INTRODUCTION

Swine lameness on farm can result in negative affective states (i.e., pain) to individual animals (Farm Animal Welfare Council, 1992; Jensen et al., 2012). Caretakers and veterinarians can use husbandry and management tools to provide supportive care for animals experiencing lameness. Supportive care may include providing additional bedding or a rubber mat to create a more comfortable area for lying and resting (Elmore et al., 2010; White, 2010; Calderon-Diaz et al., 2010).
Another approach for on-farm pain management is pharmacological techniques such as analgesics. Nonsteroidal anti-inflammatory drugs (NSAID) are common analgesic medications used in livestock as they are easy to administer, long lasting, and cost-effective. Two anti-inflammatory medications that have demonstrated efficacy in pain mitigation associated with lameness are meloxicam and flunixin meglumine (Friton et al., 2003; Schulz et al., 2011; Coetzee et al., 2014; Pairis-Garcia et al., 2014b). However, meloxicam and flunixin meglumine are not approved pain management treatments in swine in the United States. The objectives of this study were to determine the efficacy of meloxicam and flunixin meglumine for pain mitigation in lame sows using the embedded microcomputer-based force plate system and GAITFour pressure mat gait analysis walkway system.

MATERIALS AND METHODS

The protocol for this study was approved by the Iowa State University Animal Care and Use Committee. The animals were cared for in accordance with the U.S. Animal Welfare Act and the Guide for the Care and Use of Laboratory Animals (NRC, 2011). This work was performed in a facility accredited by the Association for Assessment and Accreditation of Laboratory Animal Care at Iowa State University College of Veterinary Medicine. As lameness induction resulted in transient pain states, the experiment was designed to allow each sow to serve as her own control (baseline measurements were defined as control data for each sow), thus reducing the total number of sows required while maintaining the number of experimental animals required to detect a statistical difference. Investigators established humane end point criteria in which any sow that was unable to access water for 12 h or to access food for 24 h or progressed to non-weight-bearing lameness for 48 h was removed from the study and humanely euthanized. No sows met these criteria during this study. All sows were acclimated to housing and handling for 7 d before trial initiation.

Animals and Housing

Twenty-four multiparous (mean parity 6; range 2 to 9), nonpregnant, crossbred Newsham maternal cull sows were obtained from a commercial farm in Iowa (BW 241.4 ± 15.5 kg). All sows underwent a physical examination and a lameness evaluation before selection by a trained veterinarian with expertise in sow lameness (M. Pairis-Garcia). Lameness was evaluated using the following criteria: 1) sow not moving freely using all 4 legs while walking, 2) weight shifting during walking or standing, or 3) not bearing weight on any leg. Physical examination and lameness using the GAITFour pressure mat and an embedded microcomputer-based force plate system were also conducted between each round during the trial to confirm no observable residual lameness was present. To avoid confounding injury resulting from aggression, each sow was housed in an individual pen; however, sows could see, smell, hear, and have nose to nose contact with other sows. Each pen measured 3.7 m length × 1.4 m width × 1.2 m height and had a solid concrete floor with a rubber mat (2.4 m length × 2 cm height × 1.4 m width). Metal fences (1.2 m height × 76 cm width) were affixed to the end of each home pen. Sows were provided ad libitum access to water via 1 nipple and were hand fed a custom mixed diet of 14.8% CP total mixed ration composed of ground corn, soybeans, and nutrients formulated according to NRC (2012) swine guidelines to meet or exceed nongestating sow nutrient requirements. Matrix (Food and Drug Administration approved; 0.22% altrenogest; Intervet/Schering-Plough, Milisboro, DE; dose: 6.8 mL/15 mg) was added to 1 kg of feed daily to prevent estrus initiation.

Experimental Design

Lameness was induced by injecting amphotericin B into the distal interphalangeal joint according to methods previously described by Karriker et al. (2014). Amphotericin B (X-Gen Pharmaceuticals Inc., Big Flats, NY) was obtained as a sterile, nonpyrogenic, lyophilized powder containing 50 mg of amphotericin B and 41 mg of sodium deoxycholate with 20.2 mg of sodium phosphate as buffer. The powder was reconstituted using sterile water to a concentration of 10 mg/mL. A repeated measures design was used to compare responses up to 7 d following lameness induction. Two trials consisting of 12 sows/trial were conducted for a total of 24 sows. Each trial was designed as a crossover study with 3 rounds of lameness induction followed by a treatment period (flunixin meglumine, meloxicam, sterile saline). Each treatment was administered twice during each round 24 h apart. A 10-d washout period was provided between rounds to avoid previous treatment carryover effects (Mohling et al., 2014a).

In round 1, sows were randomly assigned to 1 of the 3 treatments, and lameness induction was assigned to either the left or right rear leg so that leg assignment and treatment were balanced. In round 2, sows were randomly assigned to 1 of the remaining 2 treatments, and lameness was induced in the rear leg that was sound in the previous round. By the third round, sows received the treatment they had not been administered in rounds 1 and 2. Before beginning each trial, indi-
vidual sow gait was evaluated by the trial veterinarian (M. Pairis-Garcia) using the previously described locomotion scoring system. A blood sample was collected from each sow, and drug concentration was evaluated using high-pressure liquid chromatography and mass spectrometry to determine any residual drug carryover.

**Treatments**

Twenty-four crossbred sows were randomly assigned to treatments by BW with sows allocated to 1 of 3 treatments for each round: 1) flunixin meglumine (2.2 mg/kg administered intramuscularly [i.m.]; \( n = 24 \)), 2) meloxicam (1.0 mg/kg per os [PO] administered in 8 g of cookie dough; \( n = 24 \)), or 3) saline (administered i.m. at an equivalent volume to flunixin meglumine PO; \( n = 24 \)). Sows treated with flunixin meglumine or saline were also given 8 g of cookie dough, whereas sows treated with meloxicam received an i.m. sterile saline injection. On the basis of \( T_{\text{max}} \) (defined as the time in which the drug reaches its maximum concentration) values previously calculated in a pilot study by our laboratory (Pairis-Garcia et al., 2013), flunixin meglumine treatments were administered 27.5 and 51.5 h postinduction, and meloxicam was administered 28.5 and 52.5 h after lameness induction. Half of the saline-treated sows had treatment administered at 27.5 and 51.5 h after lameness induction to match sows receiving flunixin meglumine. The remaining half of the saline-treated sows received their treatments at 28.5 and 52.5 h after lameness induction to match sows receiving meloxicam. To control for observer bias, researchers were blinded to analgesic treatments but could not be blinded to the trial day.

**Kinematic Data Collection**

The data time point collection schedule for both objective lameness evaluation tools is described in Table 1. Data for the embedded microcomputer-based force plate system (force plate) and GAITFour pressure mat analysis walkway system (GAITRite) were collected at the following time points: −24 h (baseline), 24 h (d 1 pretreatment), 28.5 or 30.5 h (d 1, based on \( T_{\text{max}} \) for treatment administered), 37 h (d 1 half-life), 48 h (d 2 pretreatment), 52.5 or 54.5 h (d 2, based on \( T_{\text{max}} \) for treatment administered), 60 h (d 2 half-life), 72 h (d 3), 168 h (recovery), and 312 h (baseline for next round). Here \( T_{\text{max}} \) is defined as the time in which the drug reaches its maximum concentration, and half-life is defined as the amount of time it takes for the plasma drug concentration to be reduced by one-half (Maddison et al., 2008). The \( T_{\text{max}} \) for flunixin meglumine and meloxicam were 1 and 2 h after drug administration, respectively. As \( T_{\text{max}} \) for meloxicam and flunix-

<table>
<thead>
<tr>
<th>Time points, h</th>
<th>Event</th>
<th>Data sampling time point</th>
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<tbody>
<tr>
<td>−24</td>
<td>Baseline</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Lameness induction(^2)</td>
<td>Day 1 pretreatment</td>
</tr>
<tr>
<td>24</td>
<td>Most lame</td>
<td>Day 1 T(_{\text{max}}) flunixin(^4)</td>
</tr>
<tr>
<td>27.5</td>
<td>Flunixin treatment(^3)</td>
<td>Day 1 T(_{\text{max}}) meloxicam</td>
</tr>
<tr>
<td>28.5</td>
<td>Meloxicam treatment</td>
<td>Day 2 T(_{\text{max}}) flunixin</td>
</tr>
<tr>
<td>30.5</td>
<td></td>
<td>Day 2 T(_{\text{max}}) meloxicam</td>
</tr>
<tr>
<td>37</td>
<td></td>
<td>Day 1 half-life(^5)</td>
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<tr>
<td>48</td>
<td></td>
<td>Day 2 half-life</td>
</tr>
<tr>
<td>51.5</td>
<td>Flunixin treatment</td>
<td>Day 2 T(_{\text{max}}) flunixin</td>
</tr>
<tr>
<td>52.5</td>
<td>Meloxicam treatment</td>
<td>Day 3</td>
</tr>
<tr>
<td>54.5</td>
<td></td>
<td>Recovery</td>
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<tr>
<td>60</td>
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<td>72</td>
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<td>168</td>
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<tr>
<td>312</td>
<td>Baseline for next round</td>
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</table>

\(^1\)Adapted from Pairis-Garcia et al. (2014b). An embedded microcomputer-based force plate system calculated weight distribution (in kg) for the sound and lame feet. GAITFour pressure mat analysis walkway system and associated hardware/software were used to determine the stance time for the sound and lame legs. Three quality readings with at least 2 complete footfall cycles were collected for all time points.

\(^2\)Lameness induced using a chemical synovitis model (Karriker et al., 2014).

\(^3\)Treatments: 1) meloxicam (1.0 mg/kg per os in cookie dough; \( n = 24 \)), 2) flunixin meglumine (FM; 2.2 mg/kg intramuscularly [i.m.]; \( n = 24 \)), or 3) saline (equivalent volume to FM administered i.m.; \( n = 24 \)). Flunixin treatments administered 3.5 h after pretreatment data collection. Meloxicam treatments administered 4.5 h after pretreatment data collection. Saline treatments randomly administered either 3.5 or 4.5 h after morning data collection.

\(^4\)\( T_{\text{max}} \) is defined as the time in which the drug reaches its maximum concentration. \( T_{\text{max}} \) for meloxicam-treated sows was 2 h after drug administration (Pairis-Garcia et al., unpublished). \( T_{\text{max}} \) for flunixin-treated sows was 1 h after drug administration (Pairis-Garcia et al., 2013). Sows treated with saline had data collected randomly at either 1 or 2 h after drug administration.

\(^5\)Half-life is defined as the time in which the drug reaches half of its maximum concentration. Half-life for all 3 treatments was 8 h after drug or saline administration (37 and 60 h postinduction for flunixin and meloxicam, respectively; Pairis-Garcia et al., unpublished; Pairis-Garcia et al., 2013, 2014a).

The embedded microcomputer-based force plate system (force plate) was validated previously by Karriker et al. (2014) and Mohling et al. (2014a). The force plate system was positioned under a standard gestation stall. A metal feeder was located at the front in which trickling feeding was performed to facilitate a standing posture (Sun et al., 2011). The embedded microcomputer-based force plate system measured 1.5 × 0.57 × 0.11 m (length × width × height) and had 4 load cells, 1 for each foot. Each load cell had 6.4-mm-thick aluminum plating.
and measured 0.76 × 0.28 m (length × width). A bar was positioned centrally along the length of the force plate measuring 153.7 × 2.2 cm (length × width) and was 10.2 cm above the aluminum plating. This was used to separate the left and right load cells for the front and hind feet. This modification was designed to limit the sow’s ability to place more than 1 foot on an individual load cell. Each plate that the load cell was attached to was coated with nonslip Vanberg epoxy (Vanberg Specialized Coatings, Lenexa, KS). The embedded force plate system was calibrated before the initiation of the study using 68-kg weights. During data collection the force plate was accurate to 0.45 kg per load cell. Weight distribution (kg) for each of the 4 feet was collected twice per second for a total of 5 min for each time point.

**GAITFour Pressure Mat**

**Gait Analysis Walkway System**

Gait was assessed and previously validated using a GAITFour gait analysis walkway system (GAITRite; CIR Systems Inc., Havertown, PA) and associated hardware/software (Karriker et al., 2014; Mohling et al., 2014a). A sow walked in a continuous closed-loop track that measured 45.4 × 1 m (length × width) covered with clean gray carpeting. In 1 straight section of the track, a pressure mat measuring 4.3 × 0.91 m (length × width) with a 0.76 m (width) active space was located under the protective carpet. The pressure mat included 13,824 sensors. Sows were walked across the pressure mat to acclimate to the desired speed and pattern needed for footfall analysis. This was achieved through training with positive reinforcement, rewarding the sow with food each time she walked at the desired speed and pattern over the mat. Gait analysis measures collected were stride time (defined as the time [s] between 2 successive footfalls by the same foot), stride length (defined as the distance [cm] between 2 sequential footfalls from the same foot), maximum pressure (defined as the greatest amount of weight [kg/cm²] placed on a single foot), activated sensors (defined as number of sensors activated by a single foot), and stance time (defined as the duration of time [s] the sensors were activated by a foot in a single stride). Each sow was required to complete 3 quality reading for each data collection time point. A quality reading was defined as a sow that did not hesitate, stop, or run across the walkway and that had at least 2 complete footfall cycles (all 4 feet) register in the software. The data were saved to the GAITFour software program.

**Statistical Analysis**

Data were analyzed using SAS software, version 9.3 (SAS Inst. Inc., Cary, NC). Data were analyzed for normality by plotting a predicted residual plot and a quantile-quantile plot using PROC UNIVARIATE, revealing a normal distribution for force plate and GAITRite variables. All traits were evaluated as the response differences between sound and lame feet (**Response**). For the force plate data, response differences in kilograms of weight between sound and lame legs (**Response**) were analyzed using a linear mixed model method (PROC MIXED; SAS software, version 9.3; SAS Inst. Inc.). The statistical model included the fixed effects of leg induced (right or left hind leg), treatment by time point interaction, treatment, round, time point, and trial. Sow within trial × group was fitted as a random effect. Response differences between sound and lame leg were analyzed using a linear mixed model method (PROC MIXED; SAS software, version 9.3; SAS Inst. Inc.) for all measures. Fixed effects included time point, round, leg induced, and time point by treatment interaction. Sow was fitted as random effect, and walk (defined as the first, second, or third quality reading across the pressure mat) within round and time point was fitted as a repeated effect. To evaluate the embedded force plate and the GAITFour gait analysis walkway system as objective assessment tools to discriminate between sound and lame phases sows, only data from saline treated sows were analyzed using previous models as described above.

**RESULTS**

**Transient Synovitis Model**

Before lameness induction, all sows were clinically sound, defined as the ability to move freely using all 4 legs, showing no evidence of abnormal weight-shifting activities, non-weight-bearing behavior, or reluctance to walk or stand on any leg. In addition, sows also demonstrated no signs of clinical disease or sickness throughout the trial. Peak lameness was observed on d 1 pretreatment after lameness induction, and all sows developed clinical lameness signs, including weight shifting and reluctance to walk or stand on the leg that received the amphotericin b injection. No sows became non-weight-bearing during the trial. Blood analysis (data not shown; Pairis-Garcia et al., 2013) confirmed systemic drug levels were below the detection limit in between rounds, suggesting that 10 d was a sufficient washout period for systemic drug clearance.
Table 2. Leg weight distribution by sampling time least squares means (±SE) from an embedded microcomputer force plate system for 24 saline-treated sows using a lameness induction model

<table>
<thead>
<tr>
<th>Data sampling time point, h</th>
<th>Leg</th>
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<th></th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>−24</td>
<td>24</td>
<td>48</td>
<td>72</td>
</tr>
<tr>
<td></td>
<td>Lame</td>
<td>47.4 ± 1.9</td>
<td>27.1 ± 1.9</td>
<td>34.2 ± 1.9</td>
<td>37.8 ± 1.9</td>
</tr>
<tr>
<td></td>
<td>Sound</td>
<td>48.0 ± 1.6</td>
<td>61.3 ± 1.6</td>
<td>56.9 ± 1.6</td>
<td>56.5 ± 1.6</td>
</tr>
</tbody>
</table>

a–c Within a row means without a common superscript differ (P < 0.05).

1 An embedded microcomputer-based force plate system calculated weight distribution (in kg) for the sound and lame feet. Lameness was induced using a chemical synovitis model (Karriker et al., 2014), and lameness was induced on either the left or right leg.

2 This test was administered in triplicate to 24 sows at −24 h (baseline day before lameness induction), 24 h (d 1 after lameness induction; pretreatment), 48 h (d 2 after lameness induction; pretreatment), 72 h (d 3), and 168 h (resolution).

Comparisons among Treatments Using the Embedded Microcomputer-Based Force Plate System

The embedded force plate was evaluated as an objective assessment tool to discriminate between sound and lame states using only saline-treated sows. Sows administrated only saline demonstrated that weight distributed on the lame claw decreased and weight distributed on the sound claw increased 24 to 72 h (P < 0.002; Table 2) after lameness induction compared with distribution at −24 h. Weight distributions for both the sound and lame legs returned to baseline day levels by 168 h (Table 2). When comparing differences between treatments (saline vs. flunixin vs. meloxicam), no differences were observed between sound- and lame-leg responses at −24 h (P > 0.05; Fig. 1a). Weight distributed between sound and lame legs differed at 24 h compared with distribution at −24 h for all treatments (P < 0.0001). However, at 24 h before any NSAID were given, treatment groups were not different from each other (P > 0.05; Fig. 1a). At 37 to 72 h after lameness induction, both flunixin meglumine and meloxicam sows tolerated more weight on their lame leg compared with saline-treated sows (P < 0.005; Fig. 1a). Differences were observed at T_max2, with flunixin meglumine–treated sows tolerating more weight on their lame leg compared with saline-treated sows (P < 0.004; Fig. 1b). Differences were observed at T_max1 with meloxicam–treated sows tolerating more weight on their lame leg compared with saline-treated sows (P < 0.01; Fig. 1b). All sows regardless of treatment returned to baseline day levels by 312 h (baseline day for the following round) for the embedded force plate (P > 0.05; Fig. 1a).

Comparisons among Treatments Using the GAITFour Pressure Mat Gait Analysis Walkway System

The GaitFour pressure mat gait analysis walkway system was evaluated as an objective assessment tool to discriminate between sound and lame states only using saline-treated sows. Sows administrated saline demonstrated that stance time, maximum pressure, and activated sensors were not different for the sound leg when comparing −24 h to 24 h across treatment groups (P > 0.05; Table 3). However, stance time on the lame leg increased when comparing −24 h to 24 h (P < 0.0001) and remained greater than baseline levels until 72 h (P < 0.001; Table 3). Similarly, maximum pressure and activated sensors decreased on the lame leg from 24 to 48 h compared with −24 h (P < 0.01; Table 3). All parameters returned to baseline levels for the lame leg by 168 h (Table 3).

No differences were observed between sound and lame legs for all GAITRite parameters at −24 h between treatment groups (P > 0.05; Fig. 2a, 3a, and 4a). Differences between sound and lame legs for stance time, maximum pressure, and activated sensors between −24 and 24 h increased for all treatment groups. However, at 24 h before any NSAID were given, treatment groups were not different from each other for these GAITRite parameters (P > 0.05; Fig. 2a, 3a and 4a). Regardless of treatment, all sows returned to baseline day levels by 312 h (baseline day for the following round) for all GAITRite parameters (P > 0.05; Fig. 2a, 3a and 4a).

Stance Time between Treatments Using the GAITFour Pressure Mat Gait Analysis Walkway System

Sows administrated flunixin meglumine and meloxicam had a smaller difference in stance time between sound and lame legs compared with saline-treated sows at 37 h (P < 0.03). Sows administrated meloxicam had a smaller difference in stance time between sound and lame legs compared with saline-treated sows at 48 h (P < 0.04). At 168 h sows treated with flunixin meglumine had a greater difference in stance time between sound and lame legs compared with saline-treated sows (P < 0.004; Fig. 2b). Meloxicam–treated sows at Tmax had a decreased stance time compared with saline-treated sows (P < 0.0004; Fig. 2b), and flunixin meglumine–treated sows at T_max2 had a decreased stance time compared with saline-treated sows (P < 0.0001; Fig. 2b).
Drug efficacy for lame sows

Sows administered flunixin meglumine applied greater maximum foot pressure to the mat compared with saline-treated sows (Fig. 3a and 3b; \( P < 0.003 \)). Sows administered meloxicam applied greater maximum foot pressure at 60 h (Fig. 3a; \( P < 0.01 \)) when compared with saline-treated sows.

**Activated Sensors between Treatments Using the GAITFour Pressure Mat Gait Analysis Walkway System**

Sows administered flunixin meglumine or meloxicam had a smaller difference in activated sensors between sound and lame legs compared with saline-treated sows between 37 and 60 h (Fig. 4a; \( P < 0.002 \)). Sows administered flunixin meglumine had a smaller difference in activated sensors compared with saline-treated sows at both T\text{max} time points (Fig. 4b; \( P < 0.006 \)).

**Stride Length and Stride Time between Treatments Using the GAITFour Pressure Mat Gait Analysis Walkway System**

No differences were observed for stride time for sound- and lame-leg responses at 24 h (stride time average: 0.49 ± 0.02 s) compared with −24 h (stride time average: 0.47 ± 0.02 s) for saline-treated sows only. Differences were observed in stride length for sound and lame leg responses at 24 h (Stride length average: 81.3 ± 1.8 cm) compared to −24 h (Stride length average: 91.3 ± 1.8 cm) for only saline treated sows. However, there were no treatment differences found for these variables; therefore, data will not be reported.

**DISCUSSION**

**Transient Synovitis Model**

This amphotericin B–induced lameness model produced a transient and reproducible synovitis of the distal interphalangeal joint for all sows. All sows were clinically sound before lameness induction for each round, showing no evidence of weight-shifting activities, non-weight-bearing behavior, or reluctance to walk or stand on any leg. Peak lameness was observed 24 h after induction, with all sows demonstrating clinical lameness including weight shifting and reluctance to walk. This coincides with results from previously published work assessing validity of amphotericin B–induced lameness model in swine (Tapper et al., 2013; Karriker et al., 2014) and cattle (Kotschwar et al., 2009), as well as studies utilizing this model to assess pain sensitivity (Nalon et al., 2013; Mohling et al., 2014a,b; Pairis-Garcia et al., 2014b). When comparing baseline data between consecutive treatment periods, results from the

**Maximum Pressure between Treatments Using the GAITFour Pressure Mat Gait Analysis Walkway System**

Sows administered flunixin meglumine applied greater maximum foot pressure to the mat compared with saline- and meloxicam-treated sows at 37 h. In addition, at 48 h, 60 h, and both T\text{max} time points, sows administered flunixin meglumine applied greater maximum foot pressure compared with saline-treated sows (Fig. 3a and 3b; \( P < 0.003 \)). Sows administered meloxicam applied greater maximum foot pressure at 60 h (Fig. 3a; \( P < 0.01 \)) when compared with saline-treated sows.
force plate and GAITRite did not differ, confirming no lameness carryover. In addition, blood collection tests on baseline days confirmed systemic drug levels were below the detection limit (Pairis-Garcia et al, unpublished), ensuring data collected from subsequent rounds was not influenced by residual drug carryover.

**Objective Lameness Assessment Using an Embedded Microcomputer-Based Force Plate System and GaitFour Pressure Mat Gait Analysis Walkway System**

Historically, on-farm lameness evaluation has been conducted utilizing visual assessment scales that implement visual analog or categorical scoring systems (Main et al., 2000; Petersen et al., 2004; Tiranti and Morrison, 2006). However, limitations with this assessment arise because of inter- and intraobserver bias or individual variation and lack of consistency over time (D’Eath, 2012). Evaluating changes to the locomotion biomechanical parameters provides an objective, sensitive, and precise means to detect animals in lame states (Pluym et al., 2013b). Lameness detection utilizing static and dynamic gait variables has been proven effective in assessing lameness in several species, including dairy cattle (Flower et al., 2005; Maertens et al., 2011), chickens (Corr et al., 2007), horses (Weishaupt et al., 2006), and swine (Gregoire et al., 2013; Pluym et al., 2013b; Conte et al., 2014; Meijer et al., 2014; Stavarakakis et al., 2014). Gait variables primarily focused to detect swine lameness pain in previous studies include changes in stance time, absolute weight distributed per leg, leg symmetry, joint angle, and maximum pressure applied per leg. Both the embedded microcomputer-based force plate system and GaitFour pressure mat gait analysis walkway system successfully demonstrated differences in pain sensitivity between lame and nonlame states for sows induced to be lame using a chemical synovitis model.

Differences in sound- and lame-leg responses were noted −24 h up to 168 h after lameness induction. The results from the present study suggest that the force plate and GAITRite are objective tools that can assess pain sensitivity as it relates to lameness in swine.

Results from the embedded microcomputer-based force plate system coincide with results by Mohling et al. (2014a) demonstrating similar, although slight, variations. For example, Mohling et al. (2014a) reported increases in weight applied to the sound foot to be approximately 6.1 kg and decreases in weight applied to the lame foot at 15.7 kg. Our results found increases in weight applied on the sound foot to be as high as 13.3 kg and decreases in weight applied to the lame foot at 20.3 kg. This difference may be due to a 20 kg greater average weight for sows in this study. In addition, sound and lame leg responses in Mohling et al. (2014a) did not return to baseline weight levels, whereas the sows in our study returned to baseline levels by the recovery time point. It should be noted that the recovery day in Mohling et al. (2014a) was 144 h after lameness induction, and the one in this study was 168 h after lameness induction, possibly accounting for these differences. Results from studies conducted outside of our laboratory also agree with the ability of a force plate system to detect differences in lame and nonlame states. Pluym et al. (2013a) demonstrated differences in weight distribution during naturally occurring lameness and found that when sows were identified as rear hind lame, absolute weight was 510 ± 81 N (absolute weight ± SD) as compared with that of the sound hind leg at 638 ± 40 N (conversion of newtons to kilograms: lame leg: 52 ± 8.3 kg; sound leg: 65 ± 4.1 kg). The results in this study and those in our study demonstrate the same directional pattern, although the magnitude differs. This discrepancy may be due to a variety of factors, including sow weight, lameness severity, or etiology.

### Table 3. Traits by sampling time least squares means (±SE) from a GAITFour pressure mat analysis walkway system for 24 saline-treated sows using a lameness induction model

<table>
<thead>
<tr>
<th>Trait</th>
<th>Leg</th>
<th>−24</th>
<th>24</th>
<th>48</th>
<th>72</th>
<th>168</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stance time, s</td>
<td>Sound</td>
<td>0.304 ± 0.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.303 ± 0.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.319 ± 0.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.307 ± 0.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.286 ± 0.01&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Lame</td>
<td>0.296 ± 0.01&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.338 ± 0.01&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.342 ± 0.01&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>0.321 ± 0.01&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.292 ± 0.01&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td>Maximum pressure, kg/cm&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Sound</td>
<td>75.0 ± 4.1&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td></td>
<td>Lame</td>
<td>76.7 ± 3.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>58.5 ± 3.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>66.8 ± 3.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>73.6 ± 3.6&lt;sup&gt;c&lt;/sup&gt;</td>
<td>74.6 ± 3.6&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Activated sensors</td>
<td>Sound</td>
<td>20.2 ± 0.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>21.1 ± 0.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>21.8 ± 0.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>21.3 ± 0.9&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>20.5 ± 0.9&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Lame</td>
<td>19.9 ± 0.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>16.7 ± 0.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>18.3 ± 0.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>19.8 ± 0.9&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>19.7 ± 0.9&lt;sup&gt;a&lt;/sup&gt;</td>
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</tbody>
</table>

<sup>a–c</sup>Within a row means without a common superscript differ (<i>P</i> < 0.05).

<sup>1</sup>GAITFour pressure mat analysis walkway system estimated gait traits for the sound and lame foot. Lameness was induced using a chemical synovitis model (Karriker et al., 2014).

<sup>2</sup>This test was administered in triplicate to 24 sows at −24 h (baseline day before lameness induction), 24 h (d 1 after lameness induction; pretreatment), 48 h (d 2 after lameness induction; pretreatment), 72 h (d 3), and 168 h (resolution).
Drug efficacy for lame sows

The GaitFour pressure mat gait analysis walkway system calculated 5 different traits. When evaluating saline-treated sows on only the sound leg, the present data coincide with previous results by Gregoire et al. (2013), who reported stride length at 90.4 ± 1.1 cm compared with 91.3 ± 1.8 cm in the present study. They found stance time to be longer at 0.74 ± 0.02 s compared with the stance time at 0.30 ± 0.01 s in the present study. When assessing the efficacy to detect differences between lame and nonlame states, stance time,
maximum pressure, and number of activated sensors successfully demonstrated these differences. When assessing the lame leg alone, an increase in stance time and decreases in maximum pressure and total number of activated sensors were observed. Changes in these parameters coincide with previous work conducted in dairy cattle (Flower et al., 2005; Van Nuffel et al., 2013) and swine (Karriker et al., 2014; Mohling et al., 2014a). Flower et al. (2005) reported that dairy cattle exhibiting lameness had increased stance time and applied less pressure on the lame foot. For swine, Mohling et al. (2014b) and Karriker et al. (2014) reported similar results in both decreased maximum pressure and reduced number of activated sensors. One minor difference noted was that Mohling et al. (2014b) found average starting maximum pressures between 36.2 and 38.2 kg/cm², whereas our study found starting maximum pressures between 75.0 and 76 kg/cm². Again, as demonstrated with weight distribution on the force plate, these differences are most likely attributed to differences in sow BW (average BW of 220.15 ± 21.23 kg in Mohling et al., 2014a, and 241.4 ± 15.5 kg in the current study).

In conclusion, the embedded microcomputer-based force plate system and GaitFour pressure mat gait analysis walkway system successfully demonstrated differences in pressure and weight placed on the lame limb, thus indirectly indicating that the animal was in a painful state. These differences were evident up to 168 h after lameness induction and demonstrate the ability for either tool to be utilized on farm as a measurement for sow lameness.

**Analgesic Efficacy**

When assessing drug efficacy utilizing force plate data alone, flunixin meglumine and meloxicam mitigated pain sensitivity between 37 and 72 h after lameness induction compared with saline. These data coincide with previous work conducted on the same group of sows measuring mechanical nociceptive threshold tests to assess pain sensitivity (Pairis-Garcia et al., 2014b). Utilizing a pressure algometer, both flunixin meglumine and meloxicam-treated sows demonstrated greater pressure tolerance compared with saline-treated sows between 37 and 72 h after lameness induction. Utilizing traits from the GAITRite walkway system, flunixin meglumine mitigated pain sensitivity as early as 37 h after lameness induction when differences in stance time between sound and lame legs were evaluated. In addition, maximum pressure and number of activated sensor differences between sound and lame legs revealed flunixin meglumine successfully mitigated pain sensitivity at both Tₘᵢₓ time points. Tₘᵢₓ, which is defined as the time in which the drug reaches its maximum concentration, was chosen on the basis of the goal to collect data in a window of time in which the drug may be most effective. The results from the present study suggest that flunixin meglumine begins to mitigate pain sensitivity as early as 1 h postadministration. Meloxicam-treated
sows successfully mitigated pain sensitivity 37 and 48 h after lameness induction when changes in stance time were assessed and between 37 and 60 h after lameness induction when changes in activated sensors were assessed. However, differences were only detectable at T_{max} for stance time data alone. On the basis of this, T_{max} for meloxicam may not coincide with maximal drug efficacy. T_{max} for meloxicam was based on a pilot study conducted by our laboratory (Pairis-Garcia et al, unpublished). In a follow-up pharmacokinetic study, results showed that T_{max} for meloxicam was 2.40 h with a half-life at 6.8 h. On the basis of these results, it is likely that the T_{max} chosen for this study did not represent the true T_{max} and maximal drug efficacy was not captured during our data collection. Future studies evaluating meloxicam later than 2 h may help to determine when pain mitigation for lame sows begins.

Flunixin meglumine has been identified as an effective drug for pain management when treating lame cattle (Schulz et al., 2011), sheep (Welsh and Nolan, 1995), and horses (Foreman and Ruemmler, 2011). Meloxicam has also more recently been the focus of research as an effective drug for pain management for lameness in multiple species (Friton et al., 2003; Coetzee et al., 2014; Pairis-Garcia et al., 2014b). It should be noted that previous research evaluating flunixin meglumine and meloxicam efficacy, with the exception of work conducted by Friton et al. (2003), has been conducted on experimentally induced lameness. Therefore, future studies evaluating the efficacy of either NSAID need to be conducted on sows with naturally occurring lameness to determine to what extent pain is mitigated on multifactorial lameness etiologies. Although there are no approved drugs in the United States that are specifically labeled for pain for treating livestock that are lame, both meloxicam and flunixin meglumine may be administered in an extralabel manner provided the requirements described in the Animal Medicinal Drug Use Clarification Act regulations and conditions are met. According to the results in this study, flunixin meglumine and meloxicam administration resulted in pain mitigation 2 and 37 h postadministration, respectively. Because both medications mitigate pain associated with lameness, additional advantages should be considered. Such advantages for flunixin meglumine use for pain management in lame sows include its current accessibility on farm and established meat withhold period, whereas advantages for oral meloxicam use include its cost-effectiveness (meloxicam: $0.004/kg BW to administer at 1.0 mg/kg; flunixin meglumine: $0.01/kg BW to administer at 22 mg/kg), easy administration, and absence of potential injection site lesion.

In conclusion, meloxicam and flunixin meglumine were effective in mitigating pain sensitivity in lame sows evaluated using an embedded microcomputer-based force plate system and GaitFour pressure mat gait analysis walkway system. Our research suggests that meloxicam and flunixin meglumine are effective pharmacological interventions for alleviating pain associated with a chemically induced synovitis model. Further research evaluating the efficacy and optimizing the dose regimen of these drugs in chronic or naturally occurring lameness on farm should be investigated.

**LITERATURE CITED**


