Original Article

Humerus Lengthening: A Comparison of the Internal Lengthening Nail to External Fixation

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Abstract

Introduction: Magnetic internal lengthening nails (MILNs) have been used for humeral lengthening to avoid complications associated with external fixation. *Purpose/Questions*: We compared the 1-year Disabilities of the Arm, Shoulder and Hand (DASH) score, adjacent joint range of motion (ROM), bone healing index (BHI), length achieved, distraction rate, and complications when lengthening the humerus using MILN vs using external fixation. *Methods*: We conducted a retrospective cohort study of 18 patients (22 humeri) from January 2001 to March 2020 divided into 2 groups, the MILN group (7 patients, 7 humeri) and the mono-lateral fixator group (11 patients, 15 humeri). *Results*: The MILN group showed larger improvement of DASH scores (average 26.8 and 8 for MILN and fixator groups, respectively), less loss of elbow ROM (average 5° and 7° for MILN and fixator groups, respectively), and shorter time to full recovery of elbow ROM (average 39 days and 122 days for MILN and fixator groups, respectively). In the MILN group, there was slower distraction rate (average 0.66 mm/day and 0.86 mm/day for MILN and fixator groups, respectively), less lengthening achieved (average 5.2 cm and 7 cm for MILN and fixator group, respectively), and a lower lengthening percentage (average 19% and 41% for MILN and fixator group, respectively). Bone healing index (BHI) of 0.94 and 0.99 months/cm for the MILN and the fixator groups were similar. *Conclusion*: Humeral lengthening using the MILN allowed for early full recovery of joint ROM with comparable functional and radiographic outcomes compared with using external fixators.

Keywords
humerus, fixator, lengthening, PRECICE

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Introduction

Mild to moderate humeral length discrepancy is more tolerable than that of the lower extremities, as upper extremities are non-weight bearing. Shortening of the humerus resulting in length discrepancy may occur as the sequela of Ollier's disease [1], traumatic physeal injury, infection, or malignancy. Surgical intervention is indicated when there is considerable functional limitation or body image considerations. For example, length discrepancy of the upper extremity makes activities such as playing sports, lifting objects, and heavy labor difficult [14,18].

Ilizarov laid the groundwork for successful limb lengthening using distraction osteogenesis with circular external fixation. However, external fixation is limited by an array of complications including soft tissue tethering, pin site infections, neurovascular entrapment, and joint contracture [6–22,24].

Circular external fixators and mono-lateral frames have been used to manage different conditions in the upper extremity [1], but the bulky shape of the fixators alters activities of daily living. The circular frames, in particular, make clearance of the frame and the lateral chest wall difficult for patients. This requires patients to maintain their arm in an abducted position.

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There is also 10% to 14% [18] risk of refracture after device removal, which led to the adoption of hybrid techniques such as the insertion of elastic nails after frame removal which stabilizes the regenerate, prevents deformity, and shortens the length of time spent in the frame [19,21].

Magnetic internal lengthening nails (MILNs) have been used to lengthen the humerus [7,23] to avoid complications associated with external fixators altogether. It creates a setting of controlled lengthening and significantly improves function. Patient satisfaction is also improved using this technique [5]. MILNs can be used for humerus lengthening in skeletally mature patients who do not have active infections and who have a medullary canal wide enough to accommodate the ILN [13].

The use of external fixation and MILNs in the femur and tibia is well documented, but there are limited reports pertaining to their use in upper extremities. Literature comparing the use of MILNs to external fixation specifically in the humerus is lacking. The aim of this study is to compare the outcomes of lengthening the humerus using MILNs to those of using external fixation. Outcomes assessed were the 1-year postoperative Disabilities of the Arm, Shoulder and Hand (DASH) scores, range of motion (ROM) of shoulder and elbow, bone healing index (BHI), length achieved, length percentage, distraction rate, and complications.

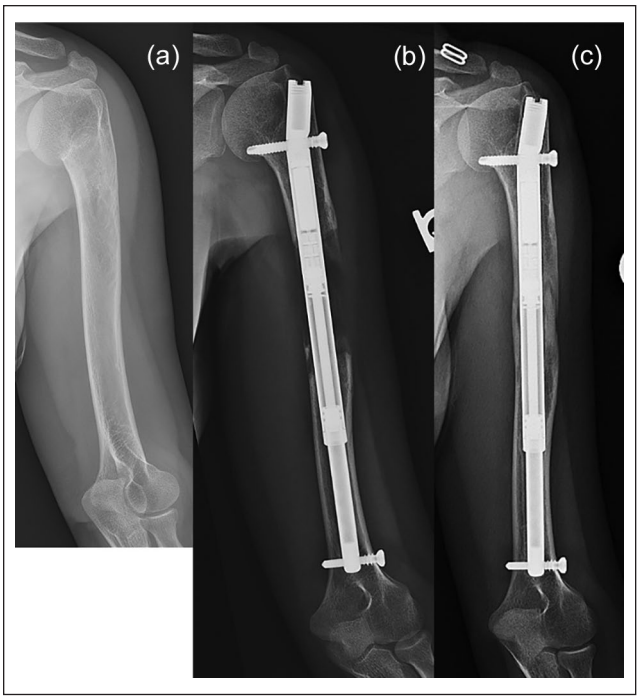

Fig. 1. Case example for PRECICE humeral lengthening: (a) pre-op anteroposterior (AP) radiograph, (b): AP radiograph at end of distraction, and (c): AP radiograph at full consolidation.

Methods

This is an Institutional Review Board (IRB) approved, single-center, level 3 retrospective cohort study performed at an academic referral center. Medical records from January 2001 to March 2020 were reviewed to collect data of humeral lengthening procedure using either MILN or external fixation. The choice of technique was largely affected by the year the surgery was performed. The external fixation cases were performed before the MILN was available to us.

A total of 18 patients (22 humeri) were included in the study and subsequently divided into 2 groups. The MILN group included 7 patients (7 humeri) and surgeries were performed between 2014 and 2020. The mono-lateral fixator group included 11 patients (15 humeri) and surgeries were performed between 2001 and 2010. All surgeries were performed by the senior author (SRR).

In both groups, surgery was done under fluoroscopic guidance with the patient in supine position on a radiolucent table. In the MILN group, using the PRECICE nail (NuVasive, Inc, San Diego, CA) (Fig. 1), the initial step was to make several transverse drill holes at the planned osteotomy site, serving to vent the canal during reaming. A rotator cuff splitting approach was used to expose the nail entry point (just medial to the greater tuberosity) in 2 cases with a relatively normal shaped proximal humerus. The starting point was confirmed with both anteroposterior and lateral fluoroscopy. In 5 cases, there was varus deformity in the proximal humerus, so the entry point was made at the tip of the greater tuberosity and lateral to the rotator cuff insertion, allowing for percutaneous insertion of the starting wire. A starting hole was created in the humerus using a 12-mm cannulated reamer placed over the starting wire, which was then replaced with a long beaded flexible guidewire inserted down the canal. We reamed 1.8 to 2 mm greater (12.5 mm reaming for a 10.7 mm MILN) than the diameter of the planned nail. Once reaming was complete, the guide wire was removed. The MILN was then inserted down the canal approximately 1 cm proximal to the planned osteotomy site. Steinmann pins or temporary external fixation pins were used to mark rotation by placing them in the proximal and distal bone segments away from the nail path. The osteotomy was then completed, and the MILN was passed across the osteotomy and down the canal and then statically locked [8].

The internal magnet was localized with fluoroscopy and marked on the skin with permanent marker to ensure optimal placement of the external remote controller (ERC) for distraction. A trial distraction of 0.5 to 1 mm may be done in the operating room to confirm that the distraction mechanism is working properly. If a rotator cuff splitting approach was used, then it was meticulously repaired using nonabsorbable stitches.

In the fixator group, a mono-lateral rail frame (EBI/Biomet Trauma, Parsippany, NJ, USA) was used. The initial

Table 1. Patients' demographics.

	PRECICE	External fixator	*P* value
Age (years)	27.9 (19–38)	24 (8–50)	.45
Gender (F/M)	2 F, 5 M	5 F, 6 M	.76
Lengthening done (cm)	5.2 (5–6)	7 (4–9)	<.0001*
Lengthening %	19% (17%–22%)	41% (23%–52%)	<.0001*

*Indicates statistically significant results.

step was to insert a reference pin just above the olecranon fossa and perpendicular to the bone in its center, the monolateral frame was then applied to the distal reference pin, and a proximal pin was inserted using the frame to guide proper alignment. Next, the frame was further secured with additional pins in the proximal and distal pin clusters so that there would be 2 pins on each side of the osteotomy. All half pins were inserted under fluoroscopic guidance. The distal pins were often inserted using a cannulated wire technique to avoid neurovascular structures and ensure precise placement. The osteotomy was performed with the frame in place but temporarily loosened from one set of pins.

Post-operatively, in both groups, distraction was started on postoperative day 7 at 0.8 to 1 mm/day (divided over 4 increments); patients were followed up every 2 weeks during the distraction phase, where the rate of distraction was adjusted based on the radiographic quality of the regenerate bone, pain, and adjacent joint ROM, and X-rays were done monthly during the consolidation phase. In the MILN group, all nails were removed after a minimum of 1 year of the primary surgery.

Physical therapy (including active and active assisted ROM) was prescribed for both groups during distraction phase and continued to consolidation phase until either full recovery of joint ROM or maximum possible improvement of ROM was achieved.

Outcomes assessed were the 1-year postoperative DASH scores (which is scaled from 0 to 100 with 0 as the best result); we used 10-point change in the DASH score as the minimal clinically important difference as recommended by Franchignoni et al [4], ROM of shoulder and elbow, BHI, length achieved, length percentage, distraction rate, and complications. The data for DASH score, ROM, distraction rate, and complications were obtained by reviewing patients' records, ROM was measured by the 2 senior authors (SRR and ATF) using a goniometer, and results obtained were rounded to the nearest 5° up or down. Radiographic outcomes (length achieved and length percentage) were reviewed by JS and SG and validated by the senior author (SRR).

Statistical Methods

The statistical analysis was performed using the statistical package SAS statistical software (SAS Institute Inc, Cary, NC). Mean and range were used to express continuous data while frequency (count) and relative frequency (percentage) were used to express categorical data.

Continuous variables were age, lengthening achieved, distraction rate, BHI, ROM, and DASH score. Categorical variables were gender and complications. The statistical difference was calculated using 2-sided, independent sample Student's *t* test for continuous variables which followed a normal distribution and Mann-Whitney *U* test for those not following a normal distribution. For comparing categorical data, the χ^2 test was performed for frequencies >5, while Fisher exact test was performed for frequencies ≤ 5. Statistical significance was set at alpha (p) $\leq .05$.

Results

Average patients' age was 28 (19–38) years and 24 (8–50) years for the MILN and fixator groups, respectively ($P = .45$). Both groups had majority male patients (5 males and 2 females in the MILN group and 6 males and 5 females in the fixator group) ($P = .76$). Follow-up was 14 (12–24) months and 16 (12–36) months in the MILN and fixator groups, respectively. Lengthening achieved was 5.2 (5–10) cm (one of the MILN patients was lengthened 10 cm in 2 stages) and 7 (4–10) cm for the MILN and fixator groups, respectively ($P = .0001$). The lengthening percentage was 19% (17%–22%) and 41% (23%–52%) for the MILN and fixator groups, respectively ($P = .0001$) (Table 1).

The BHI was 0.94 (0.67–1.3) month/cm and 1.06 (0.77–1.5) month/cm in the MILN and fixator groups, respectively ($P = .73$). The distraction rate was 0.66 (0.49–0.8) mm/day and 0.86 (0.47–1.2) mm/day in the MILN and fixator groups, respectively ($P = .04$). The MILN group started off with a worse pre-op DASH score of 40.5 (23.3–65) compared with a better pre-op DASH score of 14 (2.5–42.5) in the fixator group. The MILN group showed greater improvement in the DASH score of 23.3 (6.7–26.8) compared with an improvement of only 8 (0.84–8.6) in the fixator group ($P = .05$). The 1-year Post-op DASH score was 13.6 (1.5–58.3) and 6 (1.7–33) in the MILN and fixator groups, respectively. The change of shoulder flexion ROM was 9° improvement (10° loss–30° improvement) in the MILN group and was 6° loss (30° loss–30° improvement) in the fixator group ($P = .06$). The change of shoulder abduction ROM was 5° loss (20° loss–30° improvement) in the MILN group and was 15° loss (80° loss–30° improvement) in the fixator group ($P = .25$).

Table 2. Results.

	MILN	External fixator	*P* value
Distraction rate (mm/day)	0.66 (0.49–0.8)	0.86 (0.47–1.2)	.04*
Bone healing index (month/cm)	0.94 (0.67–1.3)	0.99 (0.72–1.5)	.73
Change of shoulder *flexion* ROM (degrees)	9° improvement (10° loss–30° improvement)	6° loss (30° loss–30° improvement)	.06
Change of shoulder *abduction* ROM (degrees)	5° loss (20° loss–30° improvement)	15° loss (80° loss–30° improvement)	.25
Loss of elbow ROM (degrees)	5° (0–10)	15° (0–30)	.05*
Time to full recovery of joints ROM	39 days (27–53)	122 (83–160)	.05*
Change in DASH score	23.3 (6.7–26.8)	8 (0.84–8.6)	.05*

MILN magnetic internal lengthening nail, *ROM* range of motion, *DASH* Disabilities of the Arm, Shoulder and Hand.
*Indicates statistically significant results.

The loss of elbow ROM was 5° (0°–10°) in the ILN group and was 15° (0°–30°) in the fixator group ($P = .05$). Time to full recovery of joints ROM (when they reached their full ROM) was 39 days (range, 27–53 days) for the MILN group, and was 122 days (range, 83–160 days) for fixator groups ($P = .05$) (Table 2).

In the fixator group, there were 4 complications (1 radial nerve palsy and 3 refractures after frame removal) [20] requiring return to operating room. The incidence of fixator complications was 4/15 (27%). There was 1 complication (deep infection requiring exchange nailing with antibiotic coated nail) in the MILN group. The incidence of MILN complications was 1/7 (14%). All complications were treated, and patients did not have any permanent sequelae. All patients healed uneventfully and in an anatomically acceptable position in both groups.

Discussion

Humerus lengthening surgery is less reported than lower limb lengthening [2]. The first report of humeral lengthening was by Dick and Tietjen in 1978 [3] having used a Wagner fixator, plating, and autogenous bone grafting. External fixation has been used successfully to achieve desired length and treat humeral deformities [25]. However, complications of external fixators are well documented [6–22,24]; Malot et al [15] and Pawar et al [18] reported that humeral lengthening using the less bulky mono-lateral fixator showed comparable complications rate compared with circular frames. Nonetheless, the mono-lateral frame was easier to apply and more comfortable for patients. MILNs have been successfully used for lower limb lengthening, with only few reports in the literature for using them for humeral lengthening. We reported in this study functional and radiographic outcome of humeral lengthening using MILN compared with using external fixation.

Among the limitations of this study is the sample size, which did not allow for statistical comparison of the complications that are infrequent; the comparison was not contemporaneous or randomized, and the outcome measures have subjective elements. These limitations are expected in small case series such as this. Rounding elbow ROM to the nearest 5° up or down has been cited [26] that it may show significant difference where there is not. Another limitation is that data about shoulder pain following insertion of MILN was not available for analysis.

The introduction of MILNs generated a disruptive change in approach to humeral lengthening. The use of the PRECICE MILN although designed for femur and tibia with its accurate control of rate and rhythm of distraction [12] has resulted in greater patient satisfaction compared with external fixation.

In our study, the MILN group showed an improvement of the DASH score of 23.3 (6.7–26.8) compared with the score before lengthening; this is consistent with the result reported by Hammouda et al [7] in their case series of humeral lengthening using MILNs where they reported an average improvement of 23 points in the DASH score. Our fixator group showed improvement of DASH score of only 8 (0.84–8.6), which is consistent with the result reported by Balci et al [2], who used mono-lateral fixator for humeral lengthening and reported an average improvement of 5 points.

Studies [9,11,25] that used circular external fixator for humeral lengthening reported a mean length achieved ranging from 5 to 11.1 cm as reported in the literature. Studies that used mono-lateral fixators [2,18] for humeral lengthening reported a mean length achieved ranging 6.5 to 10. In our study, the mean length achieved using MILNs was 5.2 cm; this attributed to the fact that the allowed maximal deployment capacity (nail stroke) of the MILNs in our study was 5 cm, that can be overcome by redeploying the nail to achieve a greater lengthening using the same implant, which has been reported by Morrison et al [16] which makes it possible to expand the use of MILN (1 of the MILN patients in our study was lengthened 10 cm in 2 stages).

In our study, the mean BHI was 0.94 (0.67–1.3) month/cm, which is less than what was reported by Hammouda et al [7], who reported a mean BHI 1.2 (0.8 –1.5). In our

fixator group, the BHI was 1.06 (0.77–1.5) month/cm, which is comparable to what was previously reported in studies [9,10,18] that used external fixator for humeral lengthening and reported an average BHI of 1 (0.9–1.1)

In a case report, Kurtz and Rozbruch [13] used a MILN for humeral lengthening to achieve a 5 cm lengthening goal, reporting full shoulder and elbow ROM equal to preoperative range 4 months postoperatively, similar to our results.

Most recently, Morrison et al [16] in their retrospective analysis of pediatric humeral lengthening demonstrated that MILNs are associated with fewer complications than external fixators. The outcomes measured in their study were length achieved, duration of lengthening, and frequency and type of complication. They concluded that humeral lengthening using MILN is a safe technique that mitigates some of the complications of external fixator including pin site infection, and it is well tolerated by patients.

In conclusion, we found in our retrospective study of 18 patients that using MILN for humeral lengthening resulted in earlier full recovery of joint ROM, with comparable functional and radiographic outcomes compared with using external fixators.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Sherif Galal, MD, PhD, Jonggu Shin, MD, Peter Principe, MS, Rena Mehta, BS, Nathan Khabyeh-Hasbani, BS, and Amber Hamilton, BS, declare that they have no conflicts of interest. Austin Fragomen, MD, reports consultant fees from Smith Nephew, NuVasive, and DePuy Synthes, outside the submitted work. S. Robert Rozbruch, MD, reports consultant fees and royalties from Nuvasive, and consultant fees and stock from Orthospin, outside the submitted work.

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Human/Animal Rights

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2013.

Informed Consent

Informed consent was waived from all patients included in this study.

Level of Evidence

Level III: Therapeutic study

Required Author Forms

Disclosure forms provided by the authors are available with the online version of this article as supplemental material.

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