Case Report

Early Rehabilitation Following Surgical Fixation of a Femoral Shaft Fracture

Background and Purpose. The purpose of this case report is to describe the outcome of a patient following fixation of a midshaft femur fracture and an evaluation-based, immediate-weight-bearing approach to rehabilitation. **Case Description.** The patient was a 28-year-old male manual laborer whose left femur was fractured in a head-on motor vehicle accident. The patient was treated with internal fixation of the left femur by use of an antegrade intramedullary nail. Following surgery, impairments in range of motion, knee extensor and hip abductor strength, and gait were observed. Intervention focused on immediate weight bearing and early progression of strengthening to address the observed impairments. **Outcomes.** All of the patient's impairments improved, and he was able to return to work as a manual laborer within 6 months. **Discussion.** Immediate weight bearing with early strengthening activities following surgical correction of a mid-shaft femur fracture may result in early resolution of impairments and functional limitations and decreased disability. [Paterno MV, Archdeacon MT, Ford KR, et al. Early rehabilitation following surgical fixation of a femoral shaft fracture. *Phys Ther.* 2006;86:558–572.]

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This case report describes the outcome of a patient following fixation of a midshaft femur fracture and an evaluation-based, immediate weight-bearing approach to rehabilitation.

Each year in the United States, approximately 60,000 patients sustain midshaft femoral fractures.[1] The majority of these injuries occur in young people and are the result of high-energy mechanisms, such as motor vehicle accidents, falls from a height, or industrial accidents.[2] Because of the traumatic nature of these injuries and the intensive surgical intervention required, soft tissue pathology is common and may limit the return of patients to their previous level of function.[3–9] Almost half of the patients treated for a leg fracture at level I trauma centers have some residual disability 12 months after the injury, and up to 20% of patients treated surgically for femoral shaft fractures are unable to return to work 3 years after the injury.[9,10]

Correction of the fracture with an intramedullary nail inserted into the femur is the standard of care for surgical fixation. Fracture healing from this procedure is effective, with union rates of between 95% and 99%.[11] Impairments and functional limitations, however, frequently persist following the injury and the surgical procedure long after adequate bony healing is demonstrated radiographically.[2,3,11] These functional limitations, impairments, and ultimately disabilities may be attributable to soft tissue injury as a result of trauma at the time of injury or surgery, or both.[3] Soft tissue limitations include hip abductor weakness with a resultant Trendelenburg gait pattern, quadriceps femoris muscle weakness, anterior knee pain, trochanteric bursitis, and decreased function with respect to gait and walking endurance.[2,4–8]

Hip abductor weakness is postulated to be an iatrogenic complication of femoral intramedullary nailing.[2,4,5,12,13] Some authors[2,5] reported side-to-side deficits in hip abductor strength (muscle force-generating capacity) with resultant alterations in gait, specifically a Trendelenburg gait pattern, that persisted for up to 47 months following surgery. In addition, hip abductor weakness following surgical management of a femoral fracture is a complication that ultimately leads to functional limitations, including stiffness, antalgic gait, decreased endurance, and difficulty ambulating stairs.[2,4,5,14,15] Residual weakness may be attributed to soft tissue damage at the time of injury or surgery, or both; an irritation of the abductor musculature from the surgical hardware; or inadequate postsurgery rehabilitation.[2] Inadequate postsurgery rehabilitation, although frequently implicated as a potential cause of this impairment, is not adequately documented in the literature, nor have the effects been analyzed prospectively.

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Table 1.
Physical Examination of Range of Motion and Strength at Various Postoperative (PO) Times

Parameter[a]	Phase I		Phase II,	Phase III	
	PO wk 2	PO wk 4	PO wk 8	PO wk 16	PO mo 8
Range of motion(°)					
Hip flexion	70	110	115	116	116
Hip LR	40	40	46	50	60
Hip MR	30	30	36	40	45
Knee flexion	90	110	130	148	148
Knee extension	0	0	0	0	0
Manual muscle test					
Hip flexion	N/T	4+/5	4+/5	5/5	5/5
Hip abduction	N/T	4−/5	4−/5	4/5	4+/5
Knee flexion	4/5	4+/5	5/5	5/5	5/5
Knee extension	4−/5	4−/5	5/5	5/5	5/5

[a] LR=lateral rotation, MR=medial rotation, N/T=not tested.

Quadriceps femoris muscle weakness is a common outcome following femoral fracture, with or without surgical management.[3,6,7,16] Long-term studies (16–44 months postinjury) documented that following both conservative[3] and surgical[6,7,16] management of femoral fractures, significant residual quadriceps femoris muscle weakness persists. This strength deficit may be attributable to muscle damage sustained at the time of injury, because quadriceps femoris muscle weakness has been shown to be related to measured fracture displacement.[3]

Ten to 20 years ago, weight bearing was delayed until radiographic evidence of bony callus formation was present.[17–21] This delay of up to 6 to 10 weeks in weight bearing and ambulation resulted in functional deficits and disability.[22] Within the last 5 to 10 years, earlier weight bearing has been encouraged, has been reported to be safe, and may facilitate fracture healing.[20,22–26] Ultimately, immediate weight bearing may result in less hospitalization, a decreased need for prolonged inpatient rehabilitation, and decreased costs of care.[22,27] This premise, however, has not been substantiated in the literature. We believe that an aggressive physical therapy program with early weight bearing may facilitate long-term success with patients following intramedullary nailing by quickly decreasing the level of impairment that leads to functional limitations and disability in these patients. The purpose of this case report is to describe physical therapist management with an evaluation-based, early intervention approach following surgical fixation of a femoral fracture with antegrade intramedullary nailing. As part of documenting improvement in function, instrumented gait analysis was used to quantify the effects of the intervention.

Case Description

Subject

The subject was an otherwise healthy 28-year-old man who had a high-energy, closed, oblique, midshaft to proximal-third-shaft fracture of the left femur while involved in a head-on motor vehicle accident. Prior to injury, the patient was a manual laborer whose job demanded prolonged standing on concrete surfaces, squatting, and heavy lifting. Informed consent was obtained prior to all testing, and all HIPAA requirements were met.

The patient was treated with internal fixation of the left femur by use of an antegrade intramedullary nail with a piriformis fossa entry portal. The patient underwent physical therapy 2 times per day in the hospital and was released from the hospital after 3 days. He continued with outpatient physical therapy, beginning 10 days following hospital discharge (postoperative week 2). An outpatient initial examination was done at this time.

Tests and Measures

Range of motion. During the initial examination, the patient's hip and knee ranges of motion were measured with a standard goniometer. These measurements were repeated at postoperative weeks 4, 8, and 16 and at month 8. Sagittal-plane hip and knee ranges of motion were measured with the patient in the supine position. Hip rotations were measured with the patient in the prone position with the hip at 0 degrees of flexion and the knee flexed to 90 degrees.[28]

The patient had full knee extension at the initial examination, but he had only 90 degrees of knee flexion. He also had limitations in hip flexion (70°) and in hip medial (internal) rotation (30°) and lateral (external) rotation (40°). A summary of range-of-motion findings is shown in Table 1. We did not estimate the reliability of our range-of-motion measurements.

Short-Form Musculoskeletal Function Assessment Survey. The patient completed the Short-Form Musculoskeletal Function Assessment Survey (SF-MFAS) (Injury and Arthritis Survey) at postoperative months 3 and 12 and at postoperative year 2. In addition, a retrospective evaluation was done at the time of injury to assess the patient's preinjury functional status. The SF-MFAS is a 46-item questionnaire that is divided into a dysfunction index and a bother index.[29] The dysfunction index uses 34 items to assess patients' perceptions of their functional performance, whereas the bother index uses a 12-item assessment of "how much patients are bothered by problems in broad functional areas."[29(p1246)] Each item on the SF-MFAS uses a 5-point response format with a range of 1 point (good function/not a bother) to 5 points (poor function/extremely bothersome). The patient's responses on each index were calculated and reported on a scale of 0 to 100 for each index. Higher scores indicated poorer function, whereas lower scores indicated better function.

Intraclass correlation coefficients for the stability of the SF-MFAS were reported as .93 for the dysfunction index (Cronbach alpha values of .95–.96) and .88 for the bother index (Cronbach alpha values of .92–.95).[29] The SF-MAS has "good content validity with good score ranges (0 to 94), little skew (0.70 to 0.75), no floor effect (0.5%) and few ceiling effects (2.5%)."[29(p1252)] The construct validity of the SF-MFAS scores was evaluated by use of the 36-Item Short-Form Health Survey; the SF-MFAS scores were found to have high construct validity, as the scores varied significantly according to the health status of the patient ($P<.01$). The tool also is responsive to changes in the health status of the patient as measured by the patient's report ($P<.01$) for both the dysfunction index and the bother index.[29] The patient had a preinjury baseline dysfunction index of 4.41 and a bother index of 6.25. An example of the SF-MFAS and the patient's responses to the preinjury baseline assessment and postsurgical assessments are shown in Table 2.

Gait. The patient's gait was assessed with 3-dimensional motion analysis including 8 digital (Eagle) cameras connected through an Ethernet hub to the data collection computer* and 2 force plates.† Assessment occurred at postoperative months 2 and 8 but not at the time of the initial outpatient examination. Observational gait analysis was used during the initial examination and frequently is used in analysis of outcomes following femoral fractures.[2,11] Computerized 3-dimensional motion analysis, however, is a more accurate means of assessing rapid and subtle characteristics of an individual's gait.[30] Observational gait analysis indicated that the patient was ambulating with 2 axillary crutches at a partial-weight-bearing status, despite medical clearance to bear full weight. The patient hesitated to increase weight bearing because of pain. Kinematically, the patient demonstrated an extended knee during most of the stance phase and decreased knee flexion during the swing phase of gait. A computerized gait examination took place at the end of the second phase of rehabilitation (postoperative month 2), when the patient was bearing full weight with no assistive device. A final examination took place at 8 months, when the patient was released from physical therapy and had successfully returned to work without limitations.

The patient was fitted with reflective markers by use of a Helen Hayes marker set in a static trial.[31] Videotaped data were collected at 240 Hz and time synchronized with data collected from the 2 force platforms at 1,200 Hz. The patient was instructed to walk at a self-selected speed. Kinematics and kinetic data also were collected and normalized to 100% of the gait cycle, and kinetic data were normalized to body weight (OrthoTrak*). Internal moments were reported. Comparison of kinematic and kinetic curves to values in a normative database of 10 age-matched control subjects was performed for qualitative analysis.

Muscle strength. Lower-extremity strength was measured with manual muscle testing at the initial examination and then again at postoperative weeks 4, 8, and 16 and at month 8. Hip flexion was measured with the patient in a supine position, and hip abduction was measured in a side-lying position. Knee flexion and extension were measured in a seated position.[32]

Manual muscle testing of the hip was not done during the initial examination because of patient discomfort. Testing at 4 weeks revealed impairments in hip abductor strength. During the initial examination, knee flexion strength was 4/5 and knee extensor strength was 4−/5. A summary of all manual muscle testing results is shown in Table 1.

Knee extensor and flexor strength also was measured isometrically with the knee positioned at 60 degrees of flexion at postoperative months 2 and 8 on a Biodex dynamometer.‡ Prerehabilitation isometric torque was not measured because of the recent surgery. Isometric testing of quadriceps femoris and hamstring muscle strength in children and in adults has been shown to

* Motion Analysis Corp, 3617 Westwind Blvd, Santa Rosa, CA 95403.
† Advanced Mechanical Technology Inc, 176 Waltham St, Watertown, MA 02472.
‡ Biodex Medical Systems, 20 Ramsay Rd, Shirley, NY 11967.

Table 2.
Example of Short-Form Musculoskeletal Function Assessment Survey and Patient's Responses

Dysfunction Index

These questions are about how much difficulty you may be having *this week* with your daily activities because of your injury or arthritis.

Key	
Not at all difficult	1
A little difficult	2
Moderately difficult	3
Very difficult	4
Unable to do	5

Question	Preinjury	3 mo	1 y	2 y
1. How difficult is it for you to get in or out of a low chair?	1	2	1	1
2. How difficult is it for you to open medicine bottles or jars?	1	1	1	1
3. How difficult is it for you to shop for groceries or other things?	1	2	1	1
4. How difficult is it for you to climb stairs?	1	3	1	1
5. How difficult is it for you to make a tight fist?	1	1	1	1
6. How difficult is it for you to get in or out of the bathtub or shower?	1	2	1	1
7. How difficult is it for you to get comfortable to sleep?	2	3	1	1
8. How difficult is it for you to bend or kneel down?	1	4	1	1
9. How difficult is it for you to use buttons, snaps, hooks, or zippers?	1	1	1	1
10. How difficult is it for you to cut your own fingernails?	1	1	1	1
11. How difficult is it for you to dress yourself?	1	1	1	1
12. How difficult is it for you to walk?	1	4	1	1
13. How difficult is it for you to get moving after you have been sitting or lying down?	1	2	1	1
14. How difficult is it for you to go out by yourself?	1	2	1	1
15. How difficult is it for you to drive?	1	2	1	1
16. How difficult is it for you to clean yourself?	1	1	1	1
17. How difficult is it for you to turn knobs or levers, for example, open doors or roll down car windows?	1	1	1	1
18. How difficult is it for you to write or type?	1	1	1	1
19. How difficult is it for you to pivot?	1	2	1	1
20. How difficult is it for you to do your usual physical recreational activities, such as bicycling, jogging, or walking?	1	5	2	1
21. How difficult is it for you to do your usual leisure activities, such as hobbies, crafts, gardening, card playing, or going out with friends?	1	2	1	1
22. How much difficulty are you having with sexual activity?	1	2	1	1
23. How difficult is it for you to do light housework or yard work, such as dusting, washing dishes, or watering plants?	1	2	1	1
24. How difficult is it for you to do heavy housework or yard work, such as washing floors, vacuuming, or mowing lawns?	1	4	1	1
25. How difficult is it for you to do your usual work, such as a paid job, housework, or volunteer activities?	1	5	1	1

These questions ask how often you are experiencing problems *this* week because of your injury or arthritis.

Key	
None of the time	1
A little of the time	2
Some of the time	3
Most of the time	4
All of the time	5

Question	Preinjury	3 mo	1 y	2 y
26. How often do you walk with a limp?	1	4	3	2
27. How often do you avoid using your painful limb(s) or back?	1	2	2	1
28. How often does your leg lock or give way?	1	2	1	1
29. How often do you have problems with concentration?	1	1	1	1
30. How often does doing too much in one day affect what you do the next day?	2	2	3	1
31. How often do you act irritably toward those around you, for example, snap at people, give sharp answers, or criticize easily?	2	2	1	1
32. How often are you tired?	2	2	3	2
33. How often do you feel disabled?	1	3	1	1
34. How often do you feel angry or frustrated that you have this injury or arthritis?	1	2	1	1

(Continued)

Table 2.
Continued

Bother Index

These questions are about how much you are bothered by problems you are having *this* week because of your injury or arthritis.

Key	
Not at all bothered	1
A little bothered	2
Moderately bothered	3
Very bothered	4
Extremely bothered	5

How much are you bothered by				
35. Problems using your hands, arms, or legs	1	3	1	1
36. Problems using your back	1	1	1	1
37. Problems doing work around your home	1	2	1	1
38. Problems with bathing, dressing, toileting, or other personal care	1	2	1	1
39. Problems with sleep and rest	2	3	1	1
40. Problems with leisure or recreational activities	1	3	1	1
41. Problems with your friends, family, or other important people in your life	2	2	1	1
42. Problems with thinking, concentrating or remembering	1	1	1	1
43. Problems adjusting or coping with your injury or arthritis	1	2	1	1
44. Problems doing your usual work	1	2	1	1
45. Problems with feeling dependent on others	1	1	1	1
46. Problems with stiffness and pain	2	2	1	1

have good test-retest reliability, with intraclass correlation coefficients ranging from .81 to .94 in various studies.[33–36]

For knee extensor and flexor strength measurements, the patient was secured in a seated position on the dynamometer with his trunk perpendicular to the floor and his hip flexed to 90 degrees. Stabilization straps were secured at the waist, distal femur, and distal shank, just proximal to the medial malleolus. For the isometric test sessions, the uninvolved limb was secured at 60 degrees of knee flexion. The patient was asked to execute a maximum-effort isometric knee extension contraction at this angle and to hold this position for 10 seconds. This procedure was followed by 30 seconds of rest. This cycle was repeated until 3 extension efforts were executed. The patient then executed a maximum-effort isometric knee flexion contraction at a 60-degree angle and held this position for 10 seconds. This procedure was followed by 30 seconds of rest. The patient repeated this cycle until 3 flexion efforts were recorded. The patient repeated this protocol with the involved limb. Peak torque and the average ratio of torque to body weight were recorded.

Summary of Initial Examination Findings

At the time of the initial examination at postoperative week 2, several key impairments were identified. Range-of-motion deficits were noted in knee flexion, hip flexion, and hip rotation. The patient was toe-touch weight bearing with 2 axillary crutches, despite being given medical clearance to bear weight as tolerated with an assistive device. Manual muscle testing revealed strength impairments, most notably in knee extension (4−/5 at postoperative week 2) and hip abduction (unable to assess at postoperative week 2 because of pain).

Diagnosis and Prognosis

On the basis of the initial examination findings, we determined that the patient had specific impairments including, but not limited to, quadriceps femoris muscle weakness, hip abductor weakness, loss of hip and knee range of motion, and gait abnormalities, specifically an altered weight-bearing status. These limitations resulted in functional impairments of activities of daily living as well as recreational activities, as per the patient's report. In addition, the patient was unable to return to work. Our prognosis was based on the level of impairment at the time of the examination, the age of the patient, the potential discharge needs related to home and work demands, current evidence regarding facilitated fracture healing with early weight bearing,[20,22–26] and our clinical expertise. We hypothesized that, following successful completion of a rehabilitation program focused on early weight bearing, the patient would meet all goals and return to all home- and work-related activities without limitations within 6 months.

Intervention and Rehabilitation Protocol

The patient participated in our femur fracture rehabilitation program (Tab. 3), which focuses on immediate weight bearing and progression of gait training, range of

Table 3.
Postoperative Femur Fracture Rehabilitation Program[a]

Parameter	Phase I, PO wk 0–4, 10 Visits (5 IP, 5 OP)	Phase II, PO wk 4–8, 10 Visits	Phase III, PO wk 8–18, 15 Visits
Criteria for progression	PO d 1	• 50% WB • Minimal effusion • Fair quadriceps femoris muscle contraction • Fair hip abductor strength	• Full WB without crutches or walker • Minimal effusion • Good quadriceps femoris muscle contraction • Fair to good hip abduction contraction
WB	WB as tolerated with walker or crutches	WB as tolerated with walker or crutches	WB as tolerated without assistive device
ROM	Passive or active ROM: • Hip • Knee • Ankle Focus on full knee extension (static propping)	Continue phase I activities as appropriate	Continue phase II activities as appropriate
Modalities	As indicated for: • Muscle re-education • Swelling control • Pain management	Continue as indicated	Continue as indicated
Stretching	Gastrocnemius, soleus, and hamstring muscles (seated)	Progress as tolerated	Progress as indicated
Strengthening	• Quadriceps femoris muscle sets • Ankle dorsiflexion, plantar flexion, inversion, and eversion with Thera-Band • Straight leg raises in 4 planes • Ankle pumps	Progress to: • Knee extension (90°–30° with weight up to 2.25 kg [5 lb]) • Toe or heal raises • Minisquats • Wall sits (50% WB) • Standing hip abduction or flexion with resistance (Thera-Band or ankle weights) • Standing knee flexion PREs	Progress to: • Increased weight with PREs • Full WB activities, such as step-ups (forward and lateral) and single-leg minisquats
Balance, proprioception, and gait	Cup walking, weight shifting, progressive WB	Progression of gait training, including: • Side stepping • Backward walking (guarded)	Progress to: • Single-leg stance activities • Balance and proprioception activities
Fitness conditioning		Stationary bicycling, pool therapy (if available)	Treadmill walking

[a] PO=postoperative, IP=inpatient, OP=outpatient, WB=weight bearing, ROM=range of motion, PREs=progressive resistive exercises.

motion, strength, balance, and return to function; specific descriptions of and modifications to the femur fracture rehabilitation program unique to this case are described later in this case report. The patient's rehabilitation program combined both inpatient and outpatient physical therapy services and was divided into 3 phases. Each phase was evaluation based, as progression was dependent on successful attainment of baseline goals. These goals addressed weight-bearing status, range of motion, quadriceps femoris muscle control, and hip abductor strength. The program was a combination of weight-bearing progression, gait training, range-of-motion activities, physical therapy modalities, stretching, progressive resistive exercises (PREs), balance, proprioception activities, and conditioning.

Phase I. Phase I (Tab. 3) of the femur fracture rehabilitation protocol began on postoperative day 1 in the hospital and lasted 4 weeks. Inpatient physical therapy was ordered twice daily and consisted of gentle range-of-motion activities, initiation of a weight-bearing-as-tolerated ambulation program with either a walker or bilateral axillary crutches, and lower-extremity isometric exercises. The patient used bilateral axillary crutches immediately following surgery. Following discharge from the hospital on postoperative day 3, the patient started an outpatient physical therapy program 2 or 3 days per week. The patient began this program at postoperative week 2. At the time of the initial outpatient examination, the patient utilized a toe touch to 25% weight-bearing status. During the time between inpatient physical therapy and outpatient physical therapy, the patient continued his home exercise program, which was prescribed at the time of discharge and which focused on range of motion of the hip and knee, isometric exercises for the quadriceps femoris and gluteal muscles, and patellar mobilization.

Exercises in phase I focused on hip and knee joint mobility, non–weight-bearing strengthening, and progression of weight bearing during gait. The patient was required to demonstrate an ability to ambulate with 50% weight bearing, fair quadriceps femoris muscle contraction, and fair hip abductor muscle strength prior to progressing to phase II. Active-range-of-motion and passive-range-of-motion exercises of the hip, knee, and ankle were initiated immediately following surgery in all 3 cardinal planes. The main focus initially was knee extension. Full knee extension was pursued aggressively immediately following surgery to decrease the risk of knee flexion contracture. The patient performed posterior lower-extremity stretching, including seated hamstring muscle stretching and seated gastrocnemius muscle stretching with the assistance of a towel. In addition, the patient's involved lower extremity was elevated with the heel propped up for 10 minutes 3 or 4 times per day. This static heel propping stretch was intended to provide a low-load, long-duration stretch of the posterior knee. The patient attained full active knee extension prior to discharge from the hospital.

Knee flexion exercises were initiated immediately following surgery. Passive and active assisted knee flexion exercises were initiated while the patient was in the seated position on a chair or table. These exercises progressed to stool sliding or supine wall sliding as tolerated by the patient. The patient demonstrated a steady progression of knee flexion through phase I.

Modalities were used during phase I to attain 2 goals. First, neuromuscular reeducation with electrical stimulation (NMES) was initiated following surgery for the quadriceps femoris muscle to help regain volitional control of this muscle. The NMES was initiated during the first outpatient visit at postoperative week 2 and continued through phase I of rehabilitation. Second, effusion and edema management was addressed with the regular use of elevation and cryotherapy until edema was minimized after 5 postsurgery visits. The patient continued to have difficulty activating a strong quadriceps femoris muscle contraction; therefore, NMES was continued into phase II.

Initial strengthening exercises focused on the attempt to regain active control of knee extensor and hip abductor musculature. Quadriceps femoris muscle isometric exercises were initiated immediately following surgery to activate the knee extensor muscle group, and gravity-minimized supine hip abduction slides were initiated to activate the abductor musculature. Gravity-resisted standing hip flexion (marching), hip abduction, and knee flexion were initiated at the initial outpatient physical therapy visit. The patient progressed in gravity-resisted exercises as soon as tolerated to a more challenging position, such as straight leg raises on a table. The patient was able to perform these exercises during the final visit of phase I. In addition to the focus on the proximal lower-extremity musculature, distal lower-extremity strength was addressed. Progressive resistive exercises in all planes at the ankle were initiated at this time with the use of Thera-Band[§] to provide resistance.

Balance and proprioception activities began during phase I, specifically at postoperative week 3. The patient performed simple weight-shifting exercises without an assistive device to encourage increased comfort and confidence with progression of weight bearing. These exercises were transitioned to gait-training activities with an assistive device, such as walking over cones to promote knee flexion during the swing phase of gait and to facilitate a more normal gait pattern. These activities ultimately were transitioned to full weight bearing without an assistive device in subsequent phases. This goal was reached during the final 4 visits of phase I.

Following 5 inpatient and 5 outpatient physical therapy sessions as well as participation in a daily home exercise program that consisted of all range-of-motion and strengthening exercises that were executed in the clinic, the patient met the necessary criteria to advance to phase II at postoperative week 4. The patient was able to bear at least 50% of his weight with 2 axillary crutches during ambulation, as assessed clinically with a bathroom scale. He had minimal knee effusion and lower-extremity edema, and he had fair quadriceps femoris and hip abductor muscle strength. A fair quadriceps femoris muscle contraction was defined as the ability to generate a superior patellar glide, and fair hip abductor strength was defined as the ability to elevate the lower extremity against gravity from a resting side-lying position. Successful attainment of these goals resulted in progression to phase II.

Phase II. Our patient began phase II at postoperative week 4 and continued in this phase until postoperative week 8. The frequency of physical therapy during this phase was 2 or 3 times per week for a total of 10 visits.

Several portions of phase I continued as appropriate into phase II. Weight bearing continued to be as tolerated with the use of 2 axillary crutches. The patient

[§] The Hygenic Corp, 1245 Home Ave, Akron, OH 44310.

progressed at postoperative week 6 to 1 crutch for assistance with balance during gait and could bear full weight without any assistive device at postoperative week 8. The NMES was continued to assist with the facilitation of volitional quadriceps femoris muscle contraction throughout phase II for a total of 15 treatments in both phases I and II. General lower-extremity stretching, including the stretching of the gastrocnemius and soleus muscles, and hamstring muscle stretching also were prescribed.

Exercises during phase II included a progression of phase I exercises to more strengthening activities in a weight-bearing position, more gait retraining, and initiation of fitness conditioning. The patient was required to achieve an independent full-weight-bearing status and to have good quadriceps femoris muscle contractions and fair to good hip abductor strength while maintaining minimal effusion prior to progression to phase III. A focus on progression of range of motion continued in phase II. Activities to maintain knee extension were continued. Knee flexion activities, including passive range of motion, active range of motion, stool slides, supine wall slides, and use of a bicycle, were continued until range of motion necessary to perform all activities of daily living was attained.

Strengthening progressed to more weight-bearing activities once the patient demonstrated an ability to bear at least 50% of his weight, as assessed with a bathroom scale. Exercises requiring 50% weight bearing, including toe raises, bilateral minisquats, and wall slides, were instituted at this time. In addition, more non–weight-bearing activities, such as knee extension with ankle weights from 90 degrees of flexion to 30 degrees of flexion, were begun. The patient started with 0.9 kg (2 lb) and progressed in 0.45-kg (1-lb) increments whenever he was able to execute 3 sets of 10 repetitions easily. Full extension was avoided to prevent any additional stress on the patellofemoral joint, which may have been injured at the time of injury. The patient's patellofemoral joint was palpated at the initiation of this exercise to ensure the absence of crepitation. Crepitation was not palpable, and the patient reported no anterior knee pain; therefore, the exercises progressed. Standing knee flexion with ankle weights also was initiated from 0 to 90 degrees of flexion starting with 0.90-kg (2-lb) weights. Weight was increased in 0.45-kg (1-lb) increments as outlined above. Hip strengthening progressed with the initiation of standing hip flexion and abduction activities with red Thera-Band. Exercises used in phase I were continued with increased weight and increased repetitions.

Gait training activities progressed to side-stepping activities in addition to backward walking with necessary assistance. The patient began with minimal hand-holding assistance and quickly progressed to only visual supervision within 7 to 10 days. Proprioception activities, including balance board activities, marching on a mini-trampoline, and weight-bearing PREs on an unstable surface, were initiated at the end stages of phase II, specifically during the final 2 visits of the phase. The patient participated in sets of sustained-hold activities on the balance board for 10 to 30 seconds. In addition, he performed 3 sets of 10 repetitions of toe raises and minisquats on the unstable platform. Fitness conditioning was initiated at postoperative week 6 with the addition of the use of a stationary bicycle when adequate knee flexion was achieved. The patient began with self-selected intensity on the stationary bicycle for 5 minutes and increased to 10 minutes as tolerated at the end of phase II.

Following 10 visits between postoperative weeks 4 and 8, in addition to a continued daily home exercise program that focused on range of motion and strength, the patient successfully attained several goals: full weight bearing without crutches or a walker, minimal effusion, fair to good quadriceps femoris muscle strength with a manual muscle test result of 4+/5, and fair to good hip abductor strength with a manual muscle test result of 4/5. Therefore, the patient met the necessary criteria and progressed to phase III of the femur fracture rehabilitation program.

Phase III. The patient began phase III of the rehabilitation protocol at postoperative week 8 and continued in this phase until his discharge at postoperative week 18. He attended physical therapy sessions 1 or 2 times per week during this phase for a total of 15 visits.

During phase III, the exercises focused on increasing lower-extremity strength with full-weight-bearing activities in addition to advancing mobility, balance, proprioception, and fitness conditioning. The patient continued to progress in range-of-motion and stretching activities as appropriate. He continued to increase the intensity of the strengthening exercises initiated in phase II through increased resistance with PREs. In addition, with the progression of weight bearing to 100% without the use of an assistive device, the patient began single-leg strengthening activities, such as step-ups, half-lunges, and single-leg minisquats. Each exercise was initiated with 3 sets of 10 repetitions and progressed with the addition of hand weights and increasing repetitions from 10 to 15. Balance and proprioception activities also were advanced to single-leg activities. Static balance activities on an unstable platform were advanced to single-leg activities on stable and unstable platforms. All activities on the unstable platform began with 10 repeti-

Table 4.
Results of Short-Form Musculoskeletal Function Assessment Survey (Injury and Arthritis Survey) at Various Postoperative (PO) Times

Index	Preinjury	3 mo PO	12 mo PO	2 y PO
Dysfunction (score out of 100)	4.41	30.9	5.88	1.47
Bother (score out of 100)	6.25	25	0	0

tions of 10 to 20 seconds and advanced to longer holds of 20 to 30 seconds as tolerated.

Fitness conditioning also progressed at this time to incorporate treadmill walking at postoperative week 9. The patient started ambulating at 4 km (2.5 miles) per hour on level ground for 5 minutes. The speed of ambulation was increased as tolerated, and the time was increased to 12 minutes by the end of phase III. He continued to use the stationary bicycle and increased the cycling time to 15 minutes at the end of phase III. Deep knee flexion was avoided with these activities to limit irritation of the patellofemoral joint; however, we believe that the activities can be used with restrictions on knee flexion.

The patient continued physical therapy for a total of 30 outpatient visits over a 4-month span, with each visit lasting approximately 1 hour. At postoperative month 4, he had achieved full range of motion but continued to lack normal hip abductor strength and to exhibit a mild residual Trendelenburg gait pattern. At that time, the physical therapist elected to have the patient continue with an independent home exercise program focusing on his residual impairments and functional limitations. This program focused on global lower-extremity strength. Key areas included continuation of both weight-bearing and non–weight-bearing strengthening exercises. In addition, the patient participated in a community walking program 3 days per week to increase walking endurance in preparation for a return to work. At postoperative month 6, the patient received medical clearance from the medical team to return to work as a full-duty manual laborer, and he continued with a home exercise program to improve residual deficits.

Outcomes

Range of Motion

The patient's progression of hip and knee range of motion is outlined in Table 1. The patient was able to attain full knee extension in phase I, prior to discharge from the hospital. Full knee flexion was not attained until phase III, approximately 16 weeks after surgery. Hip range of motion was nearing full range at the completion of phase II, at postoperative week 8, with the only exception being hip lateral rotation, which was not achieved until postoperative month 8.

SF-MFAS

The patient completed the SF-MFAS at 4 separate time points (Tab. 4). The results of each assessment are outlined in Table 2 The first assessment occurred soon after injury, while the patient was in the hospital. The patient retrospectively indicated his preinjury status. The second assessment occurred at 3 months after surgery, the third assessment occurred at 12 months after surgery, and the final assessment occurred at 2 years after surgery. The patient had a sharp increase in both the dysfunction index and the bother index from before injury to 3 months after injury, indicating poorer function on both scores. At this time, the patient reported that he was unable to perform several tasks, including usual recreational and work activities. Additionally, he reported that it was very difficult to participate in kneeling and bending activities, walking, heavy housework, and walking without a limp. The patient then reported a marked improvement in function on both the dysfunction index and the bother index from 3 months to 12 months. At this time, he reported only a little difficulty with usual recreational activity and avoided use of the involved limb only a little of the time. Moderate difficulty still was noted with walking without a limp, feeling tired, and having day-after effects of increased activity. At 2 years after surgery, the patient reported that the only residual deficits were a little difficulty with walking without a limp and feeling tired.

Gait Analysis

Analysis of the patient's gait mechanics demonstrated improvements in knee and hip kinematics and kinetics at the 8-month assessment compared with the 2-month assessment. All gait parameters of the involved limb were compared with values in a normative database for adult control subjects. The patient ambulated at a self-selected gait speed of 0.8 m/s at the 2-month assessment and increased his self-selected speed to 1.0 m/s at the 8-month assessment.

Hip Kinematics and Kinetics

Hip abduction kinematics and kinetics were analyzed with regard to several factors. First, the initial examination showed hip abductor weakness, which appeared to be a critical impairment related to gait abnormalities during the stance phase of gait. Second, the surgical intervention required a piriformis fossa entry portal for insertion of the internal fixation into the femur. This point of entry has been described as the most geometric for the femur but potentially the most disruptive for the abductor tendon.[37] Therefore, we were concerned about impairments in hip abduction following this procedure. Finally, a previous study evaluating gait following femoral fractures identified hip abduction during stance as a critical variable.[38]

Table 5.
Lower-Extremity Kinematics (Motion) of Involved Limb Versus Values for Age-Matched Normative Sample (n=10) at Various Postoperative Times

	2 mo PO		8 mo PO	
Parameter[a]	Involved Limb	Normative Sample	Involved Limb	Normative Sample
Hip peak abduction (°)	1.4	7.7	8.3	7.7
Knee peak flexion (°) (IS)	1.8	19.2	12.5	19.2

[a] PO=postoperative, IS=initial stance.

Analysis of hip kinematics at the 2-month assessment demonstrated a marked decrease in hip abduction throughout the stance cycle of gait on the involved side versus the uninvolved side (Tab. 5, Fig. 1). At 8 months, the peak hip abduction angle increased bilaterally to a normal range. Kinetic analysis of the hip also revealed marked improvement between the 2-month and 8-month analyses. At 2 months, the patient demonstrated a decrease in both peak hip abduction values (Tab. 6, Fig. 2). These reductions in hip abductor moments improved at the 8-month assessment.

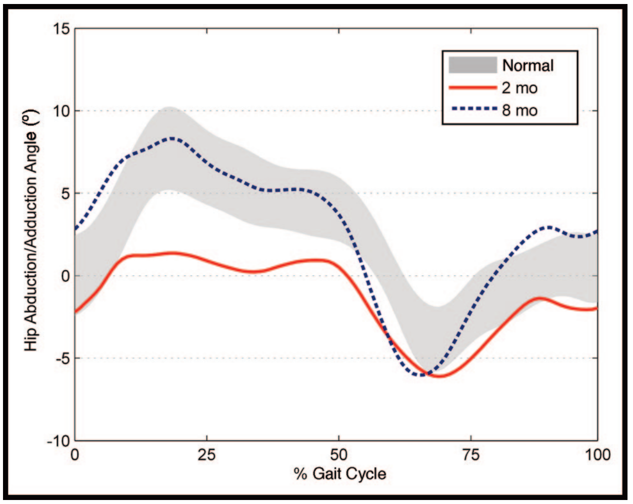

Figure 1.
Coronal-plane hip kinematics (degrees) during gait at 2 months and 8 months after surgery. The shaded area represents the normal database value (±1 SD). Positive values indicate adduction, negative values indicate abduction.

Knee Kinematics and Kinetics

Knee kinematics and kinetics were evaluated during gait for several reasons. First, the patient's initial examination demonstrated a marked deficit in knee extensor strength, which was a potential major impairment. Second, prior studies[3,6,7,16] indicated that knee extensor weakness is a frequent impairment that ultimately may limit function in patients following midshaft femoral fractures. Knee extensor muscle activation is necessary to display a normal gait pattern from initial contact through mid-stance[30,39] and therefore was determined to be a critical variable to evaluate in this case.

Knee kinematics at 2 months revealed a marked decrease in knee flexion during initial stance in the involved limb compared with that in a normative population (Tab. 5, Fig. 3). Knee flexion in the involved lower extremity improved at 8 months as the value approached a normal range.

Kinetic data for the knee at postoperative month 2 revealed a knee extensor torque during initial stance of −0.084 N·m/kg, far below the normative value of 0.317 N·m/kg. This variable improved to 0.018 N·m/kg at postoperative month 8 but continued to be far below the normative value for this point in the gait cycle (Tab. 6, Fig. 4).

Muscle Strength

Manual muscle testing. The patient's progression of strength, as assessed by manual muscle testing, is outlined in Table 1. At the end of phase I, the patient continued to have strength deficits in knee extension and hip abduction. At the end of phase II, hip abductor strength continued to demonstrate deficits, whereas knee extensor strength improved to the normal range. At postoperative month 8, the patient continued to have slight deficits in hip abductor strength, but all other planes assessed were within normal limits.

Isometric knee strength. Knee extensor and flexor strength were assessed isometrically at postoperative months 2 and 8. Isometric test results (Tab. 7) revealed improvement in knee extensor and knee flexor strength over time after surgery. At 8 months, there was only a 20.3% deficit in quadriceps femoris muscle strength compared with a 36.6% deficit at 2 months. The knee flexor peak torque deficit was reduced from 27.3% to 13.0%.

Discussion and Conclusion

Femoral fractures heal reliably following intramedullary nailing.[11] Impairments and functional limitations, however, often persist beyond 1 year after surgery, limiting the patient's ability to resume activities of daily living, normal gait, or employment.[2,3,11] Butcher et al[40] reported that only 72% of people treated for lower-

Table 6.
Lower-Extremity Kinetics (Internal Moments) of Involved Limb Versus Values for Normative Sample at Various Postoperative Times

	2 mo PO		8 mo PO	
Parameter[a]	Involved Limb	Normative Sample	Involved Limb	Normative Sample
Hip (N·m/kg)				
Peak abduction (IS)	0.410	0.681	0.595	0.695
Peak abduction (TSt)	0.595	0.856	0.549	0.856
Knee peak extention (N·m/kg)	−0.084	0.317	0.018	0.317

[a] PO=postoperative, IS=initial stance, TSt=terminal stance.

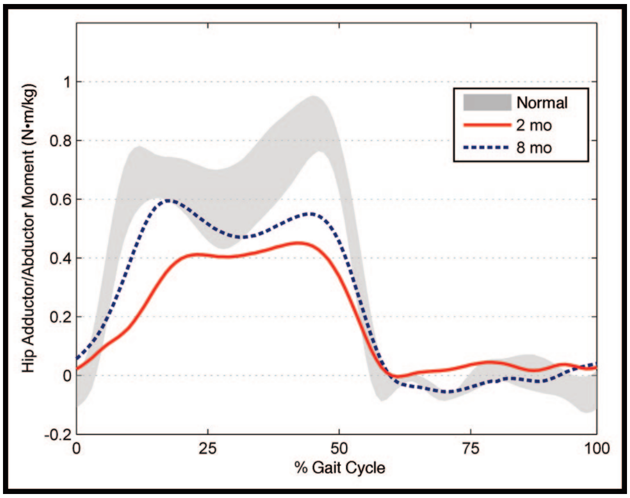

Figure 2.
Coronal-plane hip kinetics, in internal moments (newton-meter per kilogram), during gait at 2 months and 8 months after surgery. The shaded area represents the normal database value (±1 SD). Positive values indicate internal abductor moment, negative values indicate internal adductor moment.

extremity fractures at level I trauma facilities were able to return to work at 12 months after injury and that only 82% were able to return to work at 30 months after injury; these results indicated that after 1 year, the chances of returning to work declined. Although the authors[40] reported that all measurements of impairments were obtained by physical therapists, no standard rehabilitation program was described.

Considering that the chances of returning to work decline after 1 year following surgery for lower-extremity fracture trauma,[40] the goal of medical and therapeutic management should be to promote rapid and safe return to function in the hope of minimizing disability. The implementation of programs that promote early and aggressive weight bearing and rehabilitation may better address functional impairments and minimize disability following femoral fractures with intramedullary nailing. Inadequate evidence exists, however, to substantiate this concept.

Previously reported functional limitations that impaired the outcome of patients following femoral fractures included hip abductor weakness, quadriceps femoris muscle weakness, and anterior knee pain. These impairments individually or collectively can contribute to an altered gait pattern. Hip abductor weakness is a common impairment following intramedullary nailing of a femoral fracture.[2,4,5,41,42] Bain et al[2] described significant hip abductor weakness of 10% to 20% as long as 49 months after surgery; however, even though the authors attributed this deficit to insufficient rehabilitation, they neglected to report the rehabilitation program used. Conversely, our patient achieved good hip abductor strength, as assessed with manual muscle testing and hip abductor moments measured with computerized motion analysis, at postoperative month 8.

Ostrum et al[5] reported a Trendelenburg gait in 14% of their patients following intramedullary nailing. Again, the authors did not report the rehabilitation protocol used after surgery. At postoperative month 2, our patient had deficits in the coronal-plane gait mechanics at the hip. Kinetically, there is typically a biphasic hip abductor moment pattern during the stance phase of gait, with peaks both at initial stance (peak 1) and during terminal stance (peak 2) that allow for frontal-plane stability throughout stance. Our patient did not demonstrate this typical biphasic pattern at 2 months (Fig. 3); however, a more normal kinematic pattern was demonstrated at 8 months, and no Trendelenburg gait pattern was observed. In addition, the patient demonstrated more normal coronal-plane hip kinematics at postoperative month 8, whereas more abnormal motion was present at postoperative month 2 (Fig. 1).

Quadriceps femoris muscle weakness resulting in altered gait mechanics is reported commonly in patients with femoral fractures.[3,7,16] These deficits often limit return to function for patients following intramedullary nailing of a femoral fracture. Significant deficits in quadriceps femoris muscle torque of 10% to 20% are present for up to 44 months after surgery. Inadequate rehabilitation may be a contributing factor to the observed deficits; however, rehabilitation protocols usually are not reported, and thus determination of the contributions of rehabilitation cannot be made. In this case, knee extensor strength was assessed statically with manual muscle testing and isometric dynamometry and dynamically with kinetic analysis during gait. At postoperative month 2, our patient had normal knee extensor manual muscle test results; however, he demonstrated deficits in isomet-

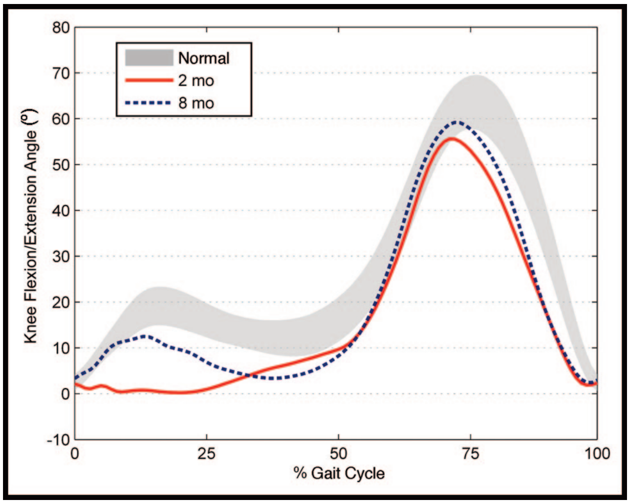

Figure 3.
Sagittal-plane knee kinematics (degrees) during gait at 2 months and 8 months after surgery. The shaded area represents the normal database value (±1 SD). Positive values indicate flexion, negative values indicate extension.

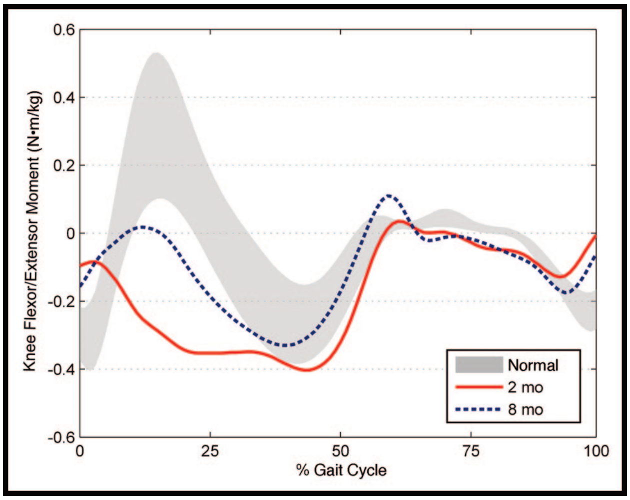

Figure 4.
Sagittal-plane knee kinetics, in internal moments (newton-meter per kilogram), during gait at 2 months and 8 months after surgery. The shaded area represents the normal database value (±1 SD). Positive values indicate internal extensor moment, negative values indicate internal flexor moment.

ric knee extensor torque. Isometric torque values improved at the 8-month assessment, although a 20% deficit remained. The gait results paralleled the isometric torque improvement. Our patient's outcomes reasonably parallel results reported in previous studies; however, our patient's deficits were present at postoperative month 8 compared with up to 44 months in the earlier literature. If the measured improvements parallel the improvements in patient-reported outcomes, which resolved as early as postoperative month 12, we could postulate that the observed deficits would resolve at a time point significantly earlier than those reported in earlier literature. However, the patient was not tested at later time points; therefore, we cannot confirm this hypothesis.

The kinematic findings at 2 months indicated a "quadriceps avoidance" gait pattern[39] that may be attributable to quadriceps femoris muscle weakness and an inability of the patient to eccentrically control his weight during initial stance. The patient may have kept the knee extended to stabilize it with static (bony or ligamentous) structures rather than use the quadriceps femoris musculature to stabilize the joint. The kinetic data at 2 months also were characteristic of a quadriceps avoidance gait pattern. During the loading response phase in subjects without impairments, there is typically an internal knee extensor moment indicating quadriceps femoris muscle activity, which holds the body in an upright posture.[30] However, in this case, because of the extended position of the knee and the patient's lack of quadriceps femoris muscle control, an internal knee flexor moment actually was observed. The knee extensor moment was improved at 8 months but continued to be severely reduced, and the patient still demonstrated a gait outside the normal range, despite the improvement in quadriceps femoris muscle torque (Tab. 5, Fig. 4). On the basis of these findings, additional gait retraining would be indicated in an attempt to normalize the gait pattern and to develop quadriceps femoris muscle strength during the initial phases of the gait cycle to facilitate normal knee kinematics.

The variation in knee extensor strength in this case highlights some of the limitations of manual muscle testing and isometric strength testing during assessments of a patient's functional status. At postoperative month 2, the patient had a normal knee extensor manual muscle test result, despite having a 37% isometric knee extensor deficit. Furthermore, at postoperative month 8, the patient had only a 20% knee extensor torque deficit but continued to have a peak knee extensor torque deficit during the loading response of gait in excess of 94%. This disparity among various methods of assessing knee extensor torque supports the need to evaluate a patient's strength during activities similar to those to which the patient desires to return. However, clinicians may not have the ability to assess joint kinetics during functional tasks because of limitations in equipment. Therefore, future studies are needed to validate better assessment tools in order to determine functional strength and a patient's ability to return to higher-level functional activities.

Despite the patient's quadriceps femoris muscle weakness with a low-level functional task such as walking, he returned to work as a manual laborer. It could be hypothesized that the patient learned a coping strategy

Table 7.
Isometric Knee Extension or Flexion Strength at Various Popstoperative (PO) Times

	2 mo PO		8 mo PO	
Parameter	Involved Limb	Uninvolved Limb	Involved Limb	Uninvolved Limb
Knee extension peak torque (ft-lb)	86.5	136.5	132.3	165.9
Knee flexion peak torque (ft-lb)	43.4	59.7	70.1	80.6

to allow him to function with higher-level tasks required at the workplace; however, we did not examine these variables. Future studies are needed to investigate what coping strategies typically are implemented by patients after surgical management of femoral fractures and whether these new patterns of movement may be detrimental to the patient.

Despite the residual weakness and altered gait pattern, an important functional variable that improved from the 2-month gait assessment to the 8-month gait assessment was self-selected gait speed. The patient improved from 0.8 m/s to 1.0 m/s, which begins to approach a more normal gait speed of 1.2 m/s to 1.3 m/s, as reported by Perry.[30]

Improvements as measured with the SF-MFAS were substantial. The most noticeable improvements from 3 months to 12 months were in the patient's ability to bend the knee and kneel, ease of walking, participation in heavy housework, and ability to participate in his normal occupation. Although the decreased ability to bend the knee and kneel could be related to the lack of knee flexion measured at postoperative week 8 (130°) compared with the final knee flexion of 148 degrees, the other parameters that were deficient likely were related to residual impairments in strength at the time of testing. Most notable was weakness in knee extensor and hip abductor strength. The improvement in these impairments during the final phase of rehabilitation suggests the importance of this phase. The focus of phase III was strength acquisition because the patient was bearing full weight and was able participate in a wide spectrum of both weight-bearing and non–weight-bearing activities that may have challenged him to improve his strength. The patient's improved strength in this phase appears to relate to his improved perception of function. At the 2-year follow-up, the only residual deficit compared with findings at prerehabilitation testing was a little difficulty walking without a limp. The patient's report of a little difficulty with feeling tired had returned to baseline, as he reported the same status before surgery. Therefore, the only deficit at 2 years after surgery was walking with a limp.

This patient attended 35 physical therapy visits (5 inpatient visits and 30 outpatient visits) over the course of the first 4 months after surgery. The *Guide to Physical Therapist Practice*[43] recommends between 6 and 70 treatments for the management of impaired joint mobility, motor function, muscle performance, and range of motion associated with bony or soft tissue surgery. This case falls within the *Guide to Physical Therapist Practice*'s recommendation for the number of visits. Several factors necessitated the 35 visits. First was the potential complication of lack of knee flexion range of motion. At postoperative week 4, at the conclusion of phase I, the patient had 110 degrees of knee flexion. Considering the prevalence of heterotopic ossification in the quadriceps femoris muscle region following this injury and surgical procedure,[44,45] the health care team was concerned that knee flexion was not progressing as quickly as preferred. Therefore, the patient was seen for additional visits in phase II to facilitate increased knee flexion range of motion, which was achieved.

Second, the patient's occupation was that of a manual laborer, a physically demanding occupation. Thus, his return-to-work goal required a high level of functional ability. The patient required 35 visits to be discharged and return to work. Conversely, an individual with lower-level occupational needs may have been discharged from physical therapy earlier, with fewer visits. The patient was able to return to work as a manual laborer at full duty without limitations at 6 months after surgery. An earlier report of the ability to return to work following intramedullary nailing of femoral fractures documented a mean return-to-work date of 6 months after surgery, with a range of 4 to 20 months.[19] The authors, however, did not report their patients' occupations or levels of physical ability necessary to return to work. Considering that our patient was able to return to an occupation that required a high level of functional abilities, we hypothesize that a cohort of patients following a similar program after femoral shaft fractures would be able to return to less demanding occupations in a shorter time, with fewer physical therapy visits. Therefore, the 35 visits with return to work at 6 months may represent the high end of the range, with the anticipated mean being lower.

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