Ultrasonographic characterization of the ovaries and the uterus in prepubertal and pubertal gilts

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Abstract

In two experiments (EXP), 44 and 52 crossbred gilts (mean age ± S.D. and weight ± S.D.: 204 ± 22 and 203 ± 9 days, 114 ± 13 and 127 ± 12 kg, respectively, in EXP 1 and 2) from four farms were examined by means of transcutaneous ultrasonography (US) to define the characteristics of the ovaries and the uterus (echotexture, size) and to investigate the appropriateness of US to determine sexual maturity. Gilts were judged as prepubertal [PRE; follicles 2–5 mm (F2–5) only] or pubertal [PUB; F7–8, corpora lutea (CL), corpora haemorrhagica (CH)] at the first (PUB-1; EXP 1) or a subsequent estrous cycle [PUB-2; additionally corpora albicantia (CA); EXP 1] by US, and results were verified by postmortem examination (EXP 1), or progesterone analysis and detection of estrous signs (EXP 2). Accuracy of US was 100% for PRE and PUB (both EXP) and 77.3% for PUB-1 and PUB-2 (EXP 1). PRE and PUB with CL/CH had uteri of homogeneous, PUB with F7–8 of heterogeneous echotexture. The size was expressed as the mean sectional area (SAsono) of 2–5 cross-sections of the uterine horns (calculated by multiplication of 1/2 the maximum × the minimum dimension of the cross-sections × π). SAsono corresponded with the sectional area of postmortem dissected transverse uterine segments relatively with r = 0.92 (P < 0.0001; EXP 1). Mean SAsono (both EXP) and mean uterine weight (EXP 1) were PRE < PUB (all P < 0.0001). SAsono and UW showed a high correlation (UW = 287 × SAsono − 66; r = 0.92; P < 0.0001; EXP 1). In conclusion, the diagnosis of sexual maturity is facilitated in prepubertal and pubertal gilts based on the characteristics of the ultrasonographic appearance of the ovaries and the size of the uteri.

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Keywords: Gilt; Sexual maturity; Ultrasonography; Ovary; Uterus

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1. Introduction

Thirty to 40% of the sow herd is replaced by gilts each year. The gilts must have attained puberty prior to introduction into a herd. Puberty attainment, however, could be associated with several problems (reviewed in [1]). For instance, in confinement-reared gilts, the onset of puberty is often delayed (reviewed in [1,2]). Other gilts are referred to as being delayed, although ovulation had occurred [3], assuming, that estrous symptoms were weak or lacking [4,5], or estrus detection was not always performed carefully (reviewed in [1]). On the other hand few gilts remain anovulatory despite showing estrous symptoms [6,7]. Therefore, producers are often confused about whether the gilts are sexually mature or not. As a result, gilts were slaughtered for anestrus despite being pubertal [3], or were mated during the first estrus, although an adverse effect on the farrowing rate [8] and litter size [9] is to be assumed. Because such management errors apparently reduce financial profit, there is a need for a reliable and practicable method to detect sexual maturity on farms. In research, besides detection of estrus [10,11], blood progesterone analysis [12,13], laparoscopy [14] and postmortem examinations [15] were used to detect sexual maturity of the gilts. However, those methods are inappropriate for use on farms because they are expensive, labor-intensive or detrimental to animal welfare. Ultrasonography was shown to be an appropriate method to visualize the ovaries and uterus in swine [16]. In more detail, this method has been used to monitor ovulation [17] and follicular growth during subsequent days [18], or to diagnose cystic degeneration [19]. Additionally, pregnancy diagnosis by ultrasonography is now common in pig production [16], and the first steps towards the diagnosis of disorders of the non-gravid uterus were reported [20,21]. Moreover, there are initial reports on the routine use of ultrasonography in female pigs with fertility problems on farms [16,22]. The comprehensive results suggest that ultrasonography might be also an appropriate method to determine puberty status in the gilt. The objectives of this study were therefore, firstly, to define the characteristics of the ovaries and uteri of prepubertal and pubertal gilts by ultrasonography, which were then verified by postmortem examinations. Secondly, we wanted to evaluate whether gilts can be correctly diagnosed as prepubertal or pubertal by ultrasonography when matched according to the defined characteristics in order to investigate the appropriateness of ultrasonography to determine sexual maturity.

2. Materials and methods

2.1. Animals

The investigations were performed in two separate experiments (EXP 1 and EXP 2). In EXP 1, 44 unmated and clinically healthy crossbred gilts (German Landrace ♀ × Large White ♂; German Landrace ♀ × Piétrain ♂; German Saddleback ♀ × Piétrain ♂) with an age range of 180–250 days (mean ± S.D.: 204 ± 22 days) and a body weight of 90–135 kg (mean ± S.D.: 114 ± 13 kg) were included. The females were located in three commercial swine farms and kept either in individual stalls with partially slatted floors or as groups of
up to 8 in fully straw bedded pens. All gilts were slaughtered after being scanned, and the genital organs were taken for postmortem examination. In EXP 2, 52 crossbred gilts (German Landrace $\varnothing \times$ Large White $\varpi\times$) at the age of 181–210 days (203 ± 9 days) and a body weight of 92–149 kg (127 ± 12 kg) from a fourth pig farm were used. Females were relocated from group housing into individual stalls a few days prior to examination. The gilts from this fourth farm were not slaughtered and underwent estrus synchronization and subsequent artificial insemination soon after scanning.

2.2. Ultrasonographic examination

The gilts had their ovaries and their uterus examined by transcutaneous ultrasonography. Gilts were scanned either in their individual stalls (EXP 1 and 2) or were relocated into separate narrow pens prior to examination (EXP 1). For scanning, the transportable ultrasound equipment HS 120 HONDA Electronics adjusted to a 5 MHz linear transducer (HONDA ELECTRONICS CO., LTD., Oiwa-cho, Japan) was used. The ultrasound machine was connected to a super VHS recorder or a video printer for documentation. Scanning was performed according to the procedure described by Weitze et al. [17] and Martinat-Botte et al. [16]. Briefly, the transducer was placed horizontally on the right ventro-lateral abdominal wall just dorsal to the last pair of teats, cranial to the hind leg. The ovaries were characterized according to the ultrasonographic findings as described previously [16,22]. Findings were then used to determine the ovarian stage of sexual maturity according to a previous classification based on postmortem examinations [15]. Sexual maturity was expressed as “prepubertal” and “pubertal” (specified according to the number of estrous cycles). Females were matched as “pubertal” after they had attained puberty, as indicated by the presence of pre-ovulatory follicles of the first estrous cycle. Consistently, the following classification was used: gilts with ovarian structures indicating an immature ovarian status having 2–5 mm follicles (F2–5) lacking any luteal structures = prepubertal gilts (PRE); gilts with ovarian structures indicating cyclic ovarian activity = pubertal females (PUB). The PUB gilts were subdivided into those at the first estrous cycle having 7–8 mm pre-ovulatory follicles (F7–8), corpora haemorrhagica (CH) or corpora lutea (CL) = PUB-1, and those at a subsequent estrous cycle having additional corpora albicantia (CA) = PUB-2. In EXP 2, the methods used for verification of the results of ultrasonography were inappropriate to confirm the presence or absence of CA (lack of progesterone synthesis). Therefore, gilts in EXP 2 were classified as PRE and PUB. To achieve clarity of the results, the PUB gilts were then specified according to the ovarian findings (for instance: F7–8 = PUB-F7–8 or CL = PUB-CL) without relating them to the number of estrous cycles.

The uterus was scanned to assess the uterine echotexture and size. The uterine echotexture was subjectively evaluated and expressed as homogeneous or heterogeneous according to principles reported by Martinat-Botté et al. [16] and De Rensis et al. [23]. To determine the uterine size, the uterine horns were imaged in cross-sections. Since most uterine images were rather of an elliptical than of a circular shape, they were measured in their maximum (“a”) and minimum (“b”) dimension instead of using only one diameter, with “b” cutting “a” perpendicular to a half of “a” (Fig. 1). Depending on the number of cross-sections that were imaged with good quality, 2–5 cross-sections were measured to
reduce erroneous results, which were thought to arise from measurement errors and from variations found in the size and shape of cross-sections of the uterine horns of an individual female (EXP 1 \( n = 44 \): 29 females with two and 15 with three measured cross-sections; EXP 2 \( n = 51 \): 3, 24, 18 and 6 with two, three, four and five measured cross-sections, respectively; the uterus was not found in one gilt). For each measured cross-section of the uterine horns, the sectional area was calculated using the mathematical equation for an elliptical figure. Accordingly, the sectional area was calculated by multiplication of half of both the measured dimensions “a” and “b” and then multiplied by \( \pi \) (i.e. \( 1/2a \times 1/2b \times \pi \)). The sectional area of the cross-sectioned uterine horns of an individual female (SAsono) was expressed as the mean of all sectional areas calculated for each animal. However, when the coefficient of variation (CV) as the percentile error for SAsono was calculated for the sectional areas (2–5) estimated for each female and then compared according to the number of measurements using one-factor ANOVA, the differences between the CV were only insignificant with a mean CV of 16.5 ± 11.7% for the pooled data from both EXP (Table 1).

2.3. Verification of the results of the ultrasonographic examination

To verify the results of the ultrasonographic examination, the females of EXP 1 were slaughtered on the same day or the day after scanning. Postmortem examination of the
ovaries and the uteri occurred within 4–6 h after slaughter. The ovaries were assessed as described previously [15] and documented photographically. According to the ovarian findings females were grouped equally as reported for the ultrasonographic examination. The uteri (including the cervix) were cut free of their ligaments, oviducts and ovaries and weighed (uterine weight = UW). One transverse section of the uterine horns (right or left, approximately 30 cm away from the tip of the uterine horn) was dissected, then placed on the table to form a circular shaped figure and measured in diameter using a ruler. The sectional area of the transverse section (SA postmortem = SApm) was calculated according to the mathematical equation for a circular figure ($r^2 \times \pi$). For females of EXP 2, the blood plasma concentrations of progesterone (P4) were determined. Females were bled by puncture of the anterior vena cava immediately after scanning. Analysis of P4 was performed by RIA according to the procedure reported by Niswender and Midley [24]. The sensitivity of the assay was 0.16 ng/ml. The intra- and inter-assay coefficients of variation were 13 and 16.1%, respectively. Sexual maturity was determined according to the criteria used by Caton et al. [12] and Flowers et al. [13] with only minor modifications: females were matched as prepubertal (PRE), if the plasma concentrations of P4 were less than 2 ng/ml and no signs of estrus (reddening and swelling of vulva and standing response, if displayed on the day of scanning) were observed. Consistently, pubertal females (PUB) had either plasma progesterone concentrations of >2 ng/ml or less than 2 ng/ml and signs of estrus.

2.4. Statistical analysis

The data were statistically analyzed in SPSS (SPSS GmbH, Munich, Germany). The ultrasonographic estimates of sexual maturity were compared to those of the postmortem examination (for EXP 1) or to the results of the hormone analysis and detection of the signs of estrus (for EXP 2), and the accuracy of ultrasonography was calculated as the percentage of correct diagnoses (correct diagnoses/all diagnoses). For the gilts grouped as PRE and PUB, the mean SAsono (for EXP 1 and 2), SApm and UW (for EXP 1) and the corresponding standard deviations (mean ± S.D.) were calculated and compared using one-factor ANOVA. For EXP 1, the correlation between SAsono and SApm and between SAsono and UW were investigated using Pearson’s correlation. The relationship between SAsono and UW was analyzed using regression analysis (for EXP 1). Multi-factor ANOVA and a post hoc test were used to investigate the influence of age, body weight and breed (if different) on SAsono (for EXP 1 and 2) and UW (for EXP 1).

### Table 1
Mean coefficient of variation (CV) for SAsono relative to the number of calculated sectional areas per female

<table>
<thead>
<tr>
<th>Number of sectional areas calculated per female</th>
<th>2 (n = 32)</th>
<th>3 (n = 39)</th>
<th>4 (n = 18)</th>
<th>5 (n = 6)</th>
<th>2–5 (n = 95)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean CV ± S.D. (%)</td>
<td>18.0 ± 15.2</td>
<td>13.8 ± 10.3</td>
<td>14.9 ± 6.4</td>
<td>20.0 ± 6.7</td>
<td>16.5 ± 11.7</td>
</tr>
<tr>
<td>Min–max (%)</td>
<td>0–42.0</td>
<td>0–31.4</td>
<td>6.3–27.3</td>
<td>10.4–28.3</td>
<td>0–42.0</td>
</tr>
</tbody>
</table>

aSectional areas of individual females.
bResults of both experiments were pooled.
3. Results

3.1. Ultrasonographic findings of the ovaries and accuracy of ultrasonography on the diagnosis of sexual maturity

In EXP 1, the ovaries were found in all gilts by ultrasonography. Twenty-two females were observed to have only F2–5, without any luteal structures (Fig. 2A). In 13, 5 and 4 gilts, CL (Fig. 2C), CH or F7–8 were found, respectively. The latter also showed external signs of estrus. CA were found in none of the gilts. Accordingly, 22 gilts were classified as PRE and a further 22 as PUB by means of ultrasonography (Table 2). Postmortem examinations

Fig. 2. Ultrasonographic images (A, C) and the corresponding postmortem photographs (B, D) of an ovary from a prepubertal (A, B) and pubertal gilt at the first estrous cycle (C, D) of EXP 1. (A, B) The follicles are between 2 and 4 mm in size (arrows; numbers indicate follicular size in mm). (C, D) Three CL of approximately 8 mm are marked (arrows). Scale bar on the left margin in mm.
confirmed the ultrasonographic findings (Fig. 2B and D), except for five gilts with CL that had also CA. Additionally, two gilts with F7–8 had CH after slaughter and are suggested to have ovulated after scanning as evident from the morphology of the CH. Therefore, in EXP 1 the accuracy of ultrasonography in detection of PRE and PUB females was 100%, but was 77.3% when consider the diagnosis of PUB-1 and PUB-2 gilts. In EXP 2, the ovaries were found in 51 (98.1%) of the 52 gilts by means of ultrasonography. The remaining gilt was prepubertal as a progesterone concentration of 0.3 ng/ml was detected. Forty-two and 9 gilts were sonographically classified as PRE and PUB, respectively (Table 3), as they had F2–5 (n = 42; PRE) or F7–8 (n = 2; PUB-F7–8) and CL (n = 7; PUB-CL). All 42 gilts matched as PRE by ultrasonography had progesterone concentrations of less than 2 ng/ml and did not show any signs of estrus. Both PUB-F7–8 females had progesterone concentrations of <0.16 ng/ml, but they showed signs of estrus. All seven gilts matched as PUB-CL had progesterone concentrations >2 ng/ml. Therefore, in EXP 2 the accuracy of ultrasonography was 100% in both the detection of PRE and PUB and of PUB-F7–8 and PUB-CL gilts.

Table 2
Results of ultrasonography of the ovaries and accuracy of ultrasonography on the diagnosis of sexual maturity as verified by postmortem examinations (n = 44)

<table>
<thead>
<tr>
<th></th>
<th>PRE</th>
<th>PUB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>PUB-1</td>
</tr>
<tr>
<td>Ultrasoundography (n)</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Postmortem examination (n)</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Accuracy of ultrasonography (%)</td>
<td>100&lt;sup&gt;a&lt;/sup&gt;</td>
<td>77.3&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

PRE: prepubertal; PUB: pubertal at the first (PUB-1) or a subsequent (PUB-2) estrous cycle.
<sup>a</sup>In detection of PRE and PUB.
<sup>b</sup>In detection of PUB-1 and PUB-2.

Table 3
Results of ultrasonography of the ovaries and accuracy of ultrasonography on the diagnosis of sexual maturity as verified by plasma progesterone concentrations and signs of estrus (n = 51)

<table>
<thead>
<tr>
<th></th>
<th>PRE</th>
<th>PUB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>PUB-F7–8</td>
</tr>
<tr>
<td>Ultrasoundography (n)</td>
<td>42</td>
<td>9</td>
</tr>
<tr>
<td>Progesterone analysis (n)</td>
<td>42&lt;sup&gt;1&lt;/sup&gt;</td>
<td>9&lt;sup&gt;1&lt;/sup&gt; or 2</td>
</tr>
<tr>
<td>Progesterone concentrations (ng/ml)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean ± S.D.</td>
<td>0.51 ± 0.36</td>
<td>&lt;0.16 ± 0</td>
</tr>
<tr>
<td>Min–max</td>
<td>&lt;0.16–1.76</td>
<td>&lt;0.16</td>
</tr>
<tr>
<td>Signs of estrus (n)</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Accuracy of ultrasonography (%)</td>
<td>100&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

PRE: prepubertal; PUB: pubertal having F7–8 (PUB-F7–8) or CL (PUB-CL).<sup>1</sup> Progesterone concentrations < 2.0 ng/ml, but <sup>1</sup> with signs of estrus, and <sup>2</sup> >2.0 ng/ml. <sup>1</sup> Not shown because comprising gilts with <sup>1</sup> and <sup>2</sup>. <sup>a</sup>In detection of PRE and PUB.
<sup>b</sup>In detection of PUB-F7–8 and PUB-CL.
3.2. Ultrasonographic findings of the uterus and their relationship to sexual maturity

The uteri were found in 44 (100%) and 51/52 (98.1%) of the gilts of EXP 1 and 2, respectively. The ultrasonographic appearance of the uterine structures varied with sexual maturity and the ovarian structures found. The uterus of prepubertal gilts were located very close and cranial to the urinary bladder and occupied only a minor space. The uterine loops were either closely attached to each other and appeared to be partially over-lapped, or in contrast, were less frequently visualized as clearly separated cross-sections (Fig. 3A). In contrast, pubertal gilts had an enlarged uterus which was extended within the caudal abdomen. The uterine loops were usually clearly shaped (Fig. 3C). Both prepubertal and pubertal gilts with CL and CH had uteri of homogeneous echotexture. The uteri of the 4 (EXP 1) and 2 (EXP 2) pubertal females with F7–8 were of a more heterogeneous echotexture with apparent central shadowing.

In EXP 1, the mean SApm and mean SAsono were lower for PRE than for PUB females ($P < 0.0001$; Table 4). Also, in EXP 2, the mean SAsono was lower for PRE than for PUB females ($P < 0.0001$; Table 5). Although there was a strong correlation between the SAsono and SApm for the PRE and PUB gilts in EXP 1 ($r = 0.92$; $P < 0.0001$), the mean SApm of the PRE and PUB group were 1.6- and 1.7-fold that of the corresponding mean SAsono ($P < 0.0001$; Table 4, Fig. 3B and D). From the postmortem examination, there was no verification for the ultrasonographic observation that the SAsono of all PRE females of EXP 1 were $\leq 1.0$ cm$^2$, nor that only PUB gilts had SAsono $\geq 1.2$ cm$^2$ (Table 4). However, a similar ultrasonographic observation was obtained for PRE and PUB females in EXP 2 (Table 5).

### Table 4
Mean sectional area of cross-sections of the uterine horns as estimated by postmortem examination (SApm) and ultrasonography (SAsono) in prepubertal (PRE) and pubertal (PUB) gilts of experiment 1 ($n = 44$)

<table>
<thead>
<tr>
<th></th>
<th>PRE ($n = 22$)</th>
<th>PUB ($n = 22$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean SApm ± S.D. (cm$^2$)</td>
<td>1.1 ± 0.3$^a$</td>
<td>3.3 ± 1.4$^a$***</td>
</tr>
<tr>
<td>Min–max</td>
<td>0.5–1.6</td>
<td>1.3–7.5</td>
</tr>
<tr>
<td>Percentage females with SApm ≤1.0/≥1.2 cm$^2$</td>
<td>36.4/31.8</td>
<td>0/100</td>
</tr>
<tr>
<td>Mean SAsono ± S.D. (cm$^2$)</td>
<td>0.7 ± 0.2$^b$</td>
<td>1.9 ± 0.6$^a$***</td>
</tr>
<tr>
<td>Min–max</td>
<td>0.3–1.0</td>
<td>1.2–3.3</td>
</tr>
<tr>
<td>Percentage females with SAsono ≤1.0/≥1.2 cm$^2$</td>
<td>100/0</td>
<td>0/100</td>
</tr>
</tbody>
</table>

(a, b): significantly different between corresponding data within a column with $P < 0.0001$.
***Significantly different within a row with $P < 0.0001$.

### Table 5
Mean sectional area of cross-sections of the uterine horns as estimated by ultrasonography (SAsono) in prepubertal (PRE) and pubertal (PUB) gilts of experiment 2 ($n = 51$)

<table>
<thead>
<tr>
<th></th>
<th>PRE ($n = 42$)</th>
<th>PUB ($n = 9$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean SAsono ± S.D. (cm$^2$)</td>
<td>0.7 ± 0.1</td>
<td>1.4 ± 0.3***</td>
</tr>
<tr>
<td>Min–max</td>
<td>0.4–1.3</td>
<td>1.0–1.8</td>
</tr>
<tr>
<td>Percentage females with SAsono ≤1.0/≥1.2 cm$^2$</td>
<td>98.0/2.0</td>
<td>9.0/91.0</td>
</tr>
</tbody>
</table>

***Significantly different within a row with $P < 0.0001$. 
3.3. The relationship between the sectional area of the uterine horns and the uterine weight and the influence of age, body weight and breed on the data

In EXP 1, the mean uterine weight was lower for PRE (113 ± 37 g; range: 22–185 g) than for the PUB gilts (506 ± 133 g; range: 244–734 g; \( P < 0.0001 \)). There was a highly correlating relationship between the SAsono and UW in the females (PRE and PUB) of
EXP 1 (UW = 287 \times \text{SAsono} - 66; r = 0.92; P < 0.0001; \text{Fig. 4}). In both EXP, age, body weight and breed (not in EXP 2 because of the same breed) had no influence on the SAsono and UW for PRE and PUB females.

4. Discussion

In this study we used transcutaneous ultrasonography to define the characteristics of the ovaries and the uterus in prepubertal and pubertal gilts. Ultrasonography has been shown to be an appropriate method of providing visual images of the ovaries \[17,18,25\] and the non-gravid uterus \[16,23\] in swine. However, results of ultrasonographic examinations have not been used to determine the sexual maturity in the gilts.

The ovaries were found in 99.0% of the females if both experiments were considered. Moreover, in all these females interpretable images were obtained, and that occurred irrespective of whatever ovarian structures were present. Such a high percentage has never been achieved in female swine \[26\]. In a German study, for instance, the ovaries were found in 59.6–70.0% of the females examined when scanning was performed thrice between day 5 and 15 of the estrous cycle \[27\]. In this study, we used previously reported ultrasonographic criteria to characterize the ovarian structures \[16,22\]. As expected, the ultrasonographic findings closely paralleled the ovarian structures found after slaughter. In addition, they corresponded well to the progesterone concentrations found in blood plasma that were only then elevated if CL were diagnosed. The only ovarian structures we did not detect were CA, which may be due to their in conspicousness (small in size; echotexture similar to accompanying CL). Despite this fact, the results of this study demonstrated again the suitability of ultrasonography for examining porcine ovaries.
Using transcutaneous ultrasonography we were able to diagnose gilts correctly as prepubertal and pubertal. In numerous previous research studies, detection of signs of estrus [10,11], laparoscopy [14], analysis of blood progesterone concentrations [12,13] or postmortem examinations [15] were used to determine the sexual maturity of the gilts. All these methods are either erroneous (anovulatory females despite signs of estrus or ovulatory without such signs [6,12,28]), laborious, stressful and cost-intensive (bleeding for progesterone analysis, laparoscopy) or terminal (slaughter). It was in 1989 that Eliasson [6] highlighted the importance of progesterone analysis in studies on puberty. From the results of this study, it is now time to recommend ultrasonography and, in particular, ultrasonographic ovarian diagnosis as a reliable and less laborious method for determining sexual maturity in gilts in research and on farms.

The uteri were found in 99.0% of the females if both experiments were considered. Similar data have not been published as yet. In this study we observed that the uterine echotexture was heterogeneous or very homogeneous, respectively, when females had either large follicles or luteal structures (CL, CH). Similar results were obtained by Martinat-Botte et al. [16] and De Rensis et al. [23], who observed that the uterine echotexture varied during the estrous cycle and was more heterogeneous during estrus and homogeneous during the luteal phase. Heterogeneity in this investigation was expressed by apparent central shadowing, likely through a decrease in echogenicity due to an endometrial edema [29]. As already noted by De Rensis et al. [23] a similar phenomenon occurs in mares [30] and cows [31]. Since the echotexture of the prepubertal uterus was also homogeneous, and estrogens are at relatively low levels in both the prepubertal [32] and the pubertal gilt at diestrus [14], it is evident that elevated estrogens during estrus cause the endometrial edema and thus the decreased uterine echogenicity. From the collective data it appears therefore, that, as in mares [33], the effects that steroids exert on the architecture of the porcine uterus can be clearly observed by ultrasonography.

In this study it was found that the mean SApm of both the prepubertal and pubertal gilts were more than 50% larger than the corresponding mean SAsono. Attempts to explain these discrepancies probably remain invalid. The most likely explanation will be, that the transverse sections used for the postmortem measurement were artificially expanded due to the preparation procedure. However, despite the discrepancies in the absolute values, mean SAsono and SApm corresponded well on a relative basis as evident from the highly significant correlation. Moreover, as it was found in two histomorphometric investigations, the diameters of the uterine horns of the prepubertal and pubertal uterus range between 6 and 7 mm and 12 and 14 mm [29,34], respectively, which would result in similar sectional areas as obtained in this study for the PRE and PUB gilts. It appears therefore that the SAsono as determined in this study truly reflect the in vivo situation and that this parameter is therefore an appropriate one to determine the uterine size in the gilt. Moreover, since the coefficients of variation on SAsono were similar irrespective of whether 2–5 of cross-sections were measured, only two cross-sections need to be measured to calculate SAsono for an individual gilt.

In this study we found a significantly lower mean SAsono in prepubertal than in pubertal females, again demonstrating that a thickening of the uterus occurs within uterine growth during puberty [29,34]. Another observation was that prepubertal and pubertal gilts had SAsono of $\leq 1.0 \text{ cm}^2$ or $\geq 1.2 \text{ cm}^2$, respectively. Although we could not verify this
observation after slaughter, it corresponded well to the subjective evaluation that the prepubertal uterus appeared as a very thin structure, whereas the pubertal uterus was extensive within the caudal abdomen. Therefore, the evaluation of uterine size may permit an initial rapid assessment of sexual maturity when scanning on farms.

The UW was higher in pubertal than in prepubertal gilts. This is in agreement with several previous investigations showing that uterine weight increases during puberty [15,35]. We observed a highly positive correlation with \( r = 0.92 \) between the SAsono and the UW in gilts. The sets of data were described using the linear regression equation \( \text{UW} = 287 \times \text{SAsono} - 66 \), which then permits the estimation of the uterine weight in vivo. This will be of advantage for research into studying the influence of factors affecting genital development during puberty. This might also be useful for animal breeding, since increasing the uterine weight also means lengthening of the uterine horns [15], and the length of the uterine horns is discussed as one factor determining uterine capacity and thus the litter size [36–38].

In conclusion, the diagnosis of sexual maturity is facilitated in prepubertal and pubertal gilts based on the characteristics of the ultrasonographic appearance of the ovaries and the size of the uteri. This investigation also shows that the uterine echotexture depends on the ovarian structures. The results further demonstrate that the sectional area of the uterine horns can be determined by ultrasonography, and that this can then be used to calculate the uterine weight in the live gilt.

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