A Case of Peroneal Neuropathy– Induced Footdrop

Correlated and Compensatory Lower-Extremity Function

Tracey C. Vlahovic, BS*
Carla E. Ribeiro, BS, BA*
Bradley M. Lamm, BS*
James A. Denmark, BA, MBA*

Robert G. Walters, BA*
Todd Talbert, BS*
Sharada Penugonda, BS*
James A. Furmato, MS, DPM†

David J. Brower, BA‡
John McMahon, BA§
Safia Bhimji, MS||
Howard J. Hillstrom, PhD¶

This article reports on the case of a man with peroneal neuropathy–induced footdrop who was seen at the authors' institution 3 years after open reduction and internal fixation of a proximal fibular fracture and a distal, spiral, oblique tibial fracture of the right leg. A comprehensive gait analysis was conducted. A significant footdrop in gait resulted in a "reverse check mark" center-of-pressure pattern, an increased transverse-plane rotation of the foot, and excessive knee and hip flexion in the sagittal plane. These objective findings documented significant dysfunction within the involved lower extremity; in addition, aberrant biomechanics were observed in structures other than the site of initial injury within both limbs. (J Am Podiatr Med Assoc 90(8): 411-420, 2000)

The common peroneal nerve is predisposed to injury owing to its anatomical location at the fibular neck. One of the mechanisms of peroneal nerve injury results from a proximal fibular fracture. Perrin and Labry¹ reported that fractures of the fibular neck

*Submitted during third year, Temple University School of Podiatric Medicine, Philadelphia, PA.

†Submitted during graduate studies, School of Biomedical Engineering, Science and Health Systems, Drexel University, Philadelphia, PA.

‡Submitted during third year, Temple University School of Podiatric Medicine, and graduate studies, School of Biomedical Engineering, Science and Health Systems, Drexel University, Philadelphia, PA.

§Submitted during fourth year, Temple University School of Podiatric Medicine, Philadelphia, PA.

||Chief Engineer, Gait Study Center, Temple University School of Podiatric Medicine, Philadelphia, PA.

¶Director, Gait Study Center, and Associate Professor, Department of Orthopedics and Medicine and Department of Community Health and Aging, Temple University School of Podiatric Medicine, Philadelphia, PA; Visiting Assistant Research Professor, School of Biomedical Engineering, Science and Health Systems, Drexel University, Philadelphia, PA. *Mailing address:* Temple University School of Podiatric Medicine, Eighth at Race St, Philadelphia, PA 19107.

commonly lead to severe peroneal nerve lesions. In the cases reported on by Platt,² fracture of the fibular styloid process also led to peroneal nerve paralysis. In general, proximal fibular fractures (Maisonneuve fractures) are associated with pronation-eversion ankle injuries. These fractures are not typically treated with open reduction because of the risk of iatrogenic damage to the common peroneal nerve.³

Alternatively, peroneal nerve damage may be attributed to external compression. Stuart et al⁴ reported the following causes of compression-related injuries: habitual cross-legged sitting, pressure on the lateral aspect of the leg during operative procedures, compression in the anterior compartment, swelling following a fracture of the tibia, and pressure from casts applied to treat lower-extremity fractures. In addition, Jones⁵ reported findings of peroneal neuropathy after casting of a femoral fracture.

This case study was undertaken to determine the primary foot and ankle dysfunction and correlated and compensatory biomechanics of the involved and uninvolved lower limbs following a peroneal nerve injury.

Case Report

A 38-year-old man presented to the Gait Study Center at the Temple University School of Podiatric Medicine in Philadelphia with joint pain in his right lower extremity, the result of fracturing his right tibia and fibula 3 years earlier following a fall on an icy sidewalk. At the time of the injury, the patient was evaluated and treated for a proximal fibular fracture and a distal, spiral, oblique tibial fracture of the right leg. Significant anterior displacement of the distal tibia was noted on conventional radiographs (Fig. 1A). The patient was admitted to a hospital, where it was determined that both dorsalis pedis and posterior tibial pulses were absent but normal capillary filling time was present. Traction was applied to the right leg, which restored arterial supply. An open reduction and internal fixation of the tibia, using an interlocking intramedullary nail, was performed (Fig. 1B). The patient was still experiencing numbness and motor-function deficits in the right foot 1 year after the injury and was referred to a physiatrist for evaluation of the residual neuropathy and treatment of the footdrop. A diminished nerve-conduction velocity of the common peroneal nerve (37.3 m/s measured at the fibular head) was recorded. The diagnosis was partial right peroneal neuropathy due to trauma. Three years after the injury, a significant footdrop deformity remained and the patient was referred to the Gait Study Center at the Temple University School of Podiatric Medicine.

When the patient presented to the Gait Study Center, a thorough patient history was obtained. Preoperative, intraoperative, and postoperative radiographs

were reviewed. A comprehensive lower-extremity clinical biomechanical examination was conducted that consisted of five parts: joint range of motion, manual muscle testing, lower-extremity alignment (open kinetic chain), postural alignment (closed kinetic chain), and neurologic screening. The architecture or foot type was determined, overall appearance of the feet and toes (eg, contractures, gross osseous deformities) was noted, and deep tendon reflexes were evaluated. An objective gait analysis was performed, which included qualitative slow-motion video; plantar pressure parameters, measured with the Musgrave Footprint system (Musgrave Systems Ltd, Wrexham, North Wales); three-dimensional (3-D) kinematic and kinetic parameters, measured by the Vicon 370 motion-analysis system (Oxford Metrics Ltd, Oxford, England) and Kistler force plates (Kistler Instrumente AG, Winterthur, Switzerland), respectively; temporal and distance foot-fall parameters, measured with the instrumented GaitMat II (EQ, Inc, Chalfont, Pennsylvania); and lower-extremity muscle-contraction dynamics, assessed with the Instech electromyography system (Instech Laboratories, Inc, Plymouth Meeting, Pennsylvania).

Materials and Methods

All gait data were collected in the barefoot condition. Plantar pressure measurements were made using the Musgrave Footprint system. Vertical force beneath the foot was recorded from a subset of the 2,048 sensors within each plate that were loaded during the stance phase. Because pressure is defined as the vertical force per unit area, and the area of each sensor

Figure 1. A, Radiograph of distal right tibia. B, Radiograph following open reduction and internal fixation of tibial fracture.

is known to be 5×5 mm, or 0.25 cm^2 , the pressures may be quantified. Pressure magnitudes were recorded from 0 to 15 kg/cm^2 during relaxed postural stance (approximately 6-Hz sampling rate) and during comfortable-cadence locomotion (approximately 28-Hz sampling rate bilaterally). Results were displayed graphically using a color code to represent the pressure magnitudes. The locations of the average pressures at each interval of time formed the center-of-pressure curve, which was overlaid on the maximum pressure throughout the stance phase plot.

The following parameters were quantified from the pressure measurements: foot angle in the transverse plane, center-of-pressure excursion index,⁶ magnitude of peak plantar pressure, location of peak plantar pressure, peak vertical forces, and the temporal sequence of loading (contact, midstance, and propulsion) expressed as a percentage of the stance phase.

For the dynamic measurements, the patient was instructed to walk in a linear path at a comfortable cadence over the Musgrave Footprint pressure plates. The patient's average velocity or speed was recorded using a digital timer that was started and stopped when he interrupted two photoelectric beams placed 4 m apart. For postural stabilograms, the patient stood quietly with his weight evenly distributed and his arms at his sides for 10 seconds. The postural center-of-pressure excursion in healthy individuals is typically less than 1 cm in radius and located in the posterior third of the foot corresponding to the body's vertical projection of the center of gravity (which is 2 cm anterior from the second sacral vertebra). The location of the postural center-of-pressure excursion with respect to each footprint is indicative of overall body alignment and is sensitive to malalignments such as limb-length discrepancy.

The five-camera, 120-Hz Vicon 370 motion-analysis system was used to study the patient's 3-D kinematics and kinetics. Thirteen passive reflective markers were placed on the patient's lower extremities using a modified Helen Hayes marker set to obtain bilateral data on the kinematics of the pelvis, hip, knee, and ankle.⁷ In addition, the 3-D ground-reaction forces were measured synchronously with the kinematics with Kistler force plates.

Slow-motion video was performed in the frontal and sagittal planes to provide a qualitative assessment of the patient's gait patterns and to document trial validity.

The GaitMat II was used to perform real-time quantitative analysis of the temporal and distance foot-fall parameters during gait.⁸ It consisted of an instrumented walkway and an IBM-compatible 66-MHz

486 microcomputer. The GaitMat II measured 12 feet in length, 40 inches in width, and 1 inch in depth and contained 9,728 switches arranged in 38 rows. When the patient traversed the mat, the switches were transiently closed and reopened as his foot broke contact with the ground. The status of all switches was constantly monitored by the computer, which tabulated step length, stride length, stance time, and swing time.

Dynamic electromyography was used to measure the agonist and antagonist activity from the tibialis anterior and medial gastrocnemius muscles bilaterally. An Iomed (Salt Lake City, Utah) electromyographic preamplifier with a pair of stainless-steel electrodes (35-mm interelectrode spacing) was affixed to the epidermis overlying the aforementioned muscles with double-sided adhesive tape. Electrolyte gel was backfilled into 1-cm-diameter wells within the adhesive tape to transduce the electromyogram signal to the electrodes. Each electromyogram electrode/preamplifier assembly provided a gain of 300 and a 0- to 10-kHz bandwidth. The amplifier system then further amplified each channel by a factor of 100. The raw electromyogram signals were processed by taking the absolute value and low-pass filtering (first order) with a 50-ms time constant. This yielded a smoother signal, which was indicative of the contraction level. The resulting electromyogram signals were graphed in amplitude (volts) *versus* time (seconds).

Findings

Clinical Examination

The clinical examination revealed that the patient's vascular status was intact. Dermatologic examination findings included hyperkeratotic lesions beneath the first, second, third, and fifth metatarsal heads bilaterally. Neurologic evaluation using a Semmes-Weinstein monofilament was conducted as a sensory screen. The patient perceived the 10-g monofilament on the plantar and dorsal aspects of both feet, with the exception of the right third, fourth, and fifth metatarsal head regions. The deep tendon reflexes were within normal limits at both the patellar and Achilles tendons. Manual muscle testing of the thigh and hip region was within normal limits bilaterally. However, the tibialis anterior, tibialis posterior, peroneus longus, flexor hallucis longus, gastrocnemius, and digital extensor muscles were weaker on the right side and classified as marginally functional ($\leq 3/5$).

Nonweightbearing clinical biomechanical examination caused the authors to suspect a limb-length

discrepancy, as measurement from the anterosuperior iliac spine to the medial malleolus revealed that the right side was longer by 1 cm. The midcalf circumference was 38 cm on the right side and 39 cm on the left side, and the thigh circumference was symmetrical. There was insufficient passive dorsiflexion of the right ankle with the knee straight (-3°) or flexed (3°). Subtalar joint range of motion was limited. The forefoot-to-rearfoot relationship was in varus bilaterally (5° on the right and 4° on the left). A cocked-up hallux and hammer toes of the lesser digits were noted on the right foot. A mild anterior cavus deformity was noted when each foot was loaded; the cavus deformity was reducible on the left side but not on the right side.

The weightbearing examination revealed hyperextension of the left knee and flexion of the right knee. The resting calcaneal stance positions were everted bilaterally (3° on the right and 4° on the left). Additionally, the right foot exhibited excessive abduction.

Objective Gait Analysis

Qualitative slow-motion video analysis revealed excessive knee and hip flexion during the midswing phase of the involved limb. The contralateral limb had normal angular excursions and no difficulty in limb clearance during midswing. The digits of the right foot were extended in the absence of ankle dorsiflexion and remained so until after the beginning of stance. The right foot adopted a varus and plantarflexed position in late swing, which imposed initial contact at the fifth metatarsal head region (Fig. 2). An excessive external transverse plane foot angle was observed during the midstance phase of the right foot. Overall, a significant footdrop and ankle equinus were present. The patient had a robotic gait pattern and compensated for the footdrop predominantly in the sagittal plane. The upper body had an anterior tilt with respect to the lower body, which limited the posterior excursion of reciprocal arm swing bilaterally. The objective gait analysis was conducted to confirm or refute these observations.

The average velocity or speed of ambulation was determined using the Musgrave Footprint system and was determined to be within normal limits (ie, 1 to 1.4 m/s). Table 1 shows the Musgrave Footprint objective data. Center-of-pressure excursion index values of less than 15% were considered pronatory.⁶ The right foot pronated more than the left (6.9% *versus* 12.8%) during comfortable-cadence locomotion. Transverse-plane foot angles in healthy individuals have been reported by various authors to range from 0° to 10° . The right foot in the current case showed

an abduction angle of 22.6° . The average temporal sequence of loading for contact, midstance, and propulsion should be 15% to 20%, 40% to 45%, and 35% to 40% of the stance phase, respectively.⁶ The left foot exhibited an approximately normal temporal sequence of loading (14.8%, 41.7%, and 43.5%, respectively); however, the right foot spent a greater amount of time in midstance (54.7%) because of the lack of heel strike. Peak plantar pressures were below 10 kg/cm² and were not considered pathologic.⁶

As shown in the the postural stabilogram in Figure 3, the center of pressure was slightly anterior and right-justified, and the right foot was greatly abducted with respect to the left.

The maximum plantar pressures throughout the stance phase are shown in Figure 4. The black line representing the center of pressure normally begins at the approximate bisection of the calcaneus and progresses in a concave fashion throughout the stance phase, exiting from the first interspace at toe-off. Mild hyperpronation was observed because of the medially deviated (ie, less concave) center-of-pressure patterns bilaterally. Most notably, the patient's plantar pressure pattern on the right side originated beneath the fifth metatarsal head, rocked back into the midfoot region, and then traveled forward into the first interspace. This "reverse check mark" center-of-pressure pattern was highly aberrant and was consistent with a footdrop deformity.

Using the Vicon 3-D kinematic system, data from four trials were collected and averaged for the right and left limbs. Figure 5 shows the average left, right, and normal angular excursions, as described by Kadaba et al.⁷ All joint rotations are expressed in degrees *versus* percentage of the gait cycle.

Figure 5A shows that, during midswing, the involved limb had approximately 8° more hip flexion as compared with the contralateral limb and normal values. Excessive knee flexion at heel strike was exhibited bilaterally for the first half of the stance phase, as shown in Figure 5B. Only the involved limb demonstrated excessive knee flexion in the swing phase. At heel strike, shown in Figure 5C, the patient manifested approximately 15° of plantarflexion of the right foot while the left foot exhibited normal dorsiflexion. In the swing phase, the right foot remained plantarflexed, which eliminated the possibility of a normal heel-toe gait pattern at the next heel strike. Figure 5D shows that the involved foot was approximately 5° more externally rotated than the normal value in midstance. The uninvolved limb was 8° more internally rotated.

Figure 6 depicts the ground-reaction forces scaled to body weight as measured by the Kistler force

Figure 2. Sagittal-plane (A) and frontal-plane (B) views of patient in the late swing phase of gait. The initial contact with the ground is beneath the fifth metatarsal head.

Table 1. Musgrave Footprint System Quantitative Foot-Function Parameters

Parameter	Mean (SD) Barefoot Values	
	Left (n = 9)	Right (n = 6)
Center-of-pressure excursion index (%)	12.8 (3.6)	6.9 (3.4)
Foot angle (transverse plane) (°)	3.7 (3.0)	22.6 (1.3)
Contact (percentage of stance phase)	14.8 (1.9)	0 (0)
Midstance (percentage of stance phase)	41.7 (3.3)	54.7 (7.9)
Propulsion (percentage of stance phase)	43.5 (3.5)	45.3 (7.9)
Peak pressure (kg/cm ²)	8.1 (0.6)	6.4 (1.0)

plates. Regarding the vertical component of the ground-reaction force vector, healthy individuals typically ambulate with symmetrical peak forces in contact and propulsion that appear graphically like a double-humped camel. Note that the second peak of the patient's forces was diminished, which is indicative of apropulsive gait. In general, the ground-reaction forces of the patient's left and right limbs were asymmetrical.

Figure 7 represents the net internal joint moments (or kinetics) about joints in the lower extremity. The

complete kinetic solution includes moments about the sagittal, transverse, and frontal planes, which were generally asymmetrical. The right knee had an excessive flexion moment in the contact phase and the left knee had an excessive extension moment in midstance. The former condition assisted with the additional knee flexion required for limb clearance and the latter condition undoubtedly stabilized the left lower extremity. In the stance phase, the involved ankle demonstrated a lack of dorsiflexion moment as compared with the uninvolved side and normal values.

The foot-fall parameters, as measured from the GaitMat II, demonstrated asymmetry in step length (Table 2).

The uninvolved (left) and involved (right) raw tibialis anterior muscle electromyogram signals are shown in Figure 8. The involved limb demonstrated a decreased electromyographic activity level at heel strike and during the swing phase as compared with the uninvolved limb.

Discussion

This quantitative gait analysis provided objective data to differentiate the biomechanics of a peroneal neuropathy-affected limb from those of an uninvolved limb. Compensatory biomechanics in the uninvolved limb were expected. The objective gait analysis

Figure 3. Postural stabilogram depicting the maximum plantar pressure (in kilograms per square centimeter) and center of load during relaxed standing. On the left side of the stabilogram, the patient's eyes are open, and on the right side the patient's eyes are closed. Note that the center of pressure is slightly anterior and right-justified in both cases. For the closed-eyes trial, there is slightly more sway. Note also that θ represents the angle between the foot bisection and the vertical line parallel to the vertical border of the plate.

Figure 4. Maximum pressure throughout the stance phase of gait, showing center-of-pressure excursion index (CPEI) and the angle of gait. The color-coded pressure distribution (in kilograms per square centimeter) is depicted. $CPEI = (CPE/FW) \cdot 100$, where CPE = center-of-pressure excursion (deviation between the center-of-pressure reference line and the center of pressure) and FW = foot width at anterior trisection.

Figure 5. Average joint-rotation angles. (See text for details.) Positive and negative values are flexion and extension, dorsiflexion and plantarflexion, and internal and external rotation, respectively. The arrows indicate large deviations from normal data.

helped to define this patient's functional limitations or disability while providing a baseline against which to evaluate future treatments.

Qualitative slow-motion video analysis showed evidence of right-foot plantarflexion and inversion before the initial contact near the head of the fifth metatarsal. The patient presented with a left shoulder drop, a left pelvic tilt, and an anteriorly tilted upper body in both posture and locomotion. Furthermore, clinical examination made the investigators suspect that this patient had a 1-cm limb-length discrepancy (right greater than left). These observations were corroborated by the postural stabilogram study,

which documented a slightly anterior and right-justified center of pressure.

The pedobarographic finding of a "reverse check mark" center-of-pressure pattern in comfortable-cadence locomotion beneath the right foot was typical of footdrop gait. The Musgrave Footprint system and the GaitMat II indicated a normal temporal sequence of loading on the left side but an abnormal pattern on the right side. The contact period was essentially eliminated on the affected side because of footdrop, which promoted immediate forefoot loading. The abducted transverse-plane foot angle and pronatory center-of-pressure excursion index value resulted in

Figure 6. The average 3-D ground-reaction force components normalized to body weight in the barefoot condition. (See text for details.) Vertical rules indicate the end of the stance phase.

Figure 7. Average joint net moments in the barefoot condition. Positive and negative values are extension and flexion and plantarflexion and dorsiflexion, respectively. The arrows indicate large deviations from normal data. Vertical rules indicate the end of the stance phase.

Table 2. Foot-Fall Parameters from the GaitMat II Program

Parameter	Mean Barefoot Values	
	Left (n = 5)	Right (n = 5)
Step length (m)	0.6	0.7
Stride length (m)	1.2	1.2
Step time (s)	0.5	0.5
Swing time (s)	0.4	0.4
Stance time (s)	0.6	0.6
Double-support time (s)	0.1	0.1
Velocity (m/s)	1.3	

a clinically aporulsive gait. This aporulsive gait pattern also correlated with the vertical force component of the ground-reaction force of the involved limb.

Increased hip and knee flexion with an externally rotated foot position was noted in the affected limb during the swing phase while the contralateral limb demonstrated excessive extension moments about the knee. In stance, the affected limb compensated for the lack of dorsiflexion by pronation and increased knee flexion. The moment about the in-

volved ankle joint lacked a positive (dorsiflexion) value during the contact phase. This aberration was due to the fact that the ground-reaction force vector, and hence ankle moment arm, was never physically behind the transmalleolar axis.

Compensation for the footdrop resulted in abnormal joint motion at the hips, knees, and ankles throughout the entire gait cycle. Similarly, the joint moments were altered at the affected ankle as well as other joints throughout the kinetic chain.

Conclusion

Objective gait analysis in conjunction with a thorough clinical and biomechanical examination was used to document the correlated and compensatory motions associated with a peroneal neuropathy-induced footdrop gait pattern. Significant dysfunction was measured within the foot and ankle of the affected limb. In addition, aberrant biomechanics were observed in structures other than the site of initial injury within both the involved and uninvolved limbs. In the investigation of complex foot and ankle pathologies, gait analysis can provide invaluable insight into the pathomechanics of the primary injury as well as the effect of injury on proximal and distal structures.

Figure 8. Superimposition of tibialis anterior muscle electromyogram signal and vertical force for the (A) uninvolved and (B) involved limbs. (Note: Vertical force is scaled at 300 N/V.)

References

1. PERRIN E, LABRY R: La fracture de l'apophyse, styloïde du péroné. *Rev Orthop* **13**: 324, 1926.
2. PLATT H: On the peripheral nerve complications of certain fractures. *J Bone Joint Surg* **10**: 403, 1928.
3. DOWNEY MS, MALAY DS, RUCH JA: "Ankle Fractures," in *Comprehensive Textbook of Foot Surgery*, 2nd Ed, ed by ED McGlamry, AS Banks, MS Downey, p 1614, Williams & Wilkins, Baltimore, 1992.
4. STUART JD, MORGAN RF, PERSING JA: Nerve compression syndromes of the lower extremity. *Am Fam Physician* **40**: 101, 1989.
5. JONES HR JR: Compressive neuropathy in childhood: a report of 14 cases. *Muscle Nerve* **9**: 720, 1986.
6. SONG J, HILLSTROM HJ, SECORD D, ET AL: Foot type biomechanics: comparison of planus and rectus foot types. *JAPMA* **86**: 16, 1996.
7. KADABA MP, RAMAKRISHNAN HK, WOOTTEN ME: Measurement of lower extremity kinematics during level walking. *J Orthop Res* **8**: 383, 1990.
8. WALSH JP: "Foot Fall Measurement Technology," in *Gait Analysis: Theory and Application*, ed by RL Craik, CA Oatis, p 125, Mosby-Year Book, St Louis, 1995.

Additional References

- FISHER MA: "Peripheral Neuropathy," in *Neurology for the Non-neurologist*, ed by WJ Weiner, CJ Goetz, JB Lippincott, Philadelphia, 1994.
- HILLSTROM HJ, TRIOLO RJ: "EMG Methodology," in *Gait Analysis: Theory and Application*, ed by RL Craik, CA Oatis, p 271, Mosby-Year Book, St Louis, 1995.
- MEALS RA: Peroneal nerve palsy complicating ankle sprain. *J Bone Joint Surg Am* **59**: 966, 1977.
- SHIN OJ: "Normal Values for Common Nerve Conduction Tests," in *Clinical Electromyography: Nerve Conduction Studies*, p 93, University Park Press, Baltimore, 1984.
- SHIN OJ: "Traumatic Peripheral Nerve Injuries," in *Clinical Electromyography: Nerve Conduction Studies*, p 481, University Park Press, Baltimore, 1984.
- WHITE J: The results of traction injuries to the common peroneal nerve. *J Bone Joint Surg Br* **50**: 346, 1968.
- WINTER DA: *The Biomechanics and Motor Control of Human Gait: Normal, Elderly, and Pathological*, 2nd Ed, University of Waterloo Press, Waterloo, Ontario, Canada, 1991.