Continuing Medical Education

Gait Analysis: A Modern Approach for Today's Specialist: Part 2

Computer-assisted gait analysis advances diagnostic ability.

BY JOSEPH C. D'AMICO DPM, DSC

Goals and Objectives

- To present an overview of computer assisted gait analysis.
- To discuss its clinical indications, limitations and importance.
- To offer a methodology for its application in clinical practice.
- To enhance the understanding and role of plantar pressure and temporal parameter analysis in the diagnosis and management of pedal pathology and locomotor disturbances.

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*Following this article, an answer sheet and full set of instructions are provided (pg. 104).—**Editor***

Editor's Note: *Part 1 of this article (September 2025 issue)explored the history and evolution of gait analysis, its importance of the assessment of ambulatory ability, and a rationale and protocol for its application. Part 2 will discuss the points listed under the "Goals and Objectives" atop this page.*

The human foot performs distinct, repetitive, universal, sequential motions which have therefore been able to be identified and charted.

Why Computer-Assisted Gait Analysis?

The pathologic forces that have created the overwhelming majority of musculoskeletal concerns that patients present with occur under the foot, inside the shoe, and are repeated thousands of times each day. These stresses take place so rapidly that they cannot be seen with the naked eye nor timed with a stopwatch. Observational Gait Analysis (OGA), although expedient, has been

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proven to be an unreliable indicator of foot and limb pathology, yielding a generalized description of gait variables, usually differing from one examiner to another.[1,2,14,15]

With OGA, it is also difficult to record and compare findings visit-to-visit.[36] The examiner's perspective is limited, and thus at best is only moderately reliable.[37] The overall assessment is based on observed movements, not forces, and depends upon the skill of the observer. Whenever a subject is aware of their gait being observed, they subconsciously alter their gait. This is known as the Hawthorne effect, and although it has been mentioned as a negative aspect of OGA, it would also apply to Video Gait Analysis (VGA) and Computer Assisted Gait Analysis (CAGA). GK Rose, a British orthopedic surgeon, has stated that observing someone walk and noting abnormalities is by itself of little value. He goes on to explain that what is being observed is the effect of pathologic processes, not its causes, and what is presented is the subject's attempts to compensate for it.

Therefore, what one is observing is what is left after all available avenues of compensation have been exhausted. Gait analysis is the synthesis of these observations, considering history and physical examination findings coupled with examiner intelligence and experience.[34]

Computer-Assisted Gait Analysis (CAGA) allows the identification of "many more gait abnormalities".[39]

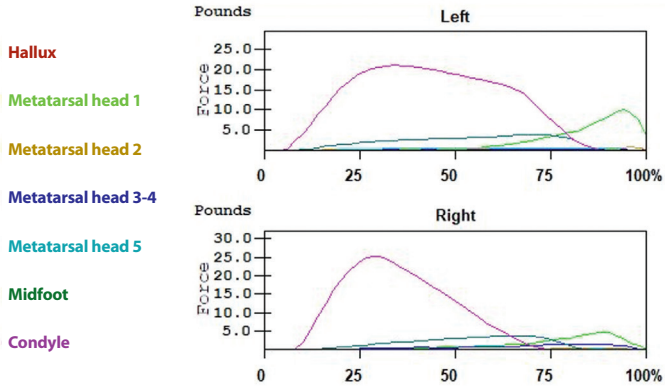


Figure 2: Force/time waveforms in the same patient with the purple curve depicting the heel and all other colors representing the mid- and forefoot segments. Note the asymmetry, poor propulsion, and flattened left heel curve.

TAM Phases of Gait in % of Gait Cycle

Parameter	Normal Range	Left Foot Avg	Left Foot Variation	Left Foot StdDev	Right Foot Avg	Right Foot Variation	Right Foot StdDev
Stance	53 - 67	64	59 - 65	2	63	60 - 68	3
Swing	33 - 47	36	35 - 41	2	37	32 - 40	3
Contact	8 - 12	15	11 - 21	3	13	9 - 14	2
Foot Flat	9 - 12	?	? - ?	0	?	? - ?	0
Midstance	18 - 22	34	28 - 40	5	25	19 - 34	5
Propulsive	27 - 33	14	9 - 19	3	25	20 - 30	4
Active Propulsive	19 - 21	2	-5 - 9	5	12	5 - 17	5
Passive Propulsive	8 - 12	12	9 - 13	2	13	11 - 16	2
Single Support	37 - 43	36	31 - 40	3	37	34 - 39	2
Total Double Support	16 - 24	28	22 - 34	4	26	21 - 30	3
Initial Double Support	8 - 12	15	11 - 21	3	13	9 - 14	2
Terminal Double Support	8 - 12	13	9 - 15	2	13	11 - 16	2
Cadence (steps/min)	90 - 120	108	-	-	108	-	-
Heel	50 - 62	67	59 - 76	6	48	39 - 61	7

Figure 3: Timing and analysis module (TAM) providing temporal parameters along with normal range comparisons for the same subject. Note stance and swing phases are equal and normal, but midstance and propulsive phases are not.

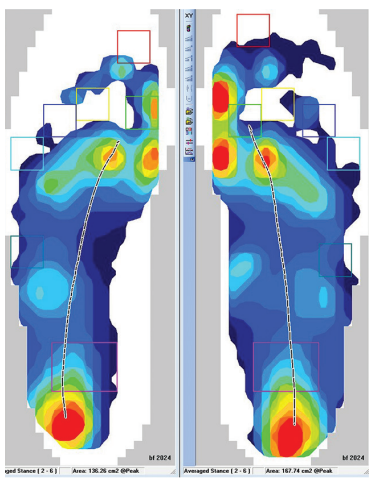
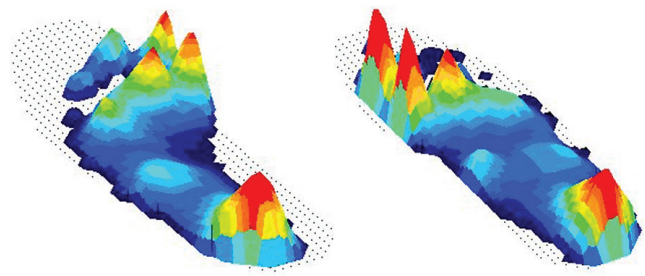


Figure 1 a, b: Two and three-dimensional averaged stance phase depictions of plantar pressure weight distribution patterns and pathways during barefoot walking.



In actuality, in-shoe pressure testing is not "gait analysis"—which is the subjective and objective observation of body part movements (kinematics) and the forces and torques (kinetics) that accompany it—but rather a clinically applicable system of deductive and diagnostic logic, using quantitative data obtained technologically and objectively in a realistic setting.

The data represents an array of significant time and pressure events directly attributable to the functional activity of key foot segments.[27] It displays and documents footprints in real time and force/time curves, and computes temporal parameters, including stance, swing, double limb support, single limb support, stride and step length, and velocity/speed (Figures 1a, 1b, 2, 3).[1,2,32,36,40-45,47,48]

CAGA also measures vertical GRFs and center as well as path of pressure (COP). Clinically, it may be utilized to influence and improve patient outcomes or expand existing knowledge, assist diagnosis, confirm clinical findings, understand etiology and progression, design and monitor treatment, and assess and improve performance. Specific applications may include the objective assessment of ambulatory ability, identification and management of limb length discrepancy, determination of hypermobility, the prescription and assessment of custom foot orthoses (CFO), the identification and management of untoward forces in the insensate foot, pre- and post-surgical intervention, management of stress fractures, predicting pathology, et al. (Figure 4).[1,2,27-32,40,44,45,47,48]

CAGA systems are offered as a sensor-embed-

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ded mat and walkway, or as an in-shoe sensor (Figure 5a, 5b). The mat system only captures one step on one side at a time, and each step must be targeted to hit the mat… thereby skewing the data. The walkway system does not require targeting; however, like the mat configuration, the only forces that may be obtained are those that are occurring from the barefoot to the walkway or from the shoe to the ground. The primary advantage of in-shoe pressure testing is that it can record all the necessary data in a realistic environment inside the shoe while the patient is walking (Figure 6).

Figure 5a, 5b: Mat and walkway computer assisted gait analysis systems provide plantar pressure and path of pressure; however, they are only capable of providing data obtained from the shoe to the ground interface or barefoot to ground testing.

Experience has shown that upon CAGA, most patients come close to a 60% stance and 40% swing phase gait with no visible pathologic gait alterations.

Pressure Testing Fundamentals

The human foot performs distinct, repetitive, universal, sequential motions which have therefore been able to be identified and charted. Since the foot functions in moveable segments, each segment must be in a specific ideal position on the ground and in the air at the appropriate time in the gait cycle. It is the direction and amplitude of pressure in a TIME context that must be addressed. How long is the part in contact with the ground? When did it reach its highest amplitude or peak? In what sequence was the force applied? These are some of the questions that are answered through the use of in-shoe pressure testing in the determination of foot and ankle functional status.

Since the stance phase accounts for 60% of the gait cycle and the swing phase 40%, each limb should generate correspondingly equal pressures along a normal path within normal ranges and for the appropriate amount of time during each segment of the gait cycle. Experience has shown that upon CAGA, most patients come close to a 60% stance and 40% swing phase gait with no visible pathologic gait alterations. This is due to the fact that what one observes watching someone walk is the sum total of every adjustment that person has made over the years to achieve the most efficient gait possible for that particular system; however, when one delves deeper into the gait cycle components, the level and site of dysfunction is revealed (Figure 3).

FIGURE 4

Selected Clinical Applications of CAGA

- Assist in diagnosis
- Confirm clinical findings
- Understand etiology and progression
- Prevent recurrence
- Design and monitor management program
- Assess and improve ambulatory status
- Identify and rectify limb discrepancy, hypermobility, plantar ulcers, etc.

The stance phase segments include heel contact, foot flat, midstance, and propulsion. Although all phases of gait are important to assess and offer clues to pathology etiology, the most destructive forces occur in the latter part of midstance and propulsion, since that is the point at which the entire weight of the body is moving forward over the foot. Forces generated through the foot just prior to heel-off transition from proximal to distal, to distal to proximal. This reversal in force direction results in retrograde stresses being applied from the forefoot, then proximally through the midtarsal and finally affecting subtalar joint motion and position.

Normal pronation occurs for 25% of the adaptive segment of the stance phase of gait. Abnormal pronation extends this period, delays re-supination, and among other things, negates the windlass mechanism effect (Figure 7). Midstance increases in a pronated foot and propulsion decreases, while in a more rigid or cavus foot type, midstance would be decreased and propulsion would be increased.

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Gait *(from page 99)*

In adults, a midstance phase of gait under 30% and equal with the contralateral limb would be considered normal; however, ideally, 18-22% would be optimum. As noted, these parameters must be assessed in conjunction with the clinical findings. A lowered midstance along with an increased propulsive phase may be a desirable objective, but in an individual with equinus function induced by lower limb posterior chain contractures, these numbers are deceiving.

Another characteristic observed in the excessively pronated foot is an increased heel loading phase. This is due to a disruption of normal stance phase component timing in response to compensatory adjustments required to allow the foot to reach the supporting surface. Since more time is spent in contact and midstance phases, the propulsive phase is correspondingly diminished. Normal propulsive range would be 27-32% of the stance phase of gait, whereas in a pronated foot, it would be much lower (Figure 7). Propulsion is divided into active and passive segments. In a normal foot, active propulsion should always be greater than passive propulsion. In a pronated foot, the passive is almost always greater than the active and the more pronated the foot, the greater the deviation observed (Figure 7).

A major, often overlooked, under-appreciated aspect of CAGA are the temporal parameters accompanying these pressures.

Figure 6: In-shoe pressure testing systems allow capture of temporal parameters, plantar pressures, and path of pressure in an unencumbered realistic environment inside the shoe.

The acquisition of plantar pressure, peak pressure, path of pressure and center of force trajectories are common CAGA parameters provided and utilized to objectively assess ambulatory ability. However, a major, often overlooked, under-appreciated aspect of CAGA are the temporal parameters accompanying these pressures. This is significant since not all high-pressure areas are injurious and not all low-pressure sites are innocuous. Forces that are low in nature applied over a longer-than-normal duration may result in tissue breakdown in susceptible individuals, whereas short-duration high pressure forces may not. What then determines whether or not tissue breakdown will occur is not only the viability of the tissue to which the forces are being applied, but also the time in the gait cycle that it occurs.

In general, early peaking indicates rigidity, late peaking instability or hypermobility, and normal peaking stability. Normal weight distribution pathways should be symmetrical and course lateral to medial calcaneus, then lateral to the 5th metatarsal, across the MPJs and out through the first met or slightly lateral through the first interspace.

As described in part 1, normal force/time curves should resemble a soft "M" double hump configuration with the first wave representing heel contact weight acceptance (passive peak), and the second forefoot (active peak) characteristics. The passive peak is the result of the collision of the foot with the ground and the active peak results from the force applied by the foot into the ground during propulsion.[39] The central depression represents the highest point for the center of mass and exhibits a 50% reduction in force from heel contact. In the metatarsal head loading section of the curve,

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TAM Phases of Gait in % of Gait Cycle

Parameter	Normal Range	Left Foot Avg	Left Foot Variation	Left Foot StdDev	Right Foot Avg	Right Foot Variation	Right Foot StdDev
Stance	53 - 67	66	64 - 69	2	64	62 - 66	1
Swing	33 - 47	34	31 - 36	2	36	34 - 38	1
Contact	8 - 12	15	13 - 17	1	15	12 - 19	2
Foot Flat	9 - 12	37	30 - 47	7	22	14 - 37	8
Midstance	18 - 22	41	40 - 42	1	35	34 - 36	1
Propulsive	27 - 33	10	9 - 11	1	14	11 - 17	2
Active Propulsive	19 - 21	-3	-4 - 0	1	0	-3 - 2	2
Passive Propulsive	8 - 12	10	9 - 11	1	13	11 - 15	2
Single Support	37 - 43	37	36 - 38	1	34	31 - 36	1
Total Double Support	16 - 24	29	28 - 31	1	30	27 - 34	3
Initial Double Support	8 - 12	15	13 - 17	1	15	12 - 19	2
Terminal Double Support	8 - 12	14	12 - 16	2	15	14 - 16	1
Cadence (steps/min)	90 - 120	100	-	-	100	-	-

Figure 7: Temporal parameters in an abnormally pronated foot, revealing an increased, unequal midstance phase, diminished propulsion, and absent active propulsion.

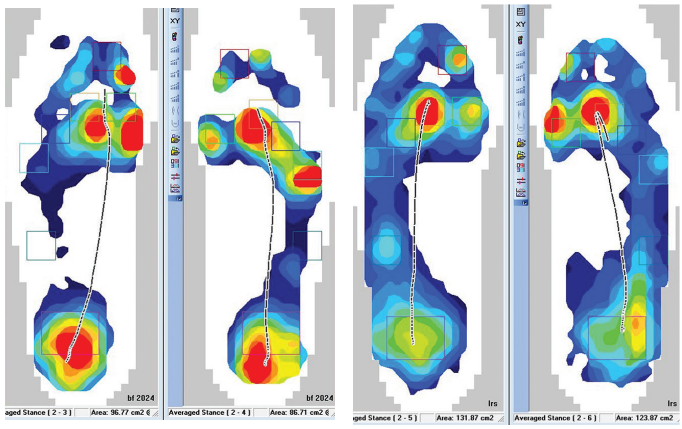

Figure 8a, 8b: Comparison of barefoot and sneaker tests in an adult patient, demonstrating greatly improved weight distribution patterns along with reduced plantar pressures.

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which is normally 10% higher than the heel contact curve, the steeper the slope observed, the greater the motion that is taking place. Conversely a flatter curve indicates less motion is occurring (Figure 2).[44,48]

The data obtained is the sum total of all musculoskeletal influences exhibiting their "end of the road" effect on the foot.

The propulsive sequence can be ascertained since each metatarsal head is individually able to be observed and evaluated. A normal propulsive sequence would be metatarsal heads 5,2,1, and hallux. An acceptable propulsive sequence would be metatarsal heads 5,1,2,and hallux, and an abnormal propulsive sequence would be any pathway not conforming to the above patterns. From this information, you can readily discern not only the obvious presence of pathology and its location but also the point in the gait cycle at which it is taking place.

Methodology

To begin a test, very thin, conformable, sensor-embedded insoles are trimmed to fit into the patient's shoes and then attached to an ankle connector which feeds into an ergonomically designed, remotely activated, small recording pack, which is then strapped around the subject's waist (Figure 6). The sensors are actually time switches and scales reporting on stop/start events along with the corresponding pressure produced and the amount of time these events are taking place. Tests are performed while walking barefoot, in most frequently-worn daily footwear, in sneakers, dress, and casual shoes, as appropriate.

The patient is asked to walk at their own pace down a hallway that is recommended to be at least 24 feet long. The information that is obtained is recorded and downloaded and the same procedure is performed for each situation that is to be assessed. Total time for the average patient requiring three tests (daily footwear, sneakers, and barefoot) would be 20-30 minutes. Once the information has been obtained, the patient is then disconnected from the recording apparatus and the findings are reviewed and presented, pointing out key points in each data section. Averaged stance is a two- or three-dimensional graphic representation of the average of every step taken, excluding the first and last steps (Figures 1a, 1b). Areas discussed typically include averaged stance weight distribution, pressures, patterns and pathways, waveform comparisons, and temporal parameters.

Patients are always amazed at the obvious and substantial improvement in weight distribution patterns and performance when in-shoe tests are compared with barefoot walking (Figures 8a, 8b). This is especially revealing when testing the pediatric patient whose parents have been led to believe that walking barefoot is good for their children and then shown the obvious improvement in weight distribution patterns and pathways with shoes (Figures 9a, 9b).

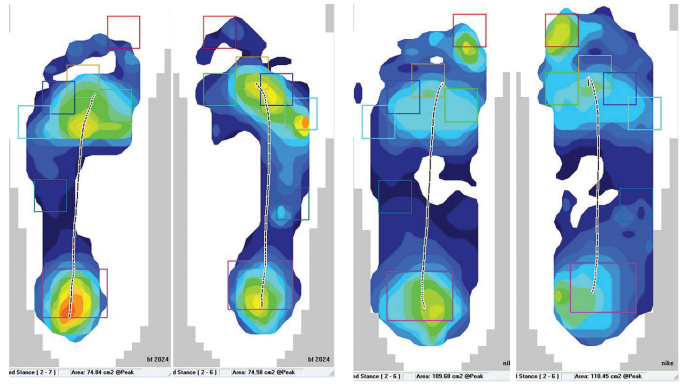

Figure 9a, 9b: Comparison of barefoot and sneaker tests in an 8-year-old. Note the greatly improved weight distribution patterns along with reduced plantar pressures.

Comparisons of results obtained in different footwear is not only objectively informative but makes it visibly evident which shoes allow the foot to function best and what characteristics would be helpful for the patient to seek or avoid in the future.

The same assessment can be made when evaluating CFO effectiveness by comparing data obtained in the same shoes with and without the devices (Figures 10a, 10b). This follow-up testing and comparison should be performed 10-14 days post-dispensing. This device adjustment period is necessary to realistically assess pedal performance in its new guided motion pathway. Tests assessing orthotic effectiveness (with CFO and without CFO) should not be performed on the same day since the data obtained walking without the CFO will have been tainted by the "mimicking"

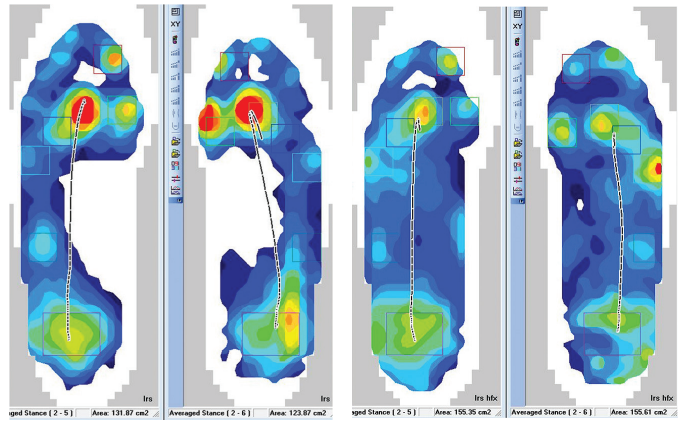

Figure 10a, 10b: Averaged stance comparisons in the same footwear without and with custom foot orthoses. Note the overall improved weight distribution patterns and more compact foot structure with the devices.

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effect that the foot exhibits as a result of having worn them.

If foot function is poor, as evidenced by irregular calcaneal waveforms of extended duration, increased midstance phases, diminished propulsion, medial deviation of the center of force, increased peak pressure of metatarsal heads 2-4, increased hallux pressure, diminished 1st met head pressure along with an increased medial calcaneal pressure; and if there is no significant improvement with CFO, then it can be concluded that the devices have not improved function, are of little to no value and should be replaced.

One additional point to keep in mind is that the patient's clinical findings must be correlated with test results. In effect, the data obtained is the sum total of all musculoskeletal influences exhibiting their "end of the road" effect on the foot; therefore, their identification through comprehensive biomechanical examination is critical. Strength and length determinations of lower extremity musculature, along with ranges of motion, must be assessed and addressed to ensure optimum function and outcomes.

The acquisition of vital, objective, quantitative foot and ankle data in a practice setting has become increasingly practical.

Conclusion

The acquisition of vital, objective, quantitative foot and ankle data in a practice setting has become increasingly practical. This information is relevant, repeatable, and reliable, and is the scientific basis for the evaluation and management of musculoskeletal disorders affecting not only the foot and ankle but the entire locomotor system. The documentary evidence it provides is as vital as blood work to the rheumatologist, an electrocardiogram to the cardiologist, and radiographs to the orthopedic surgeon. Furthermore, in this technologically-driven world of modern medicine, it should be considered the standard of care. **PM**

Note: The author wishes to encourage all those wishing to learn more regarding this subject to read a chapter I have written in *Practical Biomechanics for the Podiatrist,* Book 4 by Richard L. Blake DPM, MS. I would also like to thank Dr. Blake for allowing me to excerpt portions of this article from that chapter.

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CME EXAMINATION

SEE ANSWER SHEET ON PAGE 105.

1) With Computer Assisted Gait Analysis (CAGA), utilizing in-shoe pressure sensors measure which of the following?

- **A) Vertical ground reaction force**
- **B) Medial to lateral shearing forces**
- **C) Anterior to posterior shearing forces**
- **D) None of the above**

2) CAGA applications include which of the following?

- **A) Pre- and post-surgical functional assessment**
- **B) Determination of hypermobility**
- **C) Assessment of functional symmetry**
- **D) All of the above**

3) A major disadvantage of a CAGA mat or walkway systems is ___?

- **A) Inability to record in-shoe pressure**
- **B) It does not record vertical ground reaction forces**
- **C) It is incapable of providing center or path of pressure**
- **D) It does not capture Force/Time waveforms**

4) Which one of the following CAGA systems requires "targeting", thereby skewing the data?

- **A) In-shoe pressure sensors**
- **B) Mat**
- **C) Walkway**
- **D) Ceiling height**

5) Which of the following are components of the stance phase of gait?

- **A) Contact**
- **B) Midstance**
- **C) Propulsion**
- **D) All of the above**

6) What are the correct percentage distributions for the gait cycle?

- **A) 60% stance 40% swing**
- **B) 60% swing 40% stance**
- **C) 50% swing 50% stance**
- **D) 75% stance 25% swing**

Continued on page 104

Continuing Medical Education

CME EXAMINATION

(Continued from page 103)

7) Which of the following statements is true regarding the propulsive phase of gait?

A) Active propulsion should always be greater than passive.
B) A lower propulsive phase is seen in an abnormally pronated foot.
C) 27-32% is the normal propulsive range for the stance phase of gait.
D) All of the above

8) Which of the following CAGA findings would indicate hypermobility of the first ray?

A) Increased pressure 2,3,4 metatarsal heads
B) Decreased pressure sub first met head
C) Increased pressure hallux
D) All of the above

9) Which of the following CAGA findings would indicate a limb length discrepancy with the RIGHT functionally SHORTER?

A) Midstance greater left
B) Propulsion greater right
C) Calcaneal stance duration greater left
D) All of the above

10) Which of the following scenarios would indicate excessive pronation?

A) Extended midstance, decreased propulsive phase
B) Diminished lateral and increased medial plantar pressure
C) Medial deviation of the path of pressure
D) All of the above

SEE ANSWER SHEET ON PAGE 105.

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ENROLLMENT FORM & ANSWER SHEET *(continued)*

EXAM #1/26
Gait Analysis: A Modern Approach for Today's Specialist: Part 2
(D'Amico)

Circle:

1.	A	B	C	D	6.	A	B	C	D
2.	A	B	C	D	7.	A	B	C	D
3.	A	B	C	D	8.	A	B	C	D
4.	A	B	C	D	9.	A	B	C	D
5.	A	B	C	D	10.	A	B	C	D

Medical Education Lesson Evaluation

Strongly agree [5]	Agree [4]	Neutral [3]	Disagree [2]	Strongly disagree [1]

1) This CME lesson was helpful to my practice ____

2) The educational objectives were accomplished ____

3) I will apply the knowledge I learned from this lesson ____

4) I will makes changes in my practice behavior based on this lesson ____

5) This lesson presented quality information with adequate current references ____

6) What overall grade would you assign this lesson?

A B C D

7) This activity was balanced and free of commercial bias.

Yes _____ No _____

8) What overall grade would you assign to the overall management of this activity?

A B C D

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