Journal of the American Association for Laboratory Animal Science
Vol 59, No 1
January 2020
Pages 85–89

Effect of Cranial Flexion of Pelvic Limbs on Interlaminar Length of the Lumbosacral Space in Sternally and Laterally Recumbent Juvenile Duroc and Adult Yucatan Pigs

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Epidural puncture in swine is technically challenging. Several combinations of limb and body positions have been suggested to increase lumbosacral interlaminar space (LSS) and lumbosacral angle (LSA). This study investigated whether cranial hyperflexion of pelvic limbs increased LSS and LSA in laterally and sternally recumbent juvenile Duroc and adult Yucatan pigs and assessed which position produced the largest LSS. Juvenile Duroc (n = 7) and adult Yucatan (n = 7) pigs were euthanized and randomly placed in 4 positions: sternal with neutral limbs, sternal with cranially hyperflexed limbs, lateral with neutral limbs, and lateral with hyperflexed limbs. LSS and LSA were measured on transverse axial CT images of the spine and compared by using multivariate ANOVA and the Student t test. In both age groups, LSS was greater in lateral flexed (juvenile, 7.0 ± 0.7 mm; adult, 15.9 ± 1.1 mm) and sternal flexed (juvenile, 7.5 ± 1 mm; adult, 17.1 ± 1.1 mm) positions than in lateral neutral (juvenile, 5.4 ± 0.9 mm; adult, 9.6 ± 1.6 mm) position. In addition, in both age groups, LSS and LSA in lateral neutral position were smaller than lateral flexed, sternal neutral, and sternal flexed positions. In adults, LSS was greater in lateral flexed and sternal flexed than in sternal neutral position. Hyperflexion of pelvic limbs increases LSS and LSA in sternally recumbent adult Yucatan pigs and laterally recumbent adult Yucatan and juvenile Duroc swine. Increased LSS from positioning pigs with pelvic limbs flexed in sternal or lateral recumbence may facilitate epidural puncture compared with neutral limb positioning.

Abbreviations: LF, lateral flexed; LN, lateral neutral; LSA, lumbosacral angle; LLS, lumbosacral interlaminar space; LS ratio, ratio between LSS and LVB; LSS, lumbosacral interlaminar space; LVB, length of the last lumbar vertebral body, SF, sternal flexed; SN, sternal neutral

DOI: 10.30802/AALAS-JAALAS-19-000064

Pigs are a key model species in translational research. They are often used as an alternative to dogs or NHP as the nonrodent species of choice for preclinical toxicologic testing of drugs and have largely replaced dogs as a surgical model for research and training.[22] In the last decade, swine have gained popularity in the pet industry. This growing interest demands more species-specific scientific information to meet the clinical standard of care currently reserved for more common pet species, such as dogs and cats.

Epidural administration of drugs is commonly used to provide regional anesthesia and analgesia to veterinary patients. In pigs and humans, the epidural puncture is often performed at the level of the lumbosacral space for abdominal surgeries and reproductive and urinary tract procedures.[1,2,6-8,13,15,20,21] The anatomic references for lumbosacral puncture are the last lumbar spinous process and 2 cm caudal to the midpoint of an imaginary line that joins the iliac crests.[25] In pigs, epidural puncture is considered technically demanding due to narrow vertebral spaces and the size and orientation of spinous processes, which tend to impede access to the epidural space.[19,21] In addition, due to the conformation of the spine, the distance between the skin and dorsal lumbosacral interspinous space is greater than in other species of the same body size.[19] A search of the current literature revealed that positioning in right lateral recumbency is frequently used by medical professionals and researchers to perform epidural puncture in pigs used as translational models.[16,19] Another approach is to position the animal in sternal recumbency, with pelvic limbs flexed cranially along the abdomen or left hanging off the procedure table.[21] The purpose of this positioning is to flex the spine to favor opening of the intervertebral space to increase its length, under the assumption that this would increase the rate of successful placement of epidural and spinal punctures. The variation in length of the lumbosacral interlaminar length (LSS) and the variation of the lumbosacral angle (LSA) have been described in anesthetized dogs whose pelvic limbs were placed in either neutral or cranially flexed positions while the animals were sternally recumbent.[4] This study found that in small-, medium-, and large-breed dogs, LSS increased by 100%, 83%, and 75%, respectively, when pelvic limbs are flexed cranially to lay along the abdominal wall.

Given the range of techniques reported, an objective comparison could potentially lead to the development of a standard

Received: 29 Apr 2018. Revision requested: 10 Jun 2019. Accepted: 01 Jul 2019.
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of care for epidural access in pigs. The objective of the present study was to use measurements obtained from 2D CT images to quantify the variation of LSS and LSA in juvenile Duroc and adult Yucatan pigs positioned in sternal and right lateral recumbency, with or without hyperflexion of the pelvic limbs. The tested null hypotheses were that cranial hyperflexion of pelvic limbs would not increase LSS and LSA of the tested pigs placed in sternal and right lateral recumbency and that sternal positioning would not produce greater LSS and LSA compared with lateral. By evaluating both group ages, the results could reveal the optimal combination of body and limb positions for subjects of different sizes and ages.

Materials and Methods

Approval from the Louisiana State University's IACUC was obtained prior to study initiation. Intact adult male Yucatan (*n* = 7; age [mean ± SEM], 618 ± 16 d; weight, 65 ± 4 kg) and juvenile Duroc swine (*n* = 7; 4 females, 3 males; age, 95 ± 2 d; weight, 18 ± 3 kg) were included as 2 separate groups in this prospective, randomized, crossover study. The number of subjects in each age cohort was derived from published canine data and detected a minimal LSS increase of 30% after cranial hyperflexion of the pelvic limbs with 95% confidence.[4] Subjects were deemed healthy based on physical examination and were assigned a body condition score according to previous literature.[3] Animals with current or a history of ataxia or lameness were excluded from the study. The positioning order for each animal was determined by using a sequence generator (JMP Pro 13.0.0; SAS Institute, Cary, NC). Pigs were not fed for 12 h, but water was available until 1 h prior to sedation. After intramuscular injection of tiletamine and zolazepam (6 mg/kg; Zoetis, Kalamazoo, MI) and loss of the righting reflex, pigs were euthanized as part of an unrelated study through injection of pentobarbital sodium (1 mL/kg; Fatal Plus solution, Vortech Pharmaceutical, Dearborn, MI) into the cranial vena cava according to current AVMA guidelines.[12] Immediately after confirmation of death, subjects were positioned on a CT table. Potential rigor mortis was measured at the time of euthanasia and at 5, 10, 20 and 30 min afterward by the same investigator (TT) through finger pressure on the semimembranosus according to a modification of a published technique.[26] Rigor mortis scoring was assigned as follows: 1, surface feels soft; 2, surface feels mildly firm; 3, surface feels firm. Time from confirmation of death to last scan was recorded. Each subject's lumbosacral spine was scanned, with each pig positioned randomly in each of 4 positions: sternal with pelvic limbs in neutral position (tarsus flexed under the pelvis; SN), sternal with pelvic limbs hyperflexed cranially (medial aspect of digits touching abdominal wall; SF), lateral with pelvic limbs in a neutral position (limbs positioned with the femur at a 90° angle with the main longitudinal axis of the subject; LN), and lateral with pelvic limbs hyperflexed cranially (digits touching abdominal wall and held in place by using adjustable straps and sandbags; LF). To meet the positioning criteria, the same investigator (NR) positioned each subject. Transverse axial images of the spine were acquired by using a multidetector helical CT scanner (LightSpeed 16 slice CT Scanner, GE Healthcare, Waukesha, WI), in 3- to 5-mm slice thickness in a standard soft tissue algorithm and reconstructed in 0.625-mm slice thickness in a bone algorithm.

Images were evaluated by a board-certified radiologist (NR) using a commercially available DICOM image viewer (OsiriX version 5.6, https://www.osirix-viewer.com/, Bernex, Switzerland). Measurements were repeated twice, several days apart. The sagittal multiplanar reconstruction displayed in a bone window (length, 300; width, 1500; Figures 1 through 4) was used to measure the length of the interlaminar space between the last lumbar and the first sacral vertebrae (LSS), between the last lumbar and second-last interlaminar space (LLS), the length of the last lumbar vertebral body (measured halfway between the dorsal and ventral borders of the vertebral body, LVB), and the lumbosacral angle (LSA) at the intersection between a line tangent to the dorsal aspect of the last lumbar vertebral body and a line tangent to the dorsal aspect of the body of the sacrum.[7] The ratio between LSS and the length of the last lumbar vertebrae (LS ratio) was calculated.

Statistical analysis was performed by using JMP software (JMP Pro 13.0.0, SAS Institute). A Shapiro–Wilk test was used to verify the normality of data. A multivariate ANOVA accounting for position as a fixed effect, and paired *t* test were used to compare CT measurements (LSS, LLS, LVB, LSA, LS ratio), rigor mortis scores, and time intervals between SN and SF, SN and LN, SN and LF, SF and LN, SF and LF, and LN and LF. Parametric data are reported as mean ± SEM. Significance was set as a P value less than 0.05.

Results

All subjects were included in the study, and all data were normally distributed. Weight, body condition score, rigor mortis score, and scanning sequence and timing did not differ within age cohorts and did not affect the measures compared in the multivariate model. Whereas 3 of the adult Yucatan pigs had 5 lumbar vertebrae, the remaining 4 had 6. Similarly, 5 adult Yucatan pigs had 4 fused sacral vertebrae, and the remaining had 3. In the juvenile cohort, all subjects had 6 lumbar and 3 sacral vertebrae. No pathologic changes were noted in adult pigs, whereas one of the juvenile swine had nonclinical osteochondritis of the sacrum. Time from confirmation of death to last scan was 20.6 ± 5 min, and none of the pigs showed any rigor mortis by the end of imaging.

CT measurements (Table 1) revealed that cranial hyperflexion of the pelvic limbs increased LSS by 30% in laterally recumbent juvenile Duroc pigs and by 65% in laterally recumbent adult Yucatan swine. In contrast, in sternally recumbent animals, the increase was only 9% in juvenile Duroc and 22.9% in adult Yucatan pigs. The greatest increase in LSS was seen in adult Yucatan subjects, when LN and SF were compared (78%). In both groups, LF, SN, and SF yielded greater LSS than LN. However, in juvenile Duroc swine, LSS did not differ between lateral and sternal body positions when pelvic limbs were hyperflexed or when they were hyperflexed in sternal position. In addition, in the adult group, only SF increased LSS significantly compared with LF. In both age cohorts, LSA was greater in LF, SN, and SF when compared with LN. In the adult group, LSA decreased between SF and SN. Neither body nor leg positioning altered LLS. Body positioning affected LVB measurements only in juvenile subjects. In adult pigs, the LS ratio was greater for LF, SN, and SF than for LN and in SF compared with SN.

Discussion

In the current literature, whether sternal or lateral recumbency was adopted for performing epidural puncture in pigs often is not specified,[9,17] and in studies where recumbency is described, the pelvic limb position is often not specified.[16,19,24,27] In previous research on epidural puncture in laboratory piglets (30 to 50 kg), positioning in lateral recumbency was suggested to aid in palpation and stabilization of the pelvis.[19] According to the

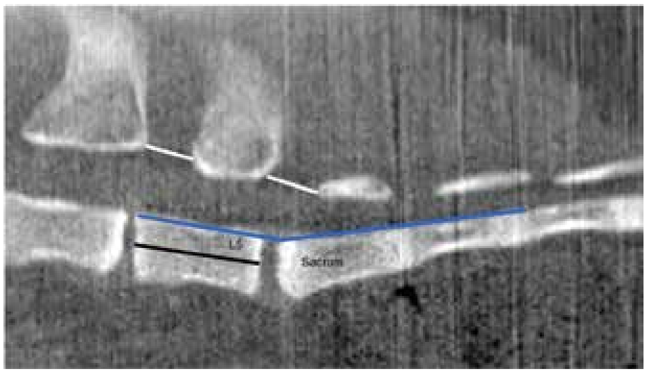

Figure 1. Multiplanar sagittal reconstruction of the lumbar spine by using a bone algorithm to demonstrate various measurements. A subject from the Yucatan group is positioned in lateral recumbency, with pelvic limbs in neutral position. The sagittal multiplanar reconstruction was used to measure the distance of the lumbosacral and second-last and last lumbar interlaminar spaces (white lines), the length of the last lumbar vertebral body (black line), the lumbosacral angle (blue line), and the ratio between LSS and the length of the last lumbar vertebrae.

Figure 2. Multiplanar sagittal reconstruction of the lumbar spine by using a bone algorithm to demonstrate various measurements. A subject from the Yucatan group is positioned in lateral recumbency, with pelvic limbs hyperflexed cranially. White lines, lumbar interlaminar spaces; black line, length of last lumbar vertebral body; blue line, lumbosacral angle.

cited study,[19] it is easier to position small animals in lateral recumbency than in sternal recumbency once they are under general anesthesia; however, the pelvic limb position was not specified. This inconsistency in positioning techniques occurs throughout the human and veterinary literature, and it is likely due to the wide ranges in the sizes and breeds of pigs (laboratory, commercial, miniature). Therefore, development of a standard positioning for epidural access is important for establishing a standard of care. The objective of the present study was to quantify the variation of LSS and LSA in juvenile and adult pigs positioned in 4 combinations of sternal and right lateral recumbency with or without hyperflexion of pelvic limbs. Our results show that in both of the age and size groups, cranial hyperflexion of the pelvic limbs was effective in increasing LSS and LSA only when performed in lateral recumbency and that both combinations of sternal recumbency are superior to a lateral neutral position in 'opening' the LSS and LSA. However, hyperflexing the pelvic limbs was advantageous in sternal recumbency for increasing LSS only in adult Yucatan pigs. The increase in LSS seen in adult Yucatan pigs is consistent with those of sternally recumbent dogs.[4] The idea is that the lordosis of the spine induced by hyperflexion of the pelvic limbs leads to lumbar spinal flexion and opening of the LSS, as demonstrated in dogs.[4,14] The same principle is adopted in human patients when the lateral decubitus or 'sitting positions' are adopted for performing neuraxial anesthesia, where patients are asked to flex their thighs onto the abdomen and to bend the neck to allow the forehead to touch the knees, to increase the intervertebral spaces.[2]

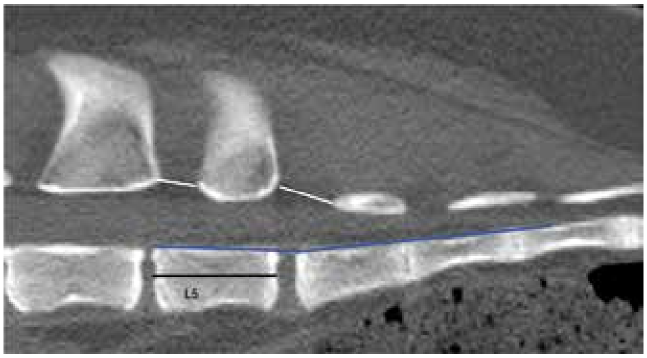

Figure 3. Multiplanar sagittal reconstruction of the lumbar spine by using a bone algorithm to demonstrate various measurements. A subject from the Yucatan group is positioned in sternal recumbency, with pelvic limbs in neutral position (flexed under pelvis). White lines, lumbar interlaminar spaces; black line, length of last lumbar vertebral body; blue line, lumbosacral angle.

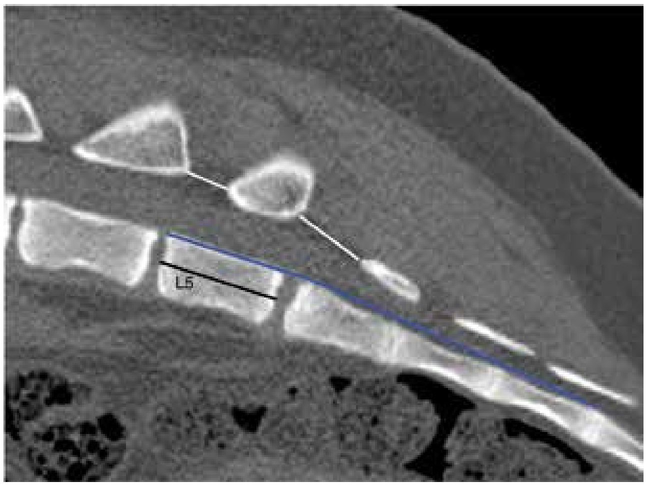

Figure 4. Multiplanar sagittal reconstruction of the lumbar spine by using a bone algorithm to demonstrate various measurements. A subject from the Yucatan group is positioned in sternal recumbency, with pelvic limbs hyperflexed cranially. White lines, lumbar interlaminar spaces; black line, length of last lumbar vertebral body; blue line, lumbosacral angle.

The LSS has been reported to measure about 2 cm craniocaudally in pigs.[5] However, it seems logical that this space would vary depending on the size and breed of pig. As demonstrated in our study, the LSS in both neutral positions ranged between 5.4 and 6.9 mm in juvenile Duroc pigs and between 9.6 and 14.4 mm in adult Yucatan pigs. This narrow space, the large vertebral bodies, and the increased distance between the skin

Table 1. Summary of the measurements obtained from 2D CT scans in recently euthanized pigs positioned in right lateral recumbency with (LF) or without (LN) cranial hyperflexion of the pelvic limbs and in sternal recumbency with (SF) or without (SN) cranial hyperflexion of the pelvic limbs

Juvenile Group	LN	LF	SN	SF
LSS (mm)	5.4 ± 0.9	7 ± 0.7[a]	6.9 ± 1.1[b]	7.5 ± 1[c]
LSA (°)	156.6 ± 6.2	169 ± 2.8[a]	167.3 ± 3[b]	170 ± 2.8[c]
LVB (mm)	19.1 ± 0.8	19.3 ± 0.9	18.4 ± 1.1[b,d,e]	18.2 ± 0.9[c]
LLS (mm)	6.7 ± 1.3	6.9 ± 1	7.5 ± 0.7	7.9 ± 1.2
LS-ratio	0.3 ± 0.04	0.4 ± 0.04[a]	0.4 ± 0.06[b,e]	0.4 ± 0.05[c]
Adult group				
LSS (mm)	9.6 ± 1.6	15.9 ± 1.1[a]	14.4 ± 1.4[b,d, f]	17.7 ± 1.1[c,e,f]
LSA (°)	166.3 ± 4	173.7 ± 3.4[a]	174.4 ± 3.2[b]	171.9 ± 3.8[c]
LVB (mm)	31 ± 1.1	31.4 ± 1.3	31 ± 0.82	31.1 ± 0.5
LLS (mm)	9.8 ± 1.6	10.3 ± 0.9	8.9 ± 2.3	10.7 ± 1f
LS-ratio	0.3 ± 0.05	0.5 ± 0.03[a]	0.5 ± 0.05[b]	0.5 ± 0.04[c,f]

Data are reported as mean ± SEM. Superscripted letters indicate statistically significant differences ($P < 0.05$) between compared positions.
[a]LN compared with LF
[b]LN compared with SN
[c]LN compared with SF
[d]LF compared with SN
[e]LF compared with SF
[f]SN compared with SF

and epidural space make epidural access in pigs challenging for operators.

LSA can be used to quantify the degree of spinal flexion among various positions. Our results indicate that hyperflexion of the pelvic limbs increased the LSA in lateral recumbency in juvenile Duroc and adult Yucatan pigs, thus confirming and quantifying the degree of spinal flexion in lateral positioning. However, unlike findings in canine subjects,[4] LSA did not differ between neutral and hyperflexed limb position when pigs were in sternal recumbency. This result might reflect an already maximal degree of spinal lordosis (independent of pelvic limb position) when pigs are placed sternally, likely due to anatomic differences between dogs and swine. However, the observed increase in LSS length seems to be an advantage to flexing the limbs in this group of adult Yucatan pigs. Due to the design of the CT table, pelvic limbs were positioned with the tarsus flexed under the pelvis when in sternal recumbency for neutral limb position. This arrangement is a fairly common way of positioning a patient in sternal recumbency. Flexing the tarsus—and therefore the stifle and coxofemoral joint—may induce some spinal lordosis may have been induced, compared with leaving the limbs at a 90° angle to the spine, as defined for the lateral neutral position.

The traditional vertebral formula for swine often describes between 6 and 7 lumbar vertebrae.[5] The pigs included in this study had 5 or 6 lumbar vertebrae. A longer lumbar column might allow for increased flexibility, possibly favoring the further opening of LSS. However, although the juvenile Duroc had more lumbar vertebrae than the adult Yucatan, the absolute length of the spine was shorter due to their younger age, possibly explaining the smaller percentage of increase in LSS in juveniles. Inherently, juvenile pigs have a proportionally smaller lumbosacral space, vertebrae, and surrounding structures, therefore limiting the maximal degree of flexion. Similarly, the group of small-breed dogs (weight greater than 10 but less than 15 kg) had a smaller increase in the LSS distance than did medium- and large breed groups.[4] There was an increased variability in the measurements in the juvenile group with the length of the last lumbar vertebra between the 4 positions. In theory, the vertebral body is a bony structure that should not change when body position changes. The observed variability could be due to the stage of development of this group. Many juvenile subjects had open physes in their vertebral bodies, which made this parameter difficult to measure and could have played a role in this finding. Although the LS ratio could be used to compare the LSS in all positions regardless of body size,[4] this ratio could not be used for comparison in juvenile subjects due to the difference in the length of last lumbar vertebrae in this group.

One juvenile Duroc presented osteochondrosis dissecans of the caudal facet of the last lumbar vertebra. This condition is characterized by the separation of a fragment of joint cartilage from the subchondral bone, and it is clinically associated with leg weakness.[10,11,18] Osteochondrosis dissecans is present in high frequency in growing pigs,[23] and it has been shown to have hereditability in Duroc, Landrace, and Yorkshire swine.[11] Although the pathophysiology has not been fully clarified, it has been suggested that compression injury may play a role in swine.[18] Common sites of presentation include the femoral and humeral condyles, distal ulna, and tibia, hock, and talus.[10,11] The affected subject did not present clinical signs of leg weakness, ataxia, or lameness, although, interestingly, this subject belonged to one of the breeds linked to gene-based hereditary osteochondrosis dissecans.

The null hypothesis tested in this study was that cranial hyperflexion of pelvic limbs would not increase LSS and LSA of juvenile Duroc and adult Yucatan pigs placed in sternal and right lateral recumbency. According to our results, hyperflexion of pelvic limbs increases LSS and LSA in sternally recumbent adult Yucatan pigs and in laterally recumbent adult Yucatan and juvenile Duroc pigs, whereas hyperflexing the pelvic limbs of juveniles in sternal recumbency does not increase LSS size. Increasing LSS and LSA would presumably facilitate epidural puncture due to the presence of a 'bigger target.' Data on the causal link between greater LSS and LSA and ease of performance are not available currently, and whether placing human patients in one position compared with another would facilitate successful epidural anesthesia is unknown.[2] Therefore, an investigation to determine whether flexing the spine to increase LSS and LSA would actually increase the likelihood of successful epidural access in pigs is warranted. By evaluating the practical application of the combination of body–limb positions with the rate of successful epidural access, a standard of care can be developed in the future for commercial, research, and pet pigs. Cranial hyperflexion of pelvic limbs increases the LSS and LSA in sternally recumbent adult Yucatan pigs and in laterally recumbent adult Yucatan and juvenile Duroc swine. Therefore, cranial hyperflexion of the pelvic limbs in these positions may facilitate epidural puncture due to the increased LSS and LSA. In juveniles Duroc, the results indicate that pelvic limb hyperflexion in sternal recumbency offers no clear advantage in regard to epidural access.

Acknowledgments

We sincerely thank Dr Rhett Stout for help with the swine colony, Mark Hunter for acquisition of the images, Mr Takashi Taguchi for data collection, and Dr Chin Chi Liu for the statistical analysis. We also thank the Louisiana State University Competitive Organized Research Program for funding this study.

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