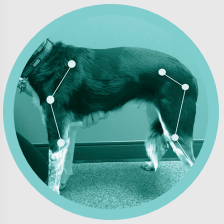

CANINE GAIT ANALYSIS

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Understanding canine locomotion and gait is imperative to diagnosing numerous musculoskeletal and neurologic conditions. Prior to any orthopedic or neurologic examination, a gait evaluation should be performed.

Gait evaluation typically includes visual and/or subjective observation of the dog from a number of angles at both the walk and trot on a flat surface. To the trained eye, lameness can often be detected upon gait evaluation. However, a more subtle lameness may not be apparent on subjective gait evaluation and can be difficult to detect.

Recently, new validated objective gait analysis technologies have become available to help veterinarians quantitate characteristics of gait, which can greatly assist in the detection of a subtle lameness as well as response to various treatments.

NORMAL CANINE GAIT

Prior to detecting abnormalities in gait, one must understand normal canine locomotion. In dogs, there are 4 main gaits: walk, trot, canter, and gallop (**Table 1**, page 94).

Horses use these same 4 gaits; however, dogs have 2 different ways of cantering and 2 different ways of galloping. Therefore, the canter and gallop that dogs perform preferentially are different from those used by horses.[1]

In addition, dogs have a transitional gait between the walk and the trot called the *amble*. There also is a relatively common, but abnormal, gait in dogs called the *pace*, which is a normal gait for some breeds of horses.[1]

OBSERVING CANINE GAIT

Key considerations when evaluating gait include:

- Choosing a surface for observation that is even and flat
- Observing both the walk and trot
- Watching the animal from multiple vantage points, including going away, coming toward, from both sides, and while circling
- If the patient is a performance or working dog, evaluating the animal perform its specific tasks, such as jumping over obstacles or running
- Noting any signs of neurologic abnormalities, such as ataxia, paw scuffing, or stumbling.

While the walk is often the easiest gait in which to observe abnormalities because it is the slowest gait, a mild lameness may not be detectable. The trot is the best gait to use for detecting lameness as it is the only gait in which the forelimbs and hindlimbs never receive assistance from the contralateral limb in bearing weight.

Forelimb Lameness

Generally, with forelimb lameness, weight is shifted caudally, and the head goes "down on the sound" limb or, conversely, the head goes up when the lame limb is on the ground (although this observation has not been verified in dogs). In forelimb lameness, the hindlimbs may also appear tucked under and the back appear arched, and affected dogs may take short strides with the hindlimbs.

Dogs with a shoulder lameness tend to appear short strided, while dogs with an elbow lameness (eg, medial compartment disease) appear to circumduct the limb to ease pressure on the medial aspect of the elbow.

Hindlimb Lameness

On the contrary, with hindlimb lameness, weight is shifted cranially. The forelimbs may be placed more caudally, with the head and neck extended and lowered to help offset weight from the hind end. A "hip hike"—in which the hip on the lame side has increased vertical motion, making the hip on the unaffected side appear lower when observing the gait from behind—is often noted on the same side as the lameness. The tail may also rise as the lame leg contacts the ground.

METHODS OF GAIT ANALYSIS

It is imperative to have a means for objective gait analysis because gait is difficult to consistently and

TABLE 1.
Summary of Canine Gaits

GAIT	FORWARD MOVEMENT	EXAMPLE	COMMENTS
Walk	1. One rear foot 2. Ipsilateral front foot 3. Other rear foot 4. Front foot on that side	1. RR 2. RF 3. LR 4. LF	• 2 or 3 feet on the ground at any given time • Only canine gait in which there are ever 3 feet on the ground
Amble	1. One rear foot 2. Quickly followed by ipsilateral front foot 3. Other rear foot 4. Quickly followed by front foot on that side *Begins to appear as if ipsilateral feet are moving forward together*	1. RR 2. RF 3. LR 4. LF	• A faster form of the walk but not preferred gait • Moments when 3 feet are on the ground observed on close inspection or slow motion video • Very inefficient gait: Rear end sways from side to side; rear feet are not lifted very high, often scuffling along the ground; wasted horizontal energy and less pleasing to the eye • Should only be used for short periods: transitioning from walk to trot or resting trotting muscles
Pace	1. Ipsilateral legs move forward together while other 2 legs bear weight 2. Moment when body is suspended in the air 3. Other 2 legs move forward together *Only 2 feet on ground at any given time*	1. RF–RR 2. No ground contact 3. LF–LR	• Abnormal gait for all dog breeds • Very inefficient gait: Center of gravity keeps shifting from side to side; energy expended to keep recentering weight • Cannot respond quickly when a change in speed is required • Wide range of speeds for movement unavailable unless dog slows to amble or speeds up to trot
Trot	1. Two diagonal front and rear feet 2. Moment when body is suspended in the air 3. Other diagonal front and rear feet	1. RF–LR 2. No ground contact 3. LF–RR	• Most efficient gait • Often gait of choice for gait evaluation: The front and rear leg must support the body without help from opposite leg
Rotary Canter	1. One rear leg 2. Both legs on other side of body together 3. Other front leg *Different lead legs in front and rear*	1. RR 2. LR–LF 3. RF	• Predominant canter in dogs (90%) • Allows very sharp turns with greater drive from the rear • Referred to as *cross cantering* in horses
Transverse Canter	1. One rear foot 2. Other rear foot and diagonal front foot together 3. Other front foot *Same side leads in the front and rear*	1. RR 2. LR–RF 3. LF	• Less efficient for dogs; only used in about 10% of cantering • Used predominantly by horses
Rotary Gallop	1. Spine flexes, with both rear feet on ground; lead foot slightly ahead of the other 2. Spine extends, stretching front feet forward, which hit ground at same time, one slightly ahead of the other, with lead front on opposite side of lead rear 3. Spine flexes to bring rear feet forward *Different lead legs in front and rear*	1. RR–LR 2. LF–RF 3. RR–LR	• Used by dogs preferentially
Transverse Gallop	1. Spine flexes, with both rear feet on ground; lead foot slightly ahead of the other 2. Spine extends, stretching front feet forward, which hit ground at same time, one slightly ahead of the other, with lead front on same side as lead rear 3. Spine flexes to bring rear feet forward *Same side leads in the front and rear*	1. RR–LR 2. RF–LF 3. RR–LR	• Very uncommon dog gait • Gallop used by horses

LF = left front; LR = left rear; RF = right front; RR = right rear

TABLE 2.
Methods for Canine Gait Analysis

Subjective:
• Visual observation of gait (eg, numerical rating scale, visual analog scale)
Objective:
• Kinematic gait analysis • Kinetic gait analysis (force plate analysis) • Temporospatial gait analysis (pressure sensing walkways)

reliably assess subjectively. Objective analysis is especially important when developing treatment plans and monitoring patient progress. Numerous methods for gait analysis have been developed (**Table 2**).

Visual Observation of Gait

A systematic and disciplined approach must be used to clinically evaluate a patient's gait. To document this clinical evaluation in the medical record, findings are often semiquantified using a numerical rating scale (**Table 3**) or visual analog scale (**Figure 1**).

Both types of scales were developed to provide a systematic approach to visual observation of gait. However, it is important to realize that, while visual or subjective gait analysis is often helpful in identifying lameness, the gold standard for quantifying lameness is quantification of gait characteristics with a form of objective gait analysis, such as force plate analysis.

Evans and colleagues compared visual observation of gait to force plate analysis.[2] This study evaluated 148 Labrador retrievers—131 that were 6 months post surgery for unilateral cranial cruciate ligament injury and 17 that were free of orthopedic disease.

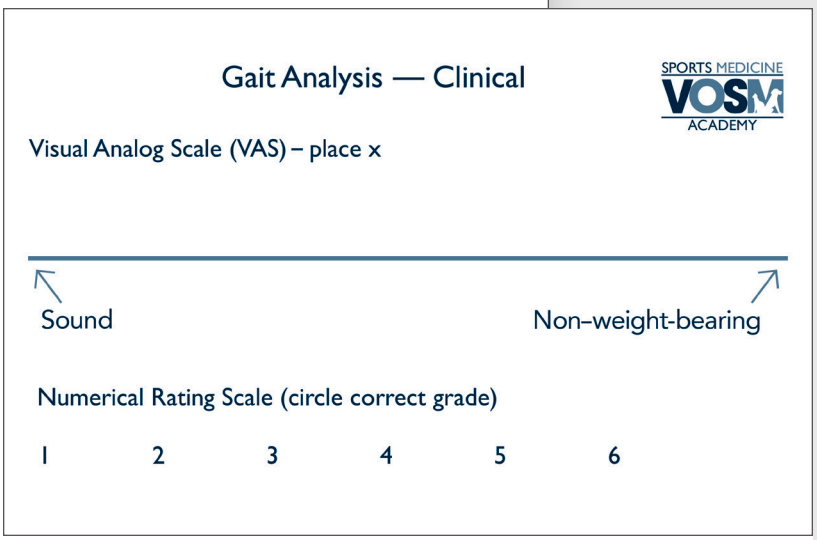


FIGURE 1. Example of the visual analog scale (VAS): The animal is graded on a 10-cm line, with one end of the line representing "sound" and the other end representing "non–weight-bearing." An "X" is placed along the scale, noting the degree of lameness, and then the VAS can be placed into the patient's record. Either the veterinarian or a trained staff member typically completes the VAS. Previous VASs can be compared to determine if there is improvement, decline, or no change.

The observer only identified 11% of the 131 dogs that were 6 months post surgery as being abnormal compared with force plate analysis, which revealed that 75% of the 131 dogs failed to achieve ground reaction forces consistent with sound Labrador retrievers.

While force plate analysis has been shown to be superior to visual observation, visual observation is still a practical tool in clinical practice, and its importance should not be discounted.

Kinematic Gait Analysis

Kinematic gait analysis quantifies the positions, velocities, acceleration/deceleration, and angles

TABLE 3.
Example of a Numerical Rating Scale for Visual Assessment of Gait

LAMENESS GRADE	DESCRIPTION
Grade 1	Sound at the walk, but weight shifting and mild lameness noted at trot
Grade 2	Mild weight-bearing lameness noted with the trained eye
Grade 3	Weight-bearing lameness, typically with distinct "head bob"
Grade 4	Significant weight-bearing lameness
Grade 5	Toe-touching lameness
Grade 6	Non–weight-bearing lameness

Note: *Grades 2 through 6 lameness can be observed at the walk or trot.*

For more information, visit **tvpjournal.com** and select **Clinical Resources** to download the numerical rating scale and visual analog scale described in this article. The scales have been kindly provided by Veterinary Orthopedic & Sports Medicine Group.

FIGURE 2. Example of how reflective markers would be placed for a patient undergoing kinematic gait analysis.

FIGURE 3. A force plate walkway; note the gray square in the center of the mat—this is the force plate that the dog must step on during the analysis.

of various anatomic structures in space. Most kinematic gait analysis systems use colored, retroreflective, or light-emitting diode (LED) markers that identify specific anatomic landmarks (**Figure 2**).

A few of the most common locations for markers include the dorsal scapular spine, acromion/greater tubercle, lateral humeral epicondyle, ulnar styloid process, iliac crest, femoral greater trochanter, femorotibial joint, lateral malleolus of the distal tibia, and spinous process at T13. Typically, markers are attached by shaving and cleaning the skin with alcohol; then pressing the marker's adhesive back directly to the skin. The marker can be further secured with tape, if needed.

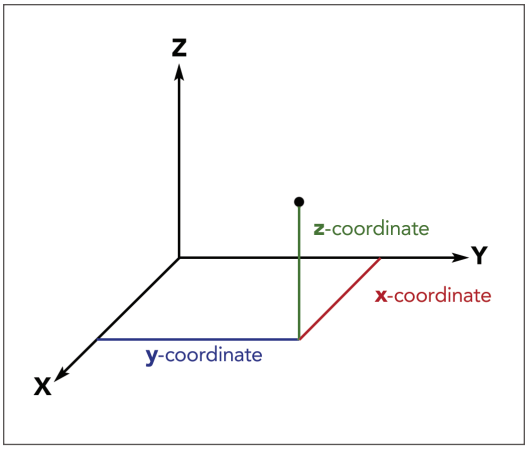


FIGURE 4. Diagram showing the forces measured during force plate analysis: The forces in the Z direction are generated by a vertical compression, which results in larger forces than those in the X or Y direction. Because of this, most veterinary publications derive and use the peak vertical force from the Z direction. *Courtesy en.wiktionary.org*

TABLE 4.
Types of Ground Reaction Forces

- Peak vertical force
- Vertical impulse
- Rising and falling slope
- Braking force
- Braking impulse
- Propulsive force
- Propulsive impulse
- Mediolateral force

When the dog is in gait, the movement of the markers is tracked by a series of cameras. The locations of the markers over time are then used to create a 2- or 3-D model of the dog's gait with calculations of bone and joint excursions.

Kinematic parameters include displacements, angular velocities, and range of motion[3]:

- *Displacement* is the distance recorded when a marker changes position.
- *Angular velocity* is the speed at which this change occurs.
- *Range of motion* is calculated from the displacement at a specific joint.

While a multitude of information can be gathered from this form of gait analysis, one major limitation is the variation of structures between breeds, as well as within breeds.[3] Further limitations include the potential for skin

movement, and accuracy and repeatability of marker placement.

Kinetic Gait Analysis

Kinetic gait analysis measures the ground reaction forces that are the result of an individual's step.

The most commonly used method for kinetic gait analysis is force plate analysis, in which metal plates are mounted on the floor or walkway (**Figure 3**) to measure ground reaction forces (**Table 4** and **Figure 4**). The forces are measured in 3 dimensions: vertical, craniocaudal, and mediolateral.

These forces are often presented graphically, with the peak forces as the maximum forces generated in the described phase of gait, represented by the force–time curve. The impulse is then represented as the area under the force–time curve.

- *Peak vertical force* (PVF) is the single largest force during the stance phase and represents only a single data point on the force–time curve.
- *Vertical impulse* (VI) can be derived by calculating the area under the vertical force curve using time.
- PVF and VI are the two most commonly used indices to detect lameness[3-5] and, in general, a dog with lameness has a lower PVF and VI in that limb.

While braking, propulsion, and mediolateral forces may be useful in evaluating mechanisms of locomotion, they are not commonly used for diagnostic purposes or to assess outcome.[4]

Force plate measurements have been the most widely used and validated quantitative gait application in veterinary medicine to date.[3] Thus, force plate analysis is considered the optimum approach to quantification of gait characteristics by objective gait analysis.

However, there are disadvantages to force plate analysis. Limitations include:

- Inability to measure stride or step length
- Need for consistent velocity, long dedicated walkway, and multiple trials
- Difficulty in setting up, breaking down, and moving
- Complexity of software and data analysis
- Cost and impracticality for clinical practice.

Tips for Obtaining an Acceptable Recording on a Pressure Sensing Walkway

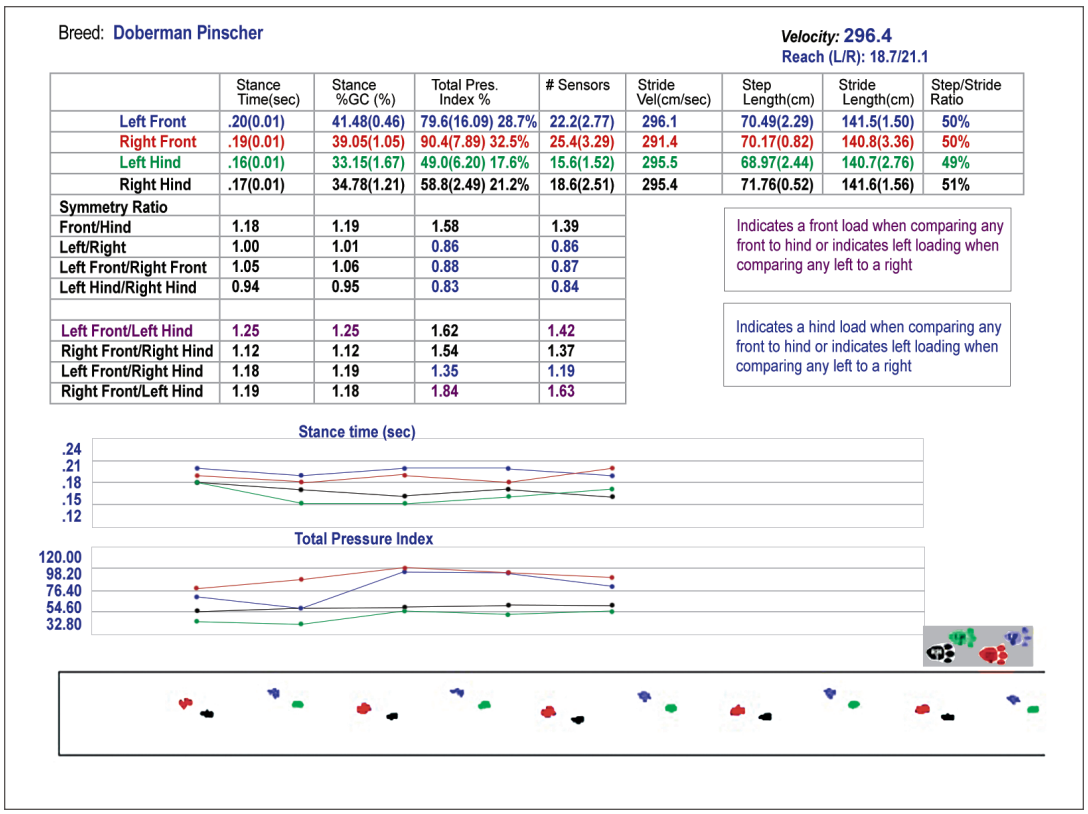
- Walk or trot the dog down the mat at a consistent velocity or steady state gait.
- Keep dogs on a loose leash, their heads looking forward in the direction of travel, and moving down the center of the mat.
- One recent study has shown that the side the handler is on may affect gait analysis, particularly when evaluating the forelimbs; thus, it is recommended to perform multiple passes with the handler switching sides between passes.[12]
- Place the mat in a quiet location where dogs won't become easily distracted.
- Start the pass 2 meters before the mat to encourage the dog to be straight and maintain a steady gait prior to stepping on the mat.
- If the dog has been trained for competitions, such as agility or obedience, it is most helpful to have the owner run the dog on the mat; otherwise, have the owner leave the room and have technical staff run the dog over the mat.
- Practice with the dog before recording to acclimate the dog to the mat and surroundings.
- Do not look at the dog while it is gaiting; this almost invariably makes the dog look at the owner or handler, although it might take three to four passes for this to work.
- If there is uncertainty regarding whether or not the pass down the mat was acceptable, it is often possible to review the video footage captured by the software's camera.

Temporospatial Gait Analysis with Pressure Sensing Walkways

Pressure sensing walkways have been validated to analyze normal and abnormal gaits in dogs.[6-13] Having this information aids in diagnosing orthopedic, muscular, and neurologic disorders

TABLE 5.
Description of Measurements Calculated in Temporospatial Gait Analysis

TERM	DEFINITION
Stance time	Stance phase of gait cycle and time paw is in contact with ground
Swing time	Swing phase of gait cycle and time paw is in air
Stride length	Distance from one footfall to the next footfall of same limb
Step length	Distance between heel point of one foot to heel point of contralateral foot
Total pressure index	Sum of peak pressure values recorded from each activated sensor by a paw during mat contact; related but not equal to peak vertical force



	Stance Time(sec)	Stance %GC (%)	Total Pres. Index %	# Sensors	Stride Vel(cm/sec)	Step Length(cm)	Stride Length(cm)	Step/Stride Ratio
Left Front	.20(0.01)	41.48(0.46)	79.6(16.09) 28.7%	22.2(2.77)	296.1	70.49(2.29)	141.5(1.50)	50%
Right Front	.19(0.01)	39.05(1.05)	90.4(7.89) 32.5%	25.4(3.29)	291.4	70.17(0.82)	140.8(3.36)	50%
Left Hind	.16(0.01)	33.15(1.67)	49.0(6.20) 17.6%	15.6(1.52)	295.5	68.97(2.44)	140.7(2.76)	49%
Right Hind	.17(0.01)	34.78(1.21)	58.8(2.49) 21.2%	18.6(2.51)	295.4	71.76(0.52)	141.6(1.56)	51%
Symmetry Ratio								
Front/Hind	1.18	1.19	1.58	1.39				
Left/Right	1.00	1.01	0.86	0.86				
Left Front/Right Front	1.05	1.06	0.88	0.87				
Left Hind/Right Hind	0.94	0.95	0.83	0.84				
Left Front/Left Hind	1.25	1.25	1.62	1.42				
Right Front/Right Hind	1.12	1.12	1.54	1.37				
Left Front/Right Hind	1.18	1.19	1.35	1.19				
Right Front/Left Hind	1.19	1.18	1.84	1.63				

Indicates a front load when comparing any front to hind or indicates left loading when comparing any left to a right

Indicates a hind load when comparing any front to hind or indicates left loading when comparing any left to a right

FIGURE 5. Results from temporospatial gait analysis using a pressure sensing walkway in a patient with a left cranial cruciate ligament rupture. Dogs carry about 60% of body weight on their forelimbs and 40% of body weight on their hindlimbs. Thus, the total pressure index percentage should be 30% in each forelimb and 20% in each hindlimb. This patient is placing 17% on the left hindlimb and 21% on the right hindlimb.

that affect gait. These measures provide novel information about temporal and spatial gait characteristics (**Figure 5**).

The portable pressure walkway system was originally developed for use in the human medical field[9,14,15] and has since been adapted and validated for use in veterinary medicine. Previous studies have established a protocol for temporal–spatial analysis and determined reference values and symmetry ratios for various breeds.[6-11]

Temporospatial gait analysis uses a pressure sensing mat (**Figure 6,** page 100) and computer software system to calculate velocity, stance time, swing time, stride length, step length, and total pressure index (**Table 5**, page 97).

Forces exerted to change speed, change direction, or maintain balance can interfere and complicate measurement interpretation.[12,16] The pressure sensing walkway does not measure force directly but does measure the influence of these forces. Therefore, by limiting excess external influences, the measurements may be more representative of the dog's true gait.

As with any other gait analysis system, there are advantages and disadvantages to using a pressure sensing walkway. Advantages include:

- No size restrictions
- Multiple readings from a single pass
- Determination of stride and step length
- Information on limb placement
- User-friendly software
- Portability.

However, just as with every other system, there are disadvantages, including:

- Ability to only measure total ground reaction forces
- Inability to separate the 3 dimensions as with force plate analysis
- Cost.

IN SUMMARY

With more dogs participating in activities with their owners, canine sports, or a working role, it is essential for owners and veterinarians to

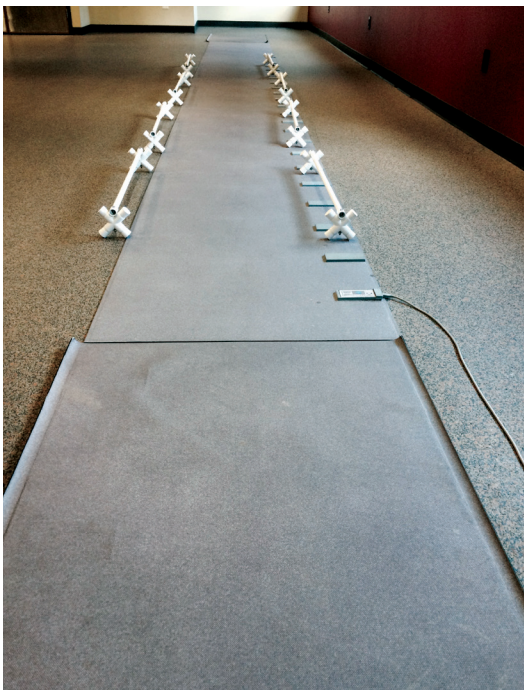


FIGURE 6. A temporospatial gait analysis system; note the series of sensors on the right side of the mat that are used to record each foot strike to calculate velocity, stance time, swing time, stride length, step length, and total pressure index. The sensors are connected to a computer (not pictured) with software to allow the gait to be analyzed.

understand canine gait. Early signs of lameness may be as subtle as a shortened stride or shorter stance time on the injured leg. Both subjective and objective gait analyses are important to not only establish a diagnosis but also monitor progression of treatment.

LED = light-emitting diode; PVF = peak vertical force; VAS = visual analog scale; VI = vertical impulse

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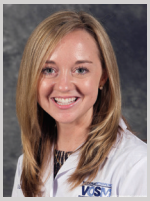

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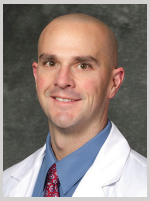

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