply an unopposed compression force toward the concavity of its curvature, which is usually parallel to the calcar. In practice, the single nail acts as an internal splint and maintains the alignment until the fracture is healed.

A stabilization method that blocks the rotation of the proximal fragment with a second nail is not needed in our opinion. Not only is there still a potential for remodeling in adolescents, but also the shoulder has several degrees of freedom in its movement according to multibody kinematic models, thus avoiding potential joint malalignment^{18,19}.

To our knowledge, this single intramedullary technique was first reported in the literature by Chee et al.⁵, who described satisfactory results in 11 consecutive cases. They showed the technique to be a valid method of treating severely displaced humeral fractures in children. We found similar results in a larger case series.

There are limitations in this study that can be addressed in future studies. This is a retrospective study of a limited number of patients treated by a number of different surgeons. A prospective study of a larger number of patients is necessary to corroborate the efficacy of this surgical technique. An additional limitation is the short-term follow-up. Although this study allowed for adequate assessments of early radiographic results and all patients were followed until functional recovery, a longer follow-up study would reveal more information on radiographically assessed remodeling or long-term complications such as growth arrest and osteonecrosis of the proximal humeral epiphysis. Although fellowship-trained pedi-

atric orthopaedic surgeons treated all patients in this study, they did not have the same amount of clinical experience, which could also be a limitation of this study. Moreover, a study comparing single and double retrograde intramedullary nailing in older children with low remodeling potential would be of greater value.

Despite these limitations, this study provides a number of clinically useful conclusions. First, both physeal and metaphyseal fractures can be successfully treated with this single retrograde intramedullary nail technique. Second, use of the single-nail technique theoretically reduces operating time and cost and simplifies the insertion and removal procedures compared with the double retrograde intramedullary nail technique. Third, lengthy and awkward immobilization regimens are avoided, and children and parents are very satisfied with the outcome of treatment at final follow-up. ■

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