ON Path: outpatient nonunion pathway for lower-extremity nonunions

Olivia M. Rice, MD[a], Abhishek Ganta, MD[a,b], Gisele Bailey, MS[a], Rachel B. Seymour, PhD[a], Joseph R. Hsu, MD[a,*]

Abstract

Objectives: The purpose of this study was to assess the safety and efficacy of outpatient and short-stay surgical nonunion treatment by incorporating minimally invasive surgical techniques, multimodal pain control, and a modernized postoperative protocol.

Design: Retrospective case series.

Setting: Tertiary referral hospital and hospital outpatient department.

Patients: All consecutive nonunion surgeries performed by 1 surgeon between 2014 and 2019 were identified. Outpatient and short-stay surgeries for patients with nonunion of the tibia and femur were eligible (n = 50).

Intervention: Outpatient and short-stay surgical nonunion treatment by incorporating minimally invasive surgical techniques, multimodal pain control, and a modernized postoperative protocol.

Main Outcome Measurements: Length of stay, postoperative emergency department visits, all complications, reoperations, and time to union.

Results: Fifty patients were eligible, with 32 male patients (64%) and an average age of 46.5 years. The patient cohort consisted of 28 femur (56%) and 22 tibia (44%) nonunions. The average length of stay was 0.36 days. Seven patients (14%) required reoperation, 6 patients because of deep infection and 1 patient because of painful implant removal. Four patients (8%) presented to the emergency department within 1 week of surgery. One patient requiring amputation and patients lost to follow-up were excluded from the union rate calculation. For the remaining patients (46/50), 100% (46/46) united their nonunion. The average time to radiographic union was 7.82 months.

Conclusions: An outpatient pathway is safe and effective for medically appropriate patients undergoing nonunion surgery. Outpatient nonunion surgery is a reasonable alternative that achieves similar outcomes compared with inpatient nonunion studies in the published literature.

Level of Evidence: IV.

Keywords: allograft, bone defect, bone healing, fracture, nonunion, outpatient

1. Introduction

Most long bone lower-extremity fractures treated operatively heal; however, nonunions are still a prevalent and significant complication.[1] Treatment of these nonunions is challenging to orthopaedic surgeons because some fail to unite despite treatment. For example, femur nonunions are a debilitating condition that lead to poor reported health-related quality of life.[2] Patients have reported pain levels that impair their ability to function with 12-Item Short Form Survey (SF-12) Mental Component Scores and SF-12 Physical Component Scores lower than the general US population.

Furthermore, nonunions harbor a sizeable financial impact from both direct and indirect expenditures. Direct costs include the medical expenses from multiple implants, surgeries, and hospitalizations. Absence or loss of productivity in the workplace contributes to indirect costs.[3,4]

Surgical treatment options for nonunions range from dynamization procedures and exchange nailing to plate fixation with or without bone grafting.[5–10] Although exchange nailing has varying degrees of success in treating diaphyseal nonunions by increasing stability and stimulating local biology, the effect is limited in the

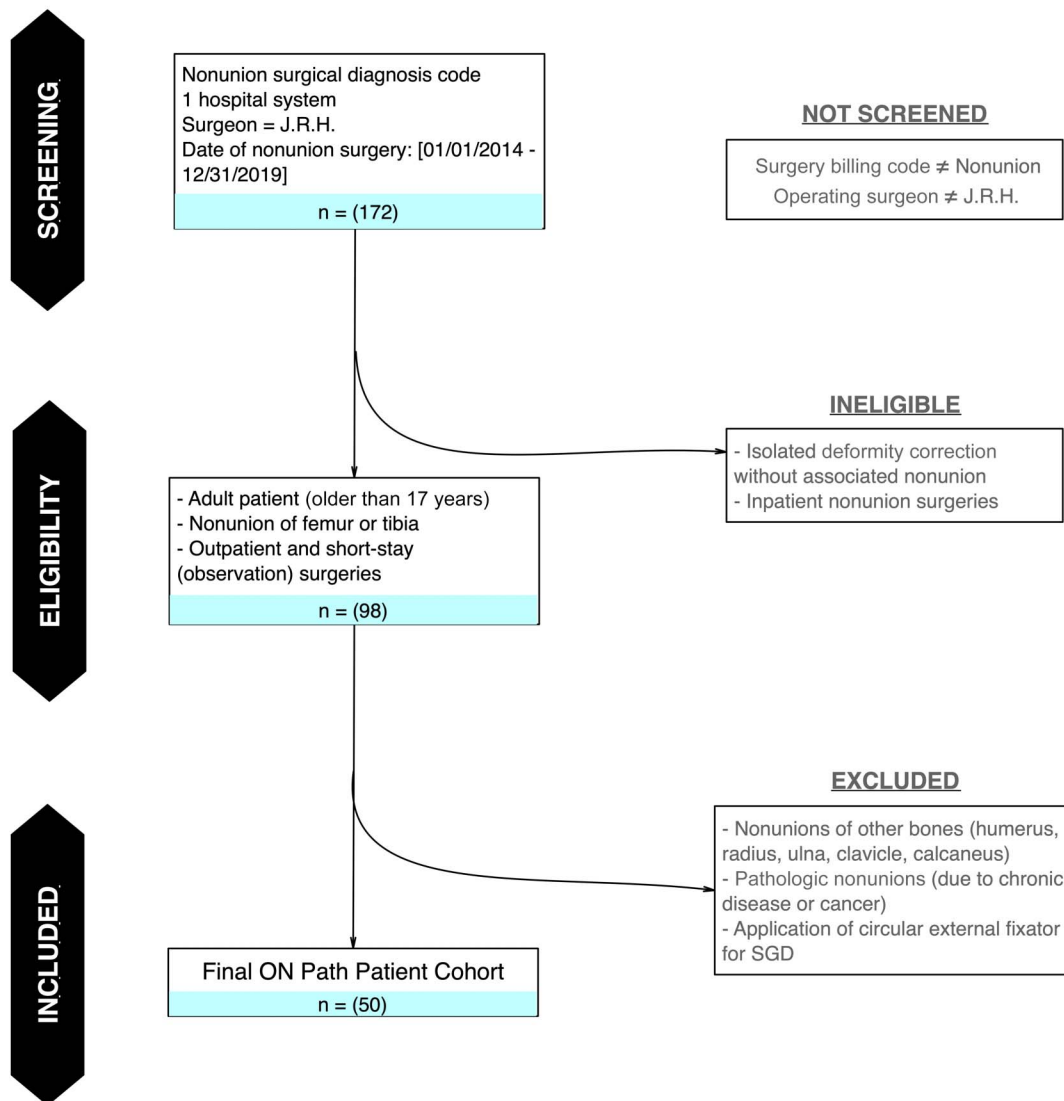## Patient Cohort Inclusion and Exclusion Criteria

Figure 1. ON Path patient cohort inclusion and exclusion criteria flowchart. EHR, electronic health record; SGD, segmental gap defect.

metadiaphyseal region and with segmental defects.[11–13] Augmentative plating of nonunions is an alternative solution, previously well described in the literature. Ueng et al[14,15] noted the successful treatment of femur nonunions with intact and broken preexisting interlocking nails with adjuvant plate placement. A subsequent series of femur nonunions confirmed this technique, demonstrating radiographic union using similar techniques.[7,16,17] Despite this, plating of long bone nonunions has been criticized because of large incisions, increased estimated blood loss, and the potential for prolonged hospitalization due to the procedure's invasiveness.[5,18,19] However, with improved plating technology and smaller incisions, these concerns can be mitigated.[20]

In addition to advances in operative management, shifts in treatment patterns within other orthopaedic subspecialties have also created new avenues for managing nonunion patients. With established institutional protocols, procedures such as total hip arthroplasty are now being performed on an outpatient basis in carefully selected patients.[21,22] We have developed an outpatient nonunion pathway (ON Path) that allows for same-day or short-stay surgery through a similar process.

The purpose of this study was to assess the safety and efficacy of outpatient and short-stay surgical nonunion treatment by incorporating minimally invasive surgical techniques, multimodal pain control, and a modernized postoperative protocol.

2. Methods

2.1. Study Design and Setting

All consecutive cases of tibia and femur nonunions treated surgically by a single surgeon at a tertiary referral hospital and hospital outpatient department from January 2014 to December 2019 were identified using a Current Procedural Terminology code search in this retrospective case series. All data were stored in Research Electronic Data Capture (REDCap), a secure cloud-based platform.[23,24] Research was conducted in accordance with the

Medical Comorbidities Prohibiting Outpatient or Short-Stay Surgery	
General	Difficult Airway, BMI > 55, Active Pregnancy
Cardiovascular	AICD, CHF with EF<35%, Unstable Angina, Uncontrolled HTN, Severe Anemia or Coagulopathy
Pulmonary	COPD Requiring Oxygen, Severe Pulmonary HTN, Lung CA
Renal/Endocrine	ESRD on Dialysis, Uncontrolled DM, Hepatic Failure
Neuromuscular	Muscular Dystrophy

Figure 2. Medical conditions that nursing staff and the anesthesia team screen for prior to scheduling patients for surgery in the hospital-owned surgery center associated with same-day or next-day discharge; it is not possible to admit a patient for an inpatient admission from this adjacent surgery center; therefore, strict screening criteria are used to minimize perioperative complications. AICD, automated implantable cardioverter defibrillator; BMI, body mass index; CA, cancer; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; DM, diabetes mellitus; EF, ejection fraction; ESRD, end-stage renal disease; HOPD, hospital outpatient department; HTN, hypertension.

Declaration of the World Medical Association. The IRB approved a waiver of informed consent for this retrospective study (IRB00082558).

2.2. Participants

Current Procedural Terminology codes used were for the repair of femur or tibia nonunion with or without graft. Patients were filtered based on encounter type, that is, whether their surgical encounter type was inpatient, observation, or outpatient, and medical records were reviewed. Only patients with observation or outpatient encounter types were included. Patients with inpatient encounter types, repair of malunion, or a nonunion after a pathologic fracture due to genetic condition (eg, sickle cell disease) or cancer were excluded (Fig. 1). The decision to treat the patient as an inpatient, observation, or outpatient was made by the treating surgeon's best judgment, considering individual patient factors at the time of evaluation. Patients treated at the hospital-owned surgery center also required preapproval by the Department of Anesthesia (Fig. 2). Patients discharged on the same day of surgery were considered outpatients, regardless of whether the surgery occurred at the tertiary referral hospital or hospital outpatient department.

2.3. Data Sources and Measurement

Two authors (O.M.R. and J.R.H.) classified nonunion types independently, using radiographs taken before nonunion surgical intervention. Classification disagreements were discussed and resolved between the 2 authors. Classifications included hypertrophic, oligotrophic, atrophic,[25] and segmental gap defect. The segmental gap defect class was applied to patients who previously underwent induced membrane technique or distraction osteogenesis using a circular external fixator. The procedure to remove the spacer or circular frame and insert implants for definitive fixation was considered their nonunion surgery date.

Limb deformity was assessed in the coronal and sagittal planes using standing mechanical axis radiographs, routinely obtained before nonunion surgery. The rotational alignment was assessed clinically for tibial nonunions and computed tomography imaging for femoral nonunions.[26] Malalignment of ~10° was the cutoff value for surgical correction.

Patients were labeled as septic or aseptic based on the presence or absence of infection findings on clinical examination or abnormal preoperative laboratory values.[27,28] Clinical signs of deep infection included deep sinus tract, persistent or malodorous drainage, and peri-incisional erythema, warmth, or wound breakdown. Preoperative laboratory values included C-reactive protein, white blood cell count, and erythrocyte sedimentation rate; abnormal values were based on institutional standards. Patients with intraoperative signs of infection, including abscess, purulent material, or necrotic bone were also considered septic nonunions. All other patients were presumed aseptic. When concerned about infection, tissue samples were sent for microbial culture, and the patient went home on oral antibiotics with close outpatient follow-up scheduled with infectious disease per our established protocol. These consultants adjust the antibiotics and route of administration based on culture sensitivities and clinical judgment. Fracture union was defined as complete bridging across at least 1 of 4 cortices on standard anteroposterior and lateral radiographs.[29–31] A single author (O.M.R.) evaluated radiographs for union status, and the senior author (J.R.H.) later reviewed and clarified borderline healing statuses. Disagreements were discussed and resolved between the 2 authors. The time interval from date of nonunion surgery performed by the senior author (J.R.H.) until date of radiographic union was used to calculate time to union.

2.4. Surgical Pathway

2.4.1. Preoperative. The orthopaedic team performs perioperative counseling with the patients in clinic at their preoperative visits. This counseling borrows from principles of motivational interviewing [32,33] to empathize with patients about prolonged inpatient stays, aligning patient goals with the pathway, adjusting to resistance rather than opposing, and building self-efficacy and optimism in patients and family members. Some details of perioperative counseling include incision size and location, perioperative pain management, weight-bearing status (WBS), dressings/incision management, and historical outpatient pathway successes. Over the years, this process has gotten
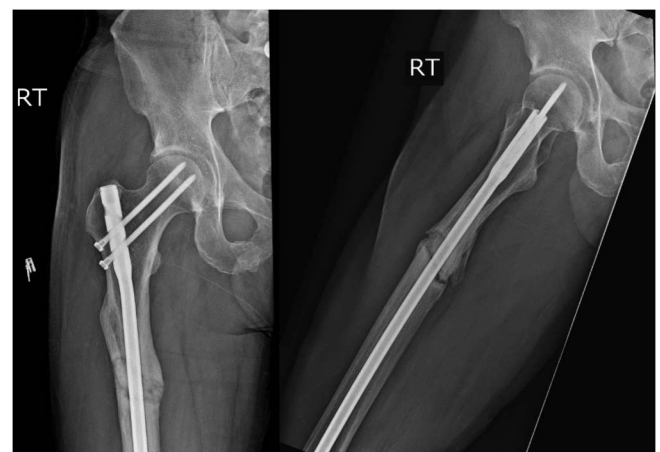
Figure 3. Anteroposterior and lateral radiograph of femoral nonunion.

Figure 4. Radiographic (A) and corresponding clinical (B) photograph showing our percutaneous plating technique, using several small incisions for plate fixation in a femoral nonunion plate + intramedullary nail combination construct.

more manageable and efficient because the baseline culture for the entire team of clinic staff has shifted to counseling patients for outpatient/observation surgery. Our office assured patients that virtual check-ins (primarily by phone) were available after surgery should problems or questions arise. For Friday surgeries, the surgeon often called the patient the next day for the virtual check-in. These points were reinforced to family members in the immediate postoperative family discussion.

2.4.2. Surgical Technique. Lower-extremity nonunions (eg, Fig. 3) were prepared in a minimally invasive fashion (Figs. 4 and 5) by creating a trough several centimeters proximal and distal to the nonunion site. The stimulated surface area was further increased using a shingling technique with a small curved osteotome or gouge.[34,35] Allograft cancellous chips[1–3,36,37] were then placed using a back-filling technique through a graft delivery tube (Fig. 5). In the cases of atrophic nonunion, more bone allograft was placed in the trough and along the shingled surfaces as well. For every 40 cc of allograft used, 1 g of vancomycin powder was added. Of note, a few patients operated on early in the case series underwent iliac crest autologous bone harvesting and grafting to their nonunion site (n = 7). However, most of the patients received allograft only without added biologic adjuncts (Table 4). The surgeon consistently used low-dose mode on the c-arm and wore radiation attenuation gloves, and all team members wore circumferential lead and lead glasses.

The surgical technique used was based on patient-specific nonunion characteristics. Augmentative plating was used in many nonunions with intact intramedullary nails without deformity. In this setting, compression was not routinely performed; however,

when plating constructs were used in isolation, compression was used. Plates were typically submuscular—their length and contour varying by location (ie, diaphyseal or metaphyseal). Locked nails were not routinely dynamized; nail dynamization was not used as an isolated treatment strategy.

2.4.3. Postoperative. Patients with high suspicion of infection were sent home on oral antibiotics. Cultures that resulted positive were treated using an established outpatient-based strategy in collaboration with our infectious disease colleagues. Strategies from the OTA Clinical Practice Guidelines for Pain Management[37] were routinely used. Most patients received supplemental local analgesia through peripheral nerve blockade or local field block injection to promote rapid recovery. Patients and families received educational materials for physical, cognitive, and pharmaceutical pain management strategies. These include cryotherapy (ice), transcutaneous electrical nerve stimulation, music therapy, aromatherapy, and pharmacologic agents, including nonsteroidal anti-inflammatory drugs and gabapentin (off-label for multimodal pain management) in addition to opioids.[38] Instructions to remove dressings and delay showering (no submersion) until 48 hours after surgery were also provided. Patients were most often made weight-bearing as tolerated after surgery and encouraged to mobilize. Self-directed range of motion exercises began immediately regardless of prescribed WBS.

2.5. Outcomes

The primary outcomes included length of stay (LOS) and postoperative emergency department (ED) visits for surgery-

Figure 5. Minimally invasive allograft insertion. A, Allograft mixed with vancomycin powder is loaded into an open-ended syringe, and (B) the syringe and graft delivery tube are used to place graft into the nonunion site, as seen in (C) clinically and (D) radiographically.

Patient Demographic Variables Collected at the Time of Nonunion Surgery.

Patient Demographics				
Patient Characteristics	Femur (n = 28)	Tibia (n = 22)	Total (n = 50)	(%) (100%)
Average age (yrs)	49.0	43.5	46.2	
Average BMI (kg/m^2)	27.6	29.2	28.4	
ASA class				
I	4	1	5	10
II	16	16	32	64
III	8	5	13	13
IV	0	0	0	0
Sex				
Male	15	17	32	64
Female	13	5	18	36
Current smoker	8	9	17	34

ASA, American Society of Anesthesiologists; BMI, body mass index.

related issues. Secondary outcomes included all reoperations, readmissions, surgical complications, and fracture union. Postoperative deep infection, hardware failure, and deep vein thrombosis were considered surgical complications. ED visits were considered pertinent to the abbreviated postsurgical hospital stay if they occurred within 7 days from the date of nonunion surgery based on previously reported LOS.

Patients were deemed lost to follow-up if they stopped showing up for clinic visits, had no radiographs taken, and were unreachable despite multiple attempts to contact them. Descriptive statistics were used to quantify results.

3. Results

3.1 Demographics of Patient Cohort

A total of 50 patients, including 28 femur (56%) and 22 tibia (44%) nonunions, were eligible and included for analysis (Fig. 1). The cohort included 32 male patients (64%) and 18 female patients (36%) (Table 1). The average age was 46.5 years, and all patients were medically fit for an outpatient procedure per our

TABLE 3

Variables Related to Nonunion Characteristics at the Time of Surgery.

Nonunion Diagnosis Characteristics				
Nonunion Characteristic	Femur (n = 28)	Tibia (n = 22)	Total (n = 50)	(%) (100%)
Infection status				
Septic nonunion*	3	8	11	22
Presumed aseptic nonunion	25	14	39	78
Associated problems at time of diagnosis				
Associated limb deformity	12	5	17	34
Associated hardware failure	4	9	13	26
Nonunion classification (Weber-Cech)				
Hypertrophic	8	8	16	32
Oligotrophic	12	4	16	32
Atrophic	8	5	13	26
Segmental gap defect	0	5	5	10

CRP, C-reactive protein; ESR, erythrocyte sedimentation rate; WBC, white blood cell count.
* Suspicion for septic nonunion based on the presence of ≥1 preoperative elevated infection laboratory results (WBC, CRP, or ESR), clinical signs (eg, wound breakdown, fever, draining fistula), or intraoperative findings (eg, loose implants, necrotic appearing tissue/bone, frank purulence); patients were "presumed aseptic" if none of these criteria were documented.

TABLE 2

Variables Related to Patients' Index Injury.

Index Injury Characteristics				
Injury Characteristics	Femur (n = 28)	Tibia (n = 22)	Total (n = 50)	(%) (100%)
	3*	4*		
Proximal (* 1)	2	4		
A	1	2		
B	1	1		
C	0	1		
Diaphyseal (*2)	15	12		
A	6	7		
B	4	2		
C	5	3		
Distal (*3)	11	6		
A	4	1		
B	0	2		
C	7	3		
Open fracture	11	16	27	54
Gustilo: Type I	0	1	1	3.5
Type II	2	3	5	18.5
Type III	8	9	17	63
A	5	3		
B	1	6		
C	2	0		
Unknown*	1	3	4	15

AO/OTA fracture classifications are listed in parenthesized italics.
* Some patients were treated at outside hospitals for their index injury, resulting in missing Gustilo grade information.

institution's guidelines determined by the Department of Anesthesia (Fig. 2). Over half (54%) of the index injuries were open fractures (Table 2). All results are delineated in Tables 1–6.

3.2. Surgical Technique

Procedure start times ranged from 07:00 to 14:50, with an average surgery duration of 154.5 minutes. Average fluoroscopy time and direct radiation exposure for patients undergoing fixation of femur nonunions, the most complex cases, were

TABLE 4

Variables Related to Nonunion Surgery: Deformity Correction Was Identified and Planned for Preoperatively.

Nonunion Surgery Details				
Surgical Information	Femur (n = 28)	Tibia (n = 22)	Total (n = 50)	(%) (100%)
Intraoperative deformity correction	15	2	17	34
Required adjacent osteotomy	3	1	4	24
Removal of intact or broken implants	18	17	35	70
Bone graft used	26	13	39	78
Allograft only	23	9	32	82
Autograft only	1	3	4	10
Allograft + autograft	2	1	3	8
Average procedure duration (min)	158.5	150.4	154.5	—
Average estimated blood loss (mL)	173.2	144.1	158.7	—
Postoperative WBS				
WBAT	25	11	36	72
LWB*	2	1	3	6
NWB	1	10	11	22

Broken implant removal was only recorded in patients with radiographic hardware failure.
LWB, limited weight-bearing; NWB, non–weight-bearing; WBAT, weight-bearing as tolerated; WBS, weight-bearing status.
* LWB ≅ partial weight-bearing (eg, patients were told they could bear 50% of their weight through lower extremity with ambulatory assistive device such as crutches).

TABLE 5
Primary Outcome Data After Nonunion Surgery.

| Outcome | Primary Outcomes | | | |
	Femur (n = 28)	Tibia (n = 22)	Total (n = 50)	(%) (100%)
Average hospital LOS (days)	0.39	0.32	0.36	—
Discharged on				
POD 0	20	15	35	70
POD 1	6	7	13	26
POD 2	1	0	1	2
POD 3	1	0	1	2
Emergency room visit*	4	0	4	8
Surgical	3	0	3	75
Medical	1	0	1	25

LOS, length of stay; POD, postoperative day.
* ER visit for reason related to surgery within 7 days from date of nonunion surgery.

TABLE 6
Additional Outcome Data After Nonunion Surgery.

| Outcome | Secondary Outcomes | | | |
	Femur (n = 28)	Tibia (n = 22)	Total (n = 50)	(%) (100%)
Reoperation, all-cause	3	4	7	14
Deep infection	2	4	6	86
Prominent hardware	1	0	1	14
Readmission, all-cause	2	2	4	8
Infection	1	2	3	75
Medical	1	0	1	25
Deep infection after nonunion surgery	2	4	6	12
(+) History of deep infection	2	3	5	83
(+) Culture results from nonunion surgery	0	0	0	0
Union	n = 25	n = 21	n = 46	92
Radiographic union	25	21	46	100
Average union rate (mo)	7.37	8.35	7.86	—

+, positive.

158.5 seconds (2.64 minutes) and 15.18 mGy (1518 mrem), respectively; 78% of patients (39/50) received bone graft during their nonunion procedure, with the majority (32/39, 82%) receiving allograft only without biologic additives. Intraoperative deep tissue cultures were sent for 11 patients with suspected septic nonunions (11/50, 22%); one patient's cultures (1/11, 9%) resulted positive. Postoperative WBS was weight-bearing as tolerated in 72% of patients (36/50), limited weight-bearing (allowed to bear 50% of total weight) in 6% (3/50), and non–weight-bearing in 22% (11/50) (Tables 3 and 4).

3.3 Outcomes

The average LOS was 0.36 days for the overall cohort. After nonunion surgery, 6 patients developed a deep infection (6/50, 12%); all required reoperation, and 3 patients were admitted from the ED after they presented with purulent drainage (Table 5). Unfortunately, the ultimate outcome for one of these patients was an amputation for recalcitrant osteomyelitis. All infected patients cleared their infection with 1 additional surgery, and this was the only additional surgery required for most (5/6, 83%) of them to achieve union. One patient required 3 total surgeries—the first for infection eradication, the second for persistent nonunion, and the third for fixation augmentation due to high physical fitness level and persistent pain despite a healed fracture.

Aside from infectious complications, 3 femur nonunion patients (3/50, 6%) presented to the ED within 1 week of surgery for saturated wound dressings (Table 5); none needed intervention beyond a dressing change. One patient went to the ED and was readmitted for postoperative pneumonia shortly after hospital discharge, and this patient also had the longest hospital stay in our cohort (LOS = 3 days). Two patients experienced screw breakages but did not require reoperation (2/50, 4%). Finally, 1 patient underwent elective reoperation for prominent hardware removal, which was not considered a surgical complication (reoperation all-cause, 7/50, 14%; Table 6). No patients were diagnosed with a deep vein thrombosis (0%, 0/50). The patient requiring amputation (1/50, 2%) and those lost to follow-up (3/50, 6%) were excluded from the union rate calculation. For the remaining patients (46/50), all (46/46, 100%) nonunions united. The average time to radiographic union was 7.86 months (Table 6). Worst-case union rate analysis including the amputation and lost to follow-up still had a union rate of 92% (46/50). Fig. 6 shows the final, healed result of a femoral nonunion patient.

4. Discussion

4.1. Interpretation of Methods and Key Results

Orthopaedic procedures from ankle fractures to total joint arthroplasty and anterior cervical discectomy and fusion have transitioned from inpatient to outpatient procedures with an acceptable safety profile in selected patient populations.[22,39,40] This transition led to decreased costs with similar patient outcomes.[41] Similar to published literature on other orthopaedic procedures,[21,22,42] it seems to be safe to treat nonunion patients with outpatient or short-stay surgery based on these results.

As detailed in the Methods section, some effort was required to initiate this outpatient pathway. However, it eventually became the default option, with a coinciding cultural shift that further normalized this surgical encounter type for both staff and patients. We believe a few principles of perioperative care underpin the feasibility of the outpatient nonunion surgery pathway:
- Minimally invasive surgical technique
- Weight-bearing as tolerated postoperatively
- Allograft only
- Multimodal pain management

In the pathway's infancy, the primary surgeon would routinely harvest autograft from the ilium. All patients presenting to the ED with bloody bandages within 1 week of surgery, 3 (3/50, 6%) had iliac autograft harvested. Each patient's saturated bandages were at the harvest site. While traditional nonunion repair typically incorporates autologous bone graft, our study reports successful use of allograft alone with comparable union rates and lower infection rates than previously reported.[43] This is consistent with prior basic science and clinical research. Animal models have demonstrated no difference between autograft and allograft for bone inducement.[44,45] A systematic analysis of mostly retrospective clinical studies has also documented no difference in union or clinical outcomes among patients treated with autograft and allograft.[16,18,19,36] Other than avoidance of autograft harvesting, case complexity did not limit the patient's ability to go home within 24 hours from surgery. Deformity correction and broken implant extraction, for example, were commonly performed within this cohort (Table 4).

Our study's overall LOS is lower than previously reported for long bone nonunions (0.36 days vs. 3.7 days).[5,46,47] The reported LOS for nonunion repair is deficient in published literature; our study is the first to emphasize "length of stay" as a primary outcome in long bone nonunion repair.

Figure 6. Anteroposterior and lateral radiograph of earlier femoral nonunion (Fig. 3), now healed, after percutaneous plate and allograft placement (Figs. 4 and 5).

The reported union rate for nonunions varies by location. Generally, it ranges from 80% to 90%, consistent with our results.[11,48,49] In the cases of augmentative plating, published series often did not include compression. Instead, they relied on the nail and plate combination's added stability to obtain enough rigidity to allow healing. The conditions where compression adds value with plate/nail combinations warrant further investigation. The minimally invasive surgical technique sometimes increases overall radiation dose because of extensive fluoroscopy use.[50] However, using the low-dose mode on the c-arm throughout cases allowed lower overall radiation exposure despite the total time used (575 mrem/min). For reference, a single radiograph of the hip delivers 500 mrem of direct radiation exposure to the patient. In orthopaedic operating rooms, standard-dose c-arm radiographs emit 1200–4000 mrem/min for extremities to the pelvis, respectively.[51]

Furthermore, we used nonsteroidal anti-inflammatory drugs ubiquitously in this cohort as part of the multimodal pain management strategy.[38] Although this remains controversial in fracture surgery, we did not find it a barrier to healing in our most challenging population—nonunions.

4.2. Limitations

Limitations of this study include its retrospective design and percentage of patients lost to follow-up.[52,53] However, rates are similar or favorable compared with published literature in orthopaedic trauma.[54]

In addition, our outcomes are limited to variables found in electronic medical record documentation, and no patient-reported outcome measures were included. The effect of nonunion and deformity correction surgery on Patient Reported Outcome Measures is a future direction for our team.

Although our patient cohort is small, it is comparable or larger than published studies on nonunion surgery, especially because we limited it to lower-extremity nonunions. Given the small sample size and absence of a comparison group, there is insufficient power to independently study or draw conclusions from the efficacy of each reported surgical technique. However, the results from this patient cohort demonstrate the feasibility and safety of an outpatient nonunion surgical pathway. Future directions include a direct comparison with more traditional techniques, including inpatient stay, non–weight-bearing, and autologous bone grafting, to evaluate outcomes and cost-effectiveness.

Finally, the importance of collaboration with infectious disease clinicians should not be understated. Our robust, outpatient-based pathway includes a confirmed infectious disease clinic appointment within 1–2 weeks from surgery plus the resources to place a peripherally inserted central catheter line in an outpatient setting if deemed necessary. This partnership certainly contributed to the success of this surgical pathway and may not be possible at all institutions.

5. Conclusion

The outpatient nonunion pathway (ON Path) is safe and effective for medically appropriate patients. Outpatient nonunion surgery is a reasonable alternative that achieves similar outcomes compared with conventional inpatient nonunion studies in published literature.

References

1. Nauth A, Lee M, Gardner MJ, et al. Principles of nonunion management: state of the art. *J Orthop Trauma*. 2018;32(suppl 1):S52–S57.
2. Brinker MR, Trivedi A, O'Connor DP. Debilitating effects of femoral nonunion on health-related quality of life. *J Orthop Trauma*. 2017;31:e37–e42.
3. Ekegren CL, Edwards ER, de Steiger R, Gabbe BJ. Incidence, costs and predictors of non-union, delayed union and Mal-union following long bone fracture. *Int J Environ Res Public Health*. 2018;15:2845.
4. Hak DJ, Fitzpatrick D, Bishop JA, et al. Delayed union and nonunions: epidemiology, clinical issues, and financial aspects. *Injury*. 2014;45(suppl 2):S3–S7.
5. Bellabarba C, Ricci WM, Bolhofner BR. Results of indirect reduction and plating of femoral shaft nonunions after intramedullary nailing. *J Orthop Trauma*. 2001;15:254–263.
6. Hak DJ, Lee SS, Goulet JA. Success of exchange reamed intramedullary nailing for femoral shaft nonunion or delayed union. *J Orthop Trauma*. 2000;14:178–182.
7. Hakeos WM, Richards JE, Obremskey WT. Plate fixation of femoral nonunions over an intramedullary nail with autogenous bone grafting. *J Orthop Trauma*. 2011;25:84–89.
8. Weresh MJ, Hakanson R, Stover MD, et al. Failure of exchange reamed intramedullary nails for ununited femoral shaft fractures. *J Orthop Trauma*. 2000;14:335–338.

9. Wu CC. The effect of dynamization on slowing the healing of femur shaft fractures after interlocking nailing. *J Trauma.* 1997;43:263–267.

10. Wu CC, Chen WJ. Healing of 56 segmental femoral shaft fractures after locked nailing. Poor results of dynamization. *Acta Orthop Scand.* 1997; 68:537–540.

11. Lynch JR, Taitsman LA, Barei DP, Nork SE. Femoral nonunion: risk factors and treatment options. *J Am Acad Orthop Surg.* 2008;16:88–97.

12. Swanson EA, Garrard EC, Bernstein DT, et al. Results of a systematic approach to exchange nailing for the treatment of aseptic femoral nonunions. *J Orthop Trauma.* 2015;29:21–27.

13. Swanson EA, Garrard EC, O'Connor DP, Brinker MR. Results of a systematic approach to exchange nailing for the treatment of aseptic tibial nonunions. *J Orthop Trauma.* 2015;29:28–35.

14. Ueng SW, Shih CH. Augmentative plate fixation for the management of femoral nonunion with broken interlocking nail. *J Trauma.* 1998;45: 747–752.

15. Ueng SW, Chao EK, Lee SS, Shih CH. Augmentative plate fixation for the management of femoral nonunion after intramedullary nailing. *J Trauma.* 1997;43:640–644.

16. Attum B, Douleh D, Whiting PS, et al. Outcomes of distal femur nonunions treated with a combined nail/plate construct and autogenous bone grafting. *J Orthop Trauma.* 2017;31:e301–e304.

17. Nadkarni B, Srivastav S, Mittal V, Agarwal S. Use of locking compression plates for long bone nonunions without removing existing intramedullary nail: review of literature and our experience. *J Trauma.* 2008;65:482–486.

18. Zhang W, Zhang Z, Li J, et al. Clinical outcomes of femoral shaft non-union: dual plating versus exchange nailing with augmentation plating. *J Orthop Surg Res.* 2018;13:295.

19. Wu CC, Shih CH, Lee ZL. A simpler surgical technique to treat aseptic nonunion-associated femoral length discrepancy. *Arch Orthop Trauma Surg.* 1992;111:160–164.

20. Krettek C, Muller M, Miclau T. Evolution of minimally invasive plate osteosynthesis (MIPO) in the femur. *Injury.* 2001;32(suppl 3):SC14–23.

21. Kim KY, Feng JE, Anoushiravani AA, et al. Rapid discharge in total hip arthroplasty: utility of the outpatient arthroplasty risk assessment tool in predicting same-day and next-day discharge. *J Arthroplasty.* 2018;33: 2412–2416.

22. Weiser MC, Kim KY, Anoushiravani AA, et al. Outpatient total hip arthroplasty has minimal short-term complications with the use of institutional protocols. *J Arthroplasty.* 2018;33:3502–3507.

23. Harris PA, Taylor R, Thielke R, et al. Research electronic data capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inf.* 2009; 42:377–381.

24. Harris PA, Taylor R, Minor BL, et al. The REDCap consortium: building an international community of software platform partners. *J Biomed Inf.* 2019;95:103208.

25. Weber B, Cech O. *Pseudoarthrosis.* Grune & Stratton: New York, NY, 1976.

26. Jaarsma RL, van Kampen A. Rotational malalignment after fractures of the femur. *J Bone Joint Surg Br.* 2004;86:1100–1104.

27. McLaren A, Lundy D. AAOS surgical site infection: diagnostic. *J Am Acad Orthop Surg.* 2019;27:e717–e720.

28. McPherson EJ, Woodson C, Holtom P, et al. Periprosthetic total hip infection: outcomes using a staging system. *Clin Orthop Relat Res.* 2002; 403:8–15.

29. DiSilvio F, Jr., Foyil S, Schiffman B, et al. Long bone union accurately predicted by cortical bridging within 4 months. *JB JS Open Access.* 2018; 3:e0012.

30. Lack WD, Starman JS, Seymour R, et al. Any cortical bridging predicts healing of tibial shaft fractures. *J Bone Joint Surg Am.* 2014;96: 1066–1072.

31. Strotman PK, Karunakar MA, Seymour R, Lack WD. Any cortical bridging predicts healing of supracondylar femur fractures after treatment with locked plating. *J Orthop Trauma.* 2017;31:538–544.

32. Skolasky RL, Maggard AM, Li D, et al. Health behavior change counseling in surgery for degenerative lumbar spinal stenosis. Part I:

improvement in rehabilitation engagement and functional outcomes. *Arch Phys Med Rehabil.* 2015;96:1200–1207.

33. Wegener ST, Carroll EA, Gary JL, et al. Trauma collaborative care intervention: effect on surgeon confidence in managing psychosocial complications after orthopaedic trauma. *J Orthop Trauma.* 2017;31: 427–433.

34. Rosen H. Compression treatment of long bone pseudarthroses. *Clin Orthop Relat Res.* 1979;138:154–166.

35. Rosen H. The treatment of nonunions and pseudarthroses of the humeral shaft. *Orthop Clin North Am.* 1990;21:725–742.

36. Lareau CR, Deren ME, Fantry A, et al. Does autogenous bone graft work? A logistic regression analysis of data from 159 papers in the foot and ankle literature. *Foot Ankle Surg.* 2015;21:150–159.

37. Readigraft® LH. *Bio-Implant Reference Manual.* LifeNet Health: Virginia Beach, VA.

38. Hsu JR, Mir H, Wally MK, Seymour RB; Orthopaedic Trauma Association Musculoskeletal Pain Task Force. Clinical Practice guidelines for pain management in acute musculoskeletal injury. *J Orthop Trauma.* 2019;33:e158–e182.

39. Adamson T, Godil SS, Mehrlich M, et al. Anterior cervical discectomy and fusion in the outpatient ambulatory surgery setting compared with the inpatient hospital setting: analysis of 1000 consecutive cases. *J Neurosurg Spine.* 2016;24:878–884.

40. Springer BD, Odum SM, Vegari DN, et al. Impact of inpatient versus outpatient total joint arthroplasty on 30-day hospital readmission rates and unplanned episodes of care. *Orthop Clin North Am.* 2017;48: 15–23.

41. Huang A, Ryu JJ, Dervin G. Cost savings of outpatient versus standard inpatient total knee arthroplasty. *Can J Surg.* 2017;60:57–62.

42. Bettin C, Nelson R, Rothberg D, et al. Cost comparison of surgically treated ankle fractures managed in an inpatient versus outpatient setting. *J Am Acad Orthop Surg.* 2019;27:e127–e134.

43. Flierl MA, Smith WR, Mauffrey C, et al. Outcomes and complication rates of different bone grafting modalities in long bone fracture nonunions: a retrospective cohort study in 182 patients. *J Orthop Surg Res.* 2013;8:33.

44. Dreyer CH, Rasmussen M, Pedersen RH, et al. Comparisons of efficacy between autograft and allograft on defect repair in vivo in normal and osteoporotic rats. *Biomed Res Int.* 2020;2020:9358989.

45. Urrutia J, Thumm N, Apablaza D, et al. Autograft versus allograft with or without demineralized bone matrix in posterolateral lumbar fusion in rabbits. Laboratory investigation. *J Neurosurg Spine.* 2008;9:84–89.

46. Tall M, Bonkoungou D, Sawadogo M, et al. Treatment of nonunion in neglected long bone shaft fractures by osteoperiosteal decortication. *Orthop Traumatol Surg Res.* 2014;100(6 suppl):S299–S303.

47. Banaszkiewicz PA, Sabbouheh A, McLeod I, Maffulli N. Femoral exchange nailing for aseptic non-union: not the end to all problems. *Injury.* 2003;34:349–356.

48. Bell A, Templeman D, Weinlein JC. Nonunion of the femur and tibia: an update. *Orthop Clin North Am.* 2016;47:365–375.

49. Peters RM, Claessen FM, Doornberg JN, et al. Union rate after operative treatment of humeral shaft nonunion—a systematic review. *Injury.* 2015; 46:2314–2324.

50. Clark JC, Jasmer G, Marciano FF, Tumialan LM. Minimally invasive transforaminal lumbar interbody fusions and fluoroscopy: a low-dose protocol to minimize ionizing radiation. *Neurosurg Focus.* 2013;35:E8.

51. Singer G. Occupational radiation exposure to the surgeon. *J Am Acad Orthop Surg.* 2005;13:69–76.

52. Stone ME Jr, Marsh J, Cucuzzo J, et al. Factors associated with trauma clinic follow-up compliance after discharge: experience at an urban Level I trauma center. *J Trauma Acute Care Surg.* 2014;76: 185–190.

53. Zelle BA, Buttacavoli FA, Shroff JB, Stirton JB. Loss of follow-up in orthopaedic trauma: who is getting lost to follow-up? *J Orthop Trauma.* 2015;29:510–515.

54. Somerson JS, Bartush KC, Shroff JB, et al. Loss to follow-up in orthopaedic clinical trials: a systematic review. *Int Orthop.* 2016;40:2213–2219.