Walking Gait Before and After Chiropractic Care Following Fifth Metatarsal Fractures: A Single Case Kinetic and Kinematic Study

Brent S. Russell, MS, DC, Kathryn T. Hoiriis, DC, and Ronald S. Hosek, PhD, DC, MPH

ABSTRACT

Objectives: The purpose of this report is to describe the kinetic and kinematic analysis of walking gait following healed left proximal fifth metatarsal fractures.

Clinical Features: A 62-year-old female presented at a chiropractic clinic with concerns that recent metatarsal fractures had not fully resolved and reported abnormal gait due to pain and several weeks use of a “walking boot.” The patient’s walking gait was evaluated with a force-sensor treadmill and an inertial measurement unit motion capture system. Recordings were made before, at midpoint, and post-chiropractic care (11 visits total). Data were analyzed for spatio-temporal gait parameters, vertical ground reaction forces, and ranges of motion of the hip, knee, and ankle.

Intervention and Outcome: Pre-care, the patient’s self-rated disability in walking was 50 out of 80 on a Lower Extremity Functional Scale, which improved to 80 out of 80, post-care. Her self-selected preferred walking speed increased, as did step length, cadence, and single support time. Increased symmetry was seen in timing of peak ground reaction forces, stance phase percentages of loading and pre-swing, and ranges of motion for hip and knee flexion and extension.

Conclusions: The patient recovered completely, and the post-injury kinematic and kinetic data allowed for quantification of gait patterns and changes in the clinical environment. (J Chiropr Med 2018;17:106-116)

Key Indexing Terms: Chiropractic; Manipulation, Chiropractic; Gait; Walking Speed; Metatarsal Bones

INTRODUCTION

Foot injuries and alterations in walking gait are some of the concerns brought to chiropractors. The fifth metatarsal is among the more commonly fractured bones of the foot, often either as avulsion or Jones fractures.¹⁻³ Jones fracture occurs at the metaphyseal–diaphyseal junction of the fifth metatarsal, an area with a low blood supply that is prone to prolonged healing or nonunion. Other types can occur in the head, neck, and mid-shaft.¹⁻⁵ Younger patients with metatarsal fractures are more often male, but older patients are more often female.⁶

Associated signs and symptoms include pain, swelling, tenderness, difficulty walking, and bruising. There is considerable variation in management, especially if a Jones fracture is

suspected.^{1,3,4,7-12} Since 1984, Torg et al’s¹³ recommendation of conservative treatment for Jones fractures, with a non-weight bearing cast for a period of 3 to 12 weeks, has been frequently followed.^{5,10,12} In 2017, Brogan et al¹⁴ concluded that all fifth metatarsal fractures can be safely managed with immediate full weight-bearing in an orthotic boot without adverse effects and that often no long-term review is needed. Most experts agree, however, that if the injury involves a displaced bone, multiple breaks, or fails to adequately heal, then surgery may be needed.^{1-3,5,12,15}

Metatarsal fractures might result in alterations of walking. Bauer et al¹⁶ reported gait asymmetry in 11 out of 20 patients with fifth metatarsal fractures, most with no visible gait disorder. Kösters et al¹⁷ reported slower walking associated with multiple metatarsal shaft fractures. Queen et al¹⁸ found that women with a history of metatarsal stress fractures exhibit decreased forefoot forces.

Chiropractic literature describes management of foot and ankle conditions.¹⁹⁻²⁵ However, only 1 chiropractic publication concerns fifth metatarsal fracture, which is only in terms of diagnostic imaging, not condition management.²⁶ The purpose of this report is to describe the kinetic and kinematic investigation of post-injury walking gait of a patient, before and after receiving chiropractic care.

Dr Sid E. Williams Center for Chiropractic Research, Life University, Marietta, Georgia.

Corresponding author: Brent S. Russell, MS, DC, Dr Sid E. Williams Center for Chiropractic Research, Life University, 1269 Barclay Circle, Marietta, GA 30060. Tel.: +1 770 426 2641. (e-mail: brussell@life.edu).

1556-3707

Paper submitted October 27, 2017; in revised form December 11, 2017; accepted February 28, 2018

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<https://doi.org/10.1016/j.jcm.2018.02.002>

CASE STUDY

Patient Characteristics

A 62-year-old female presented to the research center with concerns that recent injuries of her left foot had not fully resolved and reported abnormal gait, due to pain and several weeks use of a “walking boot.” Acute inversion injury and Jones fractures of the proximal fifth metatarsal had occurred twice within 6 months. For both fractures, she received conservative treatment with non-weight-bearing casts for periods of several weeks. At 10 weeks from the onset of the second injury, she was released from care. But, despite residual pain and swelling and the occurrence of the second fracture at the same location as the first, no physical therapy was recommended by the orthopedist.

The patient previously had a hairline fracture of the same fifth metatarsal 40 years earlier and a fracture of the fifth proximal phalanx 5 years earlier. Other medical history included Hashimoto’s Thyroiditis, menopause, psoriasis, and vitamin D insufficiency. Prescription medications included levothyroxine, ergocalciferol, and topical cortisone.

The investigation of the participant’s post-injury kinetic and kinematic data was prospectively planned by the researchers and then approved by the Life University Institutional Review Board. At the patient’s presentation to the research center, the investigators explained the protocols, had the patient sign an informed consent, and asked the patient to complete a Lower Extremity Functional Scale (LEFS) questionnaire.²⁷ According to the LEFS, she scored a 50 out of a possible 80.

Overview of the Human Gait Cycle

“Kinetic” refers to the forces involved in the actions and motions to be discussed; “kinematic” refers to descriptions of the motions themselves.²⁸⁻³⁰ To discuss gait, we start with the right hip flexing forward and the event of the right foot contacting the walking surface (or ground), most

commonly seen as a heel strike, which marks initial contact and the beginning of stance phase (Figs 1A and 2A). As the body moves forward, its center of mass drops slightly, and rapid loading of weight onto the right limb generates a vertical ground reaction force (VGRF) at the point of contact with the ground. Most people will show a sharp increase of force at heel strike (a heel strike transient, Fig 2A).³¹ The moment at which the magnitude of the VGRF reaches its maximum level is noted as the event of peak force 1 (Fig 2B), which can be about 120% of body weight.³⁰ During this loading phase, both feet are in contact with the ground (double limb support or double support). Weight gradually transfers to the advancing right limb until the trailing left foot lifts and enters swing phase, beginning a period of single limb support for the right side (Fig 1B, C, and D). As the left limb swings forward, the body’s center of mass rises slightly, such that VGRFs decrease slightly in mid-stance (Fig 2C), often to approximately 80% of body weight.³⁰ During this time, left knee flexion allows the left foot to clear the floor (Fig 1B and C), and the right ankle moves into dorsiflexion (Fig 1C). As the weight of the body moves over and past the foot below it, the right limb moves to “push-off,” with the ankle actively moving into plantarflexion. This period is marked by a second increase in VGRF, up to the event peak force 2 (Fig 2D). As the left foot ends its swing and contacts the ground again, there is a second period of double support. The left foot begins to receive a transfer of weight (Fig 1E), and the right foot undergoes a gradual “unloading” of force until the event of toe-off. The events are repeated for the left side until the right foot touches again, completing 1 stride.²⁸⁻³⁰

Evaluation

The participant was asked to walk on a treadmill with force sensors under the treadmill belt (zebris Medical GmbH, Isny im Allgäu, Germany; Noraxon USA, Scottsdale, Arizona); available data included VGRF and a number of spatial and temporal gait parameters. The treadmill was started, and she was guided to find her preferred walking

Fig 1. Excerpts from video generated by the myoMOTION software capturing its “skeletal avatar” in various positions within a gait cycle. These are from this case participant’s second post-care assessment. A, Initial contact (heel strike) of the right foot; B, early in mid-stance of the right foot, demonstrating maximum left knee flexion; C, The “legs adjacent” position of mid-stance; D, During “push-off” of the right foot, just before initial contact of the left foot; E, Pre-swing for the right foot, just before toe-off, in the loading phase for the left foot.

Fig 2. A stance-phase force-time curve, typical of human walking, for 5 consecutive steps, superimposed for illustration. Force values in Newtons are marked by the y axis. A, Most people will show a sharp increase of force at heel strike (a “heel strike transient”), during loading response; B, A peak force (“peak force 1”) occurs approximately at the beginning of mid-stance; C, Mid-stance typically has an identifiable minimum force (“valley”); D, A second peak force typically occurs at push-off, shortly before the stance limb enters a swing phase.

speed (PWS).³² She was given a few minutes for warm-up and acclimation before being instructed to walk as “consistently and symmetrically as possible.” Four 2-minute recordings were performed; the patient was allowed to step off of the treadmill for a few moments in between recordings.

Next, 2 additional 30-second walking sessions were recorded at her PWS, using a myoMOTION inertial measurement unit motion capture system (Noraxon USA, Scottsdale, Arizona) at 100 Hz. Seven inertial measurement units were placed over the sacrum, the distal lateral thighs, the distal medial tibias, and the shoe tops, using Velcro straps, double-stick tape, or, in the case of the shoes, a clip-on sensor cradle. System calibration was performed with the participant standing in a standard neutral anatomic position for 30 seconds. This configuration was used to make angular measurements of average end-ranges for the hip (flexion, extension, abduction, adduction, and internal and external rotation); knee flexion and extension; and foot dorsiflexion, plantarflexion, inversion, eversion, abduction, and adduction.

Intervention

Following the pre-care gait assessments, a brief examination that was appropriate for low back and lower

extremity mechanical dysfunction was done: visual inspection of static posture, range of motion, palpation, manual muscle testing, and provocative tests. Chiropractic adjustments were directed toward joints determined to lack normal intersegmental mobility and alignment during static and motion palpation. Adjustments of the lumbar spine, sacroiliac joints, and hips involved a combination of mobilization and high-velocity, low-amplitude thrusts with drop table assistance. Adjustments of the left talocrural and subtalar joints involved mobilization, high-velocity, and low-amplitude. Instrument-assisted adjustments of the left foot (navicular, cuboid, and first and second cuneiforms) were provided by use of an Activator IV instrument (Activator Methods International, Ltd, Phoenix, Arizona). The adjustments were supplemented by transverse massage in some muscles with palpable trigger points or fibrotic areas, including her lateral gastrocnemius, medial hamstring, short head of the biceps femoris, and the plantar region of her left foot.

Beginning immediately after the first gait recording, the participant received 5 sessions of adjustments, averaged about 4 days apart, followed by a second gait recording 17 days after the first; her PWS was determined afresh at that time. The third and final gait recording was 4½ months after the initial assessment, after 6 additional adjustment sessions, approximately 2 weeks apart.

Data Analysis

For spatio-temporal gait parameters, we used mean and standard deviation values reported by the system for clinical use but exported raw data to Excel files for joint angles and VGRFs. For joint angles, simple comparisons were made between pre-care, post-1, and post-2 mean magnitudes, and symmetry was judged by left-right differences in degrees. The magnitudes and timing of VGRF events were analyzed with a custom program written in Visual Basic by the third author (R.S.H.). Symmetry of the VGRF events and spatio-temporal parameter measures was determined with a symmetry index^{33,34}: symmetry index = $2(xR - xL) \times 100 / (xR + xL)$.

Where xR and xL are the values of interest for the left and right sides, the result expresses a ratio of the left-right difference to the left-right average. A symmetry index of 0 indicates perfect symmetry; the greater the absolute value, the greater the asymmetry.^{33,34} Some asymmetry is expected and is normal³⁵⁻³⁷; a level of 5% was set as the minimum for clinical relevance for the present study, similarly to Robinson et al,³³ although Kim and Eng³⁸ used a threshold of 6%.

Findings

During the pre-care gait assessment, the patient’s walking style seemed somewhat cautious. She admitted to being fearful; she was unsure of how much she could do

Table 1. *Unilateral Spatio-temporal Gait Parameters*

	Pre-care	Post-1	Post-2
Velocity, km/h	3.2 (0.1)	5.0 (0.1)	5.1 (0.1)
Cadence, steps/min	109.2 (2.3)	129.1 (2.1)	135.4 (2.0)
Step width, cm	11.7 (1.4)	11.1 (1.8)	9.0 (1.6)
Double support, %	31.3 (1.4)	24.3 (4.0)	22.5 (1.0)

without causing pain, appeared to have limited foot movement and short steps, and took several minutes to work up to the speed that was finally used in the recordings. At the time of the post-1 and post-2 assessments she walked quickly and confidently and, at the time of the post-2 assessment, self-scored an 80 out of a possible 80 on the LEFS questionnaire, indicating no residual disability of lower extremity function.

Magnitudes of Spatio-temporal Parameters

As seen in Table 1, the participant's self-selected walking speed was 3.2 km/h pre-care (2 mph), increasing to just over 5 km/h (3.1 mph) in the later assessments; the increased speed was accompanied by shorter step times, increases in cadence, and longer step lengths, as would be expected.²⁸ Also, post-care, there were increases in single support time and

decreased double support (Table 2), as well as decreased time spent in stance phase and more in swing phase. At her second post-care assessment, her step width (9.0 cm) was narrower than at the previous assessments (11.7 cm and 11.1 cm).

Symmetry of Spatio-temporal Parameters

In Table 2, symmetry index values of just over 7% were seen for loading and pre-swing. These represent left-right inequality of time spent in transitioning weight from the trailing foot to the advancing foot during 2 different periods of stance phase. Both dropped to 0.3% by the final assessment. Asymmetry was negligible, however, for single support, step length, and step time, and for stance phase and swing phase overall.

Vertical Ground Reaction Forces

Table 3 provides mean values for magnitudes and timing of specific VGRF events (peak 1, mid-stance, and peak 2) and may be compared to Fig 3, which illustrates typical force curves for this participant's pre-care and post-care-2 assessments (post-1 curves, omitted for brevity, are similar to post-2). Each graph in Fig 3 shows 5 consecutive, superimposed force curves; these particular stance periods were selected for purposes of illustration because, visually, they closely match the mean values seen in Table 3. The pre-care curves show very little distinction between

Table 2. *Bilateral Spatio-temporal Gait Parameters*

	Phase Percentages of Gait Cycle			Symmetry Indexes, %		
	Pre-care	Post-1	Post-2	Pre-care	Post-1	Post-2
L Single support %	33.9 (1.0)	37.8 (2.1)	38.8 (0.8)	2.3	0.3	0.2
R Single support %	34.7 (1.2)	37.9 (2.2)	38.7 (0.9)			
L Step length, cm	49.0 (2.0)	63.8 (1.7)	62.3 (1.3)	2.6	1.8	3.2
R Step length, cm	47.7 (1.8)	65.0 (1.7)	64.3 (1.0)			
L Step time, sec	0.56 (0.02)	0.46 (0.01)	0.44 (0.01)	3.8	0.1	0.1
R Step time, sec	0.54 (0.02)	0.47 (0.01)	0.44 (0.01)			
L Stance phase %	65.3 (1.1)	62.1 (2.1)	61.3 (0.8)	1.2	0.2	0.1
R Stance phase %	66.1 (1.0)	62.2 (2.0)	61.2 (0.7)			
L Loading %	15.1 (0.9)	12.3 (2.1)	11.2 (0.7)	7.2	1.4	0.3
R Loading %	16.2 (1.1)	12.1 (2.1)	11.3 (0.7)			
L Pre-swing %	16.2 (1.1)	12.1 (2.1)	11.3 (0.7)	7.1	1.3	0.3
R Pre-swing %	15.1 (0.9)	12.3 (2.1)	11.2 (0.7)			
L Swing phase %	34.7 (1.1)	37.9 (2.1)	38.7 (0.8)	2.3	0.3	0.2
R Swing phase %	33.9 (1.0)	37.8 (2.0)	38.8 (0.7)			

L, left; R, right.

Table 3. *VGRF Events*

	Force in Newtons: Means (SD)			Symmetry Index (%), Forces		
	Pre-care	Post-1	Post-2	Pre-care	Post-1	Post-2
L Peak 1	653.9 (17.0)	742.8 (21.6)	703.9 (25.6)	0.4	2.5	3.5
R Peak 1	651.4 (18.3)	724.3 (24.0)	679.9 (28.0)			
L Mid-stance	583.9 (12.9)	523.0 (17.0)	486.3 (18.1)	1.6	3.8	3.4
R Mid-stance	574.4 (12.0)	503.7 (16.6)	470.0 (19.5)			
L Peak 2	619.2 (15.8)	582.0 (27.2)	540.3 (25.2)	1.1	2.0	1.2
R Peak 2	625.9 (15.1)	593.5 (28.1)	546.6 (27.4)			

	Time: Occurrence After Initial Contact (milliseconds)			Symmetry Index (%), Timing		
	Pre-care	Post-1	Post-2	Pre-care	Post-1	Post-2
L Peak 1	220.7 (19.5)	163.5 (11.7)	139.9 (10.2)	8.0	0.8	5.2
R Peak 1	239.2 (22.4)	164.8 (15.7)	147.4 (11.2)			
L Mid-stance	387.0 (41.1)	312.8 (26.7)	279.6 (33.1)	1.7	1.6	0.8
R Mid-stance	393.6 (31.9)	317.9 (21.4)	282.0 (25.1)			
L Peak 2	476.6 (27.0)	424.0 (26.6)	384.2 (22.8)	7.5	3.7	3.2
R Peak 2	513.7 (36.0)	439.9 (15.0)	396.7 (20.7)			

L, left; *R*, right; *SD*, standard deviation; *VGRF*, vertical ground reaction force.

the peak forces and mid-stance, reflecting the participant's slower, cautious walking. The post-2 curves show a more forceful heel strike and loading to peak 1, as compared to pre-care. Asymmetry of the magnitudes of the force events was negligible (Table 3). Also seen in Table 3 are the times at which the force events occurred following initial contact; note that each respective event occurs earlier in the post-assessments, owing to the faster walking speed and shorter step times. The pre-care timings of the peak 1 and peak 2 forces showed asymmetry, with symmetry indexes of 8.0% and 7.5%, respectively, dropping to 5.2% and 3.2% at the post-2 assessment.

Joint Angle Symmetry, Hips and Knees

Typical periods of flexion and extension for the hips and knees are illustrated for a few steps in Fig 4; the greater number of cycles for the post-2 assessments, within equal time periods, reflect the participant's faster walking speed and increased cadence. In considering hip flexion and extension in Table 4 and Fig 4A and C, note that positive values indicate flexion and negative values indicate extension, relative to her neutral calibration posture. Both had high pre-care asymmetry (symmetry indexes of 7.3 and 22.8, respectively); motion of the right hip showed little difference at the post-1 and post-2 assessments, but changes in the left hip resulted in progres-

sively decreased asymmetry. Note that, post-care, the left side hip extension averages were 5.2 and 10.3 degrees; the positive values indicate that the end range of her hip "extension" was often still in flexion. This effect may be due to a slight forward lean she adopted with faster speeds.

For hip abduction and adduction, the negative values indicate that her thighs were usually slightly adducted; however, they were symmetrical. The values for hip external and internal rotation (positive and negative numbers, respectively) were small and symmetrical, and changed little from pre-care to the post-care assessments. Knee flexion and extension also had pre-care asymmetry, which progressively decreased at post-1 and post-2 (Table 4 and Figs 4B and D). Positive values for knee extension indicate that her knees rarely achieved full extension.

Joint Angle Symmetry, Feet and Ankles

In Table 5, the pre-care and post-1 measurements showed the participant to have limited dorsiflexion; the negative left side values indicate the end range of dorsiflexion of the average step was in plantarflexion, relative to her neutral calibration posture. However, the left right differences for dorsiflexion and plantarflexion were small, as were inversion–eversion and abduction–adduction, so we considered them symmetrical.

Fig 3. Typical force curves for this participant's pre-care (A, left and B, right) and post-2 assessments (C, left and D, right). The post-1 curves, omitted for brevity, are similar to post-2. Each figure includes superimposed curves from 5 consecutive steps. VGRF, vertical ground reaction force.

Unfortunately, the post-2 measurements are thought to be faulty, and thus the foot and ankle motions have not been considered further; this is discussed in the limitations section.

DISCUSSION

Several findings document the participant's improvements in walking, from pre-care to the post-1 and post-2 assessments. Considering that her main reason for seeking care was a distinctly asymmetrical problem, it's important to note the greater symmetry seen in the post-1 and post-2 assessments for hip flexion and extension, loading and pre-swing periods during stance phase, and timing of the peak 1 and peak 2 force events.

The participant's increased self-selected walking speed in itself reflects improvement; slower walking speeds can be associated with pain^{17,39-41} or decreased strength or flexibility.⁴⁰ The post-care values of shorter double support times and longer steps, and the time changes of stance and swing phases, suggest an increased ability to function when on only 1 support limb.

For the VGRF measurements, there were relatively indistinct differences, pre-care, between the forces of peak 1, mid-stance, and peak 2 (Fig 3). At her post-1 and post-2 assessments, she showed a prominent heel strike (the heel strike transient "spike" seen in Fig 3), more forceful loading to the first peak force, and more overall distinction between the force events, as is typical for normative walking (Fig 2). The increased values for the peak forces and their increased

Fig 4. Typical angular motions for the hip and knee for this participant's pre-care (A, hip and B, knee) and post-2 assessments (C, hip and D, knee); the post-1 curves, omitted for brevity, are similar to post-2. Positive values are flexion. Consecutive steps were selected in which the patterns were close to calculated means. Because excerpts are at a uniform 2.85 seconds, the increased number of cycles illustrates increased walking speed. Flex-ext, flexion extension.

distinction from mid-stance forces may reflect less fear of pain or re-injury, as lower VGRFs can be associated with pain⁴² or diminished strength.⁴³

It's important to reiterate that many of the above post-care changes would be expected accompaniments to increased walking speed^{28,44-46} and must be viewed in that context. This may also be true for the narrowing of her step width from the pre-care to the second post-care assessment. Walking with a wider base of support provides more medial-to-lateral stability than having the feet closer together,⁴⁷ and wider step widths are seen with a variety of pathologies and other challenges to stable walking.⁴⁸⁻⁵² But mechanical work is required to shift the body to the left and right, and that comes with a metabolic cost.⁵³ The narrower step width of her final assessment suggests a more efficient walking pattern.

To what degree were the noted gait changes a product of the chiropractic care she received, or simply of time, or a combination of both? It isn't possible to know from this single-subject case design. Did the participant need any care at all? Ferguson et al⁴ suggested not, reporting that 78% of patients without clinical follow-up were satisfied with their outcomes after 1 year; yet, that means 22% were *not* satisfied. Ferguson et al⁴ and Bigsby et al⁹ found that 25% to 33% of patients continued to experience pain 1 year after

their fracture. These figures may suggest an appropriate role for chiropractic care, which the participant of the current study felt she benefitted from.

Limitations

Single cases cannot be assumed to represent the general population; thus, the results for this patient may not necessarily be the same for others with similar conditions. Other possible influences may have affected outcomes, such as fatigue, emotional states, or dietary changes. Additionally, the patient had a higher than average level of health education and was possibly more likely to follow healthy behaviors and avoid complicating factors than the average member of the general public. But, in these regards, her outcome might not be different than other patients who are motivated to search for information and seek care.

The post-2 foot and ankle measurements are thought to be faulty. The participant wore cross-trainer shoes for the first 2 assessment sessions, and a clip-on sensor cradle was laced to the shoes. She wore loose-fitting sandals for the final session, and some high maximum values and odd graph images suggest extraneous motion from the sensors being tossed about. We're now more aware of footwear issues and effective use of athletic tape.

Table 4. *Hip and Knee Angular Motion: Mean End-ranges for All Trials*

	Angular Magnitudes in Degrees, Mean (SD)			Asymmetry: L-R Difference in Means (Degrees)		
	Pre-care	Post-1	Post-2	Pre-care	Post-1	Post-2
L Hip flex.	19.8 (17.1)	24.2 (14.1)	29.1 (11.2)	7.3	3.8	0.3
R Hip flex.	27.1 (7.1)	28.0 (5.6)	28.8 (4.5)			
L Hip extens.	-10.7 (4.7)	5.2 (18.6)	10.3 (20.2)	22.8	8.2	2.3
R Hip extens.	12.1 (15.0)	13.4 (16.2)	12.6 (17.2)			
L Hip abd.	-7.1 (3.1)	-6.4 (5.1)	-5.8 (6.0)	2.5	2.4	2.3
R Hip abd.	-4.6 (7.0)	-4.0 (6.2)	-3.5 (6.0)			
L Hip add.	-9.4 (2.3)	-9.1 (4.4)	-9.3 (4.9)	0.1	1.3	1.9
R Hip add.	-9.5 (5.0)	-7.8 (5.2)	-7.4 (5.3)			
L Hip ext. rot.	0.8 (5.1)	0.8 (4.2)	0.5 (3.8)	0.3	0.3	0.2
R Hip ext. rot.	0.5 (5.3)	0.5 (4.7)	0.3 (4.1)			
L Hip int. rot.	-2.2 (4.0)	-1.5 (3.3)	-1.4 (2.9)	1.6	1.4	1.2
R Hip int. rot.	-3.7 (4.4)	-3.0 (4.0)	-2.6 (3.3)			
L Knee flex.	28.1 (20.7)	33.4 (22.6)	38.0 (23.3)	10.7	7.1	3.2
R Knee flex.	38.7 (25.1)	40.5 (24.8)	41.2 (24.0)			
L Knee extens.	9.2 (7.5)	12.3 (9.4)	12.1 (9.4)	5.2	0.2	1.7
R Knee extens.	14.4 (8.1)	12.5 (6.2)	10.5 (5.6)			

Abd, abduction; *Add*, adduction; *Ext*, external; *Extens*, extension; *Flex*, flexion; *Int*, internal; *L*, left; *R*, right; *Rot*, rotation; *SD*, standard deviation.

There may be some question as to what degree measurements made during treadmill walking in a controlled laboratory setting can be generalized to walking in daily life. Some type of equipment is needed for measurement. A treadmill eliminates the effects of changes in slope, texture, and height of walking surfaces, and it allows for a large number of steps to be evaluated in a small area and for walking speed to be easily controlled and measured.⁵⁴ So, while treadmill walking is a different experience from most walking, there is evidence that it is quantitatively similar to overground gait^{55,56} and that an instrumented treadmill accurately measures the forces exerted against it.⁵⁷

The findings above, and in other gait studies, may seem “academic” for some readers. The biomechanical equipment typically used in laboratory gait analysis is not commonly found in clinics for reasons of cost and necessary expertise. This is an issue for those practitioners who might be interested in using gait analysis with their patients. The equipment in this case is in use in settings such as rehabilitation centers and athletic training facilities and could be affordable for a larger clinic or a specialized practice. The use of similar equipment could help practitioners in

identification of atypical parameters, force patterns, and asymmetries, which could be used to personalize treatment and guide return to normal physical activities.

Finally, the reader should bear in mind that this report is intended to highlight gait findings, not to recommend treatment protocols. The authors are not advocating a specific technique or analysis method and have not attempted to identify cause and effect relationships between the participant’s foot pain and specific problem areas. Such things are beyond the scope of this study and are best left to other professionals. There are a substantial number of patients with unsatisfactory outcomes after metatarsal fractures, which suggests an area of focus for chiropractic care and additional research in this area. This case is part of an ongoing investigation of gait analysis as an outcome measure of chiropractic care.

CONCLUSIONS

The patient in this case recovered completely, and the post-injury kinematic and kinetic data allowed for quantification of gait patterns and changes that, in many clinical environments, could only be judged more subjectively.

Table 5. Ankle Angular Motion: Mean End-ranges for All Trials

	Angular Magnitudes in Degrees, Mean (SD), Maximum			Asymmetry: L-R Difference in Means (Degrees)		
	Pre-care	Post-1	Post-2	Pre-care	Post-1	Post-2
L Ankle dorsi.	-1.8 (6.7)	-1.9 (7.4)	-1.1 (6.8)	2.2	3.0	1.9
R Ankle dorsi.	0.4 (8.9)	1.1 (7.5)	0.8 (6.4)			
L Ankle plant.	-5.4 (6.7)	-6.6 (7.0)	-5.9 (6.4)	2.3	0.1	1.4
R Ankle plant.	-7.7 (6.9)	-6.5 (7.9)	-7.3 (8.0)			
L Foot invers.	1.4 (4.2)	0.8 (4.4)	1.7 (7.2)	2.9	2.7	4.3
R Foot invers.	-1.5 (3.3)	-1.9 (4.1)	-2.6 (4.8)			
L Foot evers.	-0.1 (3.6)	-1.0 (3.5)	-1.3 (4.4)	2.9	2.7	3.5
R Foot evers.	-2.8 (3.0)	-3.7 (2.9)	-4.8 (3.1)			
L Foot abd.	1.8 (2.2)	1.6 (2.1)	0.8 (4.8)	0.5	0.1	1.1
R Foot abd.	1.3 (2.1)	1.7 (3.0)	1.9 (4.1)			
L Foot add.	-0.5 (3.4)	-0.5 (3.0)	-1.7 (5.6)	1.1	0.4	0.9
R Foot add.	-1.6 (3.4)	-0.9 (4.0)	-0.8 (5.2)			

Abd, abduction; *Add*, adduction; *Dorsi*, dorsiflexion; *Evers*, eversion; *Invers*, inversion; *L*, left; *Plant*, plantar flexion; *R*, right; *SD*, standard deviation.

ACKNOWLEDGMENTS

The authors thank Michael T. Weiner, DC, for data collection and review of this manuscript.

FUNDING SOURCES AND CONFLICTS OF INTEREST

No funding sources or conflicts of interest were reported for this study.

CONTRIBUTORSHIP INFORMATION

Concept development (provided idea for the research): K.T.H.

Design (planned the methods to generate the results): B.S.R., K.T.H., R.S.H.

Supervision (provided oversight, responsible for organization and implementation, writing of the manuscript): B.S.R., K.T.H.

Data collection/processing (responsible for experiments, patient management, organization, or reporting data): B.S.R., R.S.H.

Analysis/interpretation (responsible for statistical analysis, evaluation, and presentation of the results): B.S.R., R.S.H.

Literature search (performed the literature search): B.S.R., K.T.H.

Writing (responsible for writing a substantive part of the manuscript): B.S.R., K.T.H.

Critical review (revised manuscript for intellectual content, this does not relate to spelling and grammar checking): B.S.R., K.T.H., R.S.H.

Custom-written software apps for data analysis: R.S.H.

Practical Applications

- Gait analysis may be useful in assessing healing progress and may help patients understand the extent of their progress.
- The findings of this study, and the manner in which the findings are presented, can enhance the abilities of chiropractic doctors and other practitioners to monitor walking gait in similar patients.

REFERENCES

1. Boutefnouchet T, Budair B, Backshayesh P, Ali SA. Metatarsal fractures: a review and current concepts. *Trauma*. 2014;16(3):147-163.
2. Polzer H, Polzer S, Mutschler W, Prall WC. Acute fractures to the proximal fifth metatarsal bone: development of classification and treatment recommendations based on the current evidence. *Injury*. 2012;43(10):1626-1632.
3. Smith TO, Clark A, Hing CB. Interventions for treating proximal fifth metatarsal fractures in adults: a meta-analysis of the current evidence-base. *Foot Ankle Surg*. 2011;17(4):300-307.
4. Ferguson KB, McGlynn J, Jenkins P, Madeley NJ, Kumar CS, Rymaszewski L. Fifth metatarsal fractures – is routine follow-up necessary? *Injury*. 2015;46(8):1664-1668.
5. Cheung CN, Lui TH. Proximal fifth metatarsal fractures: anatomy, classification, treatment and complications. *Arch Trauma Res*. 2016;5(4):e33298.
6. Kane JM, Sandrowski K, Saffel H, Albanese A, Raikin SM, Pedowitz DI. The epidemiology of fifth metatarsal fracture. *Foot Ankle Spec*. 2015;8(5):354-359.
7. Hasselman CT, Vogt MT, Stone KL, Cauley JA, Conti SF. Foot and ankle fractures in elderly white women. Incidence and risk factors. *J Bone Joint Surg Am*. 2003;85-A(5):820-824.
8. DeVries JG, Taefi E, Bussewitz BW, Hyer CF, Lee TH. The fifth metatarsal base: anatomic evaluation regarding fracture mechanism and treatment algorithms. *J Foot Ankle Surg*. 2015;54(1):94-98.
9. Bigsby E, Halliday R, Middleton RG, Case R, Harries W. Functional outcome of 5th metatarsal fractures. *Injury*. 2014;45(12):2009-2012.
10. Hunt KJ, Goeb Y, Esparza R, Malone M, Shultz R, Matheson G. Site-specific loading at the fifth metatarsal base in rehabilitative devices: implications for Jones fracture treatment. *PM R*. 2014;6(11):1022-1029 quiz 1029.
11. Nagar M, Forrest N, Maceachern CF. Utility of follow-up radiographs in conservatively managed acute fifth metatarsal fractures. *Foot (Edinb)*. 2014;24(1):17-20.
12. Bowes J, Buckley R. Fifth metatarsal fractures and current treatment. *World J Orthop*. 2016;7(12):793-800.
13. Torg JS, Balduini FC, Zelko RR, Pavlov H, Peff TC, Das M. Fractures of the base of the fifth metatarsal distal to the tuberosity. Classification and guidelines for non-surgical and surgical management. *J Bone Joint Surg Am*. 1984;66(2):209-214.
14. Brogan K, Bellringer S, Akehurst H, et al. Virtual fracture clinic management of fifth metatarsal, including Jones', fractures is safe and cost-effective. *Injury*. 2017;48(4):966-970.
15. Mehlhorn AT, Zwingmann J, Hirschmüller A, Südkamp NP, Schmal H. Radiographic classification for fractures of the fifth metatarsal base. *Skeletal Radiol*. 2014;43(4):467-474.
16. Bauer G, Zenkl M, Schierle M, Rosenbaum D, Mutschler W, Claes L. Impaired gait after base fractures of the 5th metatarsal bone. *Unfallchirurg*. 1993;96(9):483-487.
17. Kösters C, Bockholt S, Müller C, et al. Comparing the outcomes between Chopart, Lisfranc and multiple metatarsal shaft fractures. *Arch Orthop Trauma Surg*. 2014;134(10):1397-1404.
18. Queen RM, Abbey AN, Chuckpaiwong B, Nunley JA. Plantar loading comparisons between women with a history of second metatarsal stress fractures and normal controls. *Am J Sports Med*. 2009;37(2):390-395.
19. Dimou ES, Brantingham JW, Wood T. A randomized controlled trial (with blinded observer) of chiropractic manipulation and Achilles stretching vs orthotics for the treatment of plantar fasciitis. *J Am Chiropr Assoc*. 2004;41(9):32-42.
20. Pellow JE, Brantingham JW. The efficacy of adjusting the ankle in the treatment of subacute and chronic grade I and grade II ankle inversion sprains. *J Manipulative Physiol Ther*. 2001;24(1):17-24.
21. Brantingham JW, Chang MN, Gendreau DF, Price JL. The effect of chiropractic adjusting, exercises and modalities on a 32-year-old professional male golfer with hallux rigidus. *Clin Chiropr*. 2007;10(2):91-96.
22. Köhne E, Jones A, Korporaal C, Price JL, Brantingham JW, Globe G. A prospective, single-blinded, randomized, controlled clinical trial of the effects of manipulation on proprioception and ankle dorsiflexion in chronic recurrent ankle sprain. *J Am Chiropr Assoc*. 2007;44(5):7-17.
23. Govender N, Kretzmann H, Price JL, Brantingham JW, Globe G. A single-blinded randomized placebo-controlled clinical trial of manipulation and mobilization in the treatment of Morton's neuroma. *J Am Chiropr Assoc*. 2007;44(3):8-18.
24. Wyatt LH. Conservative chiropractic management of recalcitrant foot pain after fasciotomy: a retrospective case review. *J Manipulative Physiol Ther*. 2006;29(5):398-402.
25. Hains G, Boucher PB, Lamy AM. Ischemic compression and joint mobilisation for the treatment of nonspecific myofascial foot pain: findings from two quasi-experimental before-and after studies. *J Can Chiropr Assoc*. 2015;59(1):72-83.
26. Battaglia PJ, Kaeser MA, Kettner NW. Diagnosis and serial sonography of a proximal fifth metatarsal stress fracture. *J Chiropr Med*. 2013;12(3):196-200.
27. Binkley JM, Stratford PW, Lott SA, Riddle DL. The Lower Extremity Functional Scale (LEFS): scale development, measurement properties, and clinical application. North American Orthopaedic Rehabilitation Research Network. *Phys Ther*. 1999;79(4):371-383.
28. Whittle MW. *Gait Analysis: An Introduction*. Butterworth Heineman: Edinburgh, Scotland; 2007.
29. Perry J, Burnfield JM. *Gait Analysis: Normal and Pathological Function*. 2nd ed. SLACK Inc: Thorofare, NJ; 2010.
30. Griffiths IW. Gait analysis and biomechanics. In: *Principles of Biomechanics and Motion Analysis*. Lippincott, Williams & Wilkins: Baltimore, MD; 2006.
31. Verdini F, Marcucci M, Benedetti MG, Leo T. Identification and characterisation of heel strike transient. *Gait Posture*. 2006;24(1):77-84.
32. Kang HG, Dingwell JB. Separating the effects of age and walking speed on gait variability. *Gait Posture*. 2008;27(4):572-577.
33. Robinson RO, Herzog W, Nigg BM. Use of force platform variables to quantify the effects of chiropractic manipulation on gait symmetry. *J Manipulative Physiol Ther*. 1987;10(4):172-176.
34. Kodesh E, Kafri M, Dar G, Dickstein R. Walking speed, unilateral leg loading, and step symmetry in young adults. *Gait Posture*. 2012;35(1):66-69.
35. Sadeghi H, Allard P, Prince F, Labelle H. Symmetry and limb dominance in able-bodied gait: a review. *Gait Posture*. 2000;12(1):34-45.
36. Lathrop-Lambach RL, Asay JL, Jamison ST, et al. Evidence for joint moment asymmetry in healthy populations during gait. *Gait Posture*. 2014;40(4):526-531.
37. Herzog W, Conway PJ. Gait analysis of sacroiliac joint patients. *J Manipulative Physiol Ther*. 1994;17(2):124-127.
38. Kim CM, Eng JJ. Symmetry in vertical ground reaction force is accompanied by symmetry in temporal but not distance variables of gait in persons with stroke. *Gait Posture*. 2003;18(1):23-28.
39. Khodadadeh S, Eisenstein SM. Gait analysis of patients with low back pain before and after surgery. *Spine (Phila Pa 1976)*. 1993;18(11):1451-1455.

40. Quiben MU, Hazuda HP. Factors contributing to 50-ft walking speed and observed ethnic differences in older community-dwelling Mexican Americans and European Americans. *Phys Ther*. 2015;95(6):871-883.
41. Uthaikhup S, Sunkarat S, Khamsaen K, Meeyan K, Treleaven J. The effects of head movement and walking speed on gait parameters in patients with chronic neck pain. *Man Ther*. 2014; 19(2):137-141.
42. Lee CE, Simmonds MJ, Etnyre BR, Morris GS. Influence of pain distribution on gait characteristics in patients with low back pain: part 1: vertical ground reaction force. *Spine*. 2007;32(12): 1329-1336.
43. LaRoche DP, Millett ED, Kralian RJ. Low strength is related to diminished ground reaction forces and walking performance in older women. *Gait Posture*. 2011;33(4): 668-672.
44. Nilsson J, Thorstensson A. Ground reaction forces at different speeds of human walking and running. *Acta Physiol Scand*. 1989;136(2):217-227.
45. Martin PE, Marsh AP. Step length and frequency effects on ground reaction forces during walking. *J Biomech*. 1992; 25(10):1237-1239.
46. Keller TS, Weisberger AM, Ray JL, Hasan SS, Shiavi RG, Spengler DM. Relationship between vertical ground reaction force and speed during walking, slow jogging, and running. *Clin Biomech (Bristol Avon)*. 1996;11(5): 253-259.
47. Arvin M, Mazaheri M, Hoozemans MJM, et al. Effects of narrow base gait on mediolateral balance control in young and older adults. *J Biomech*. 2016;49(7):1264-1267.
48. Browning RC, Kram R. Effects of obesity on the biomechanics of walking at different speeds. *Med Sci Sports Exerc*. 2007;39(9):1632-1641.
49. Lee JH, Lee SH, Seo IS. The characteristics of gait disturbance and its relationship with posterior tibial somatosensory evoked potentials in patients with cervical myelopathy. *Spine (Phila Pa 1976)*. 2011;36(8):E524-E530.
50. Mortaza N, Abu Osman NA, Mehdikhani N. Are the spatio-temporal parameters of gait capable of distinguishing a faller from a non-faller elderly? *Eur J Phys Rehabil Med*. 2014;50(6): 677-691.
51. Moreira Bde S, Sampaio RF, Furtado SR, Dias RC, Kirkwood RN. The relationship between diabetes mellitus, geriatric syndromes, physical function, and gait: a review of the literature. *Curr Diabetes Rev*. 2016;12(3):240-251.
52. Santos PC, Gobbi LT, Orcioli-Silva D, Simieli L, van Dieën JH, Barbieri FA. Effects of leg muscle fatigue on gait in patients with Parkinson's disease and controls with high and low levels of daily physical activity. *Gait Posture*. 2016;47:86-91.
53. Donelan JM, Kram R, Kuo AD. Mechanical and metabolic determinants of the preferred step width in human walking. *Proc Biol Sci*. 2001;268:1985-1992.
54. Riley PO, Paolini G, Della Croce U, Paylo KW, Kerrigan DC. A kinematic and kinetic comparison of overground and treadmill walking in healthy subjects. *Gait Posture*. 2007;26(1):17-24.
55. Watt JR, Franz JR, Jackson K, Dicharry J, Riley PO, Kerrigan DC. A three-dimensional kinematic and kinetic comparison of overground and treadmill walking in healthy elderly subjects. *Clin Biomech (Bristol, Avon)*. 2010;25(5):444-449.
56. Fullenkamp AM, Toluoso DV, Laurent CM, Campbell BM, Cripps AE. A comparison of both motorized and non-motorized treadmill gait kinematics to overground locomotion. *J Sport Rehabil*. 2017:1-20.
57. Willems PA, Gosseye TP. Does an instrumented treadmill correctly measure the ground reaction forces? *Biol Open*. 2013;2(12):1421-1424.