



Effect of number of 6-mm predeviation follicles and intraovarian patterns on right-side ovulation in heifers

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ABSTRACT

The mechanisms underlying the greater frequency of ovulation from right ovary (RO) than left ovary (LO) were studied in 145 *Bos taurus* heifers. Diameter deviation during a follicular wave is indicated by continued diameter increase in the future preovulatory follicle (PF) and a decrease in diameter of future subordinate follicles. The PF (ovulation) was in the RO (63/105, 60%) more frequently ($P < 0.04$) than in the LO (40%) for ovulatory wave 2 of two-wave interovulatory interval (IOI) but not for wave 3 of three-wave IOI (RO, 45%; LO, 55%). The difference between waves 2 and 3 was associated with a greater ($P < 0.01$) number of 6-mm follicles during predeviation in the RO (2.3 ± 0.2 follicles) than LO (1.8 ± 0.1) for wave 2 but not for wave 3. Combined for ovulatory waves 2 and 3, the PF developed in the ovary with more 6-mm follicles during more ($P < 0.0001$) ovulatory waves (72%) than when the PF developed in the ovary with fewer follicles (11%). Ovulation from RO was more frequent ($P < 0.02$) when both PF and CL were in RO (46/72, 64%) than in LO (36%), but not when PF was alone in RO without the CL. Results supported the hypotheses that: (1) the number of 6-mm predeviation follicles developing during the ovulatory wave is greater for RO and (2) the number of predeviation follicles is greater for the ovary in which the preovulatory follicle subsequently develops.

1. Introduction

In cattle, a dominant follicle develops during two or three follicular waves during an interovulatory interval (IOI) (Ginther et al., 1989; Jaiswal et al., 2009). The dominant follicle becomes the preovulatory follicle (PF) in the last wave of the IOI. Ovulation occurs more frequently (e.g., 60%) from the right ovary (RO) than left ovary (LO) (Pierson and Ginther, 1987; Rajakoski, 1960). Selection of the dominant follicle in anovulatory waves (ovulation does not occur) and the PF in ovulatory waves is manifested by a process known as diameter deviation (reviewed by Ginther, 2016; Ginther et al., 1996). The largest follicle continues to grow and becomes the dominant follicle or PF, and the remaining follicles (subordinates) begin to slow in growth rate and regress as illustrated (Fig. 1, left panel). Deviation occurs when the subsequent PF (F1) is an average of 8.5 mm in *Bos taurus* cattle, and a diameter closest to 8.5 mm is sometimes used to define the expected day of deviation for convenience or when experimental procedures are imposed that interfere or prevent the deviation process. The characteristics of follicle diameter deviation have been partitioned into classes based on differences in diameter of the future largest subordinate follicle (F2) at the beginning of expected time of deviation (Fig. 1) (Ginther, 2018b; Ginther et al., 2016a; Gomez-León et al., 2019).

The PF-to-CL relationship of PF and regressing CL is ipsilateral when PF and CL are in the same ovary (PF – CL intraovarian

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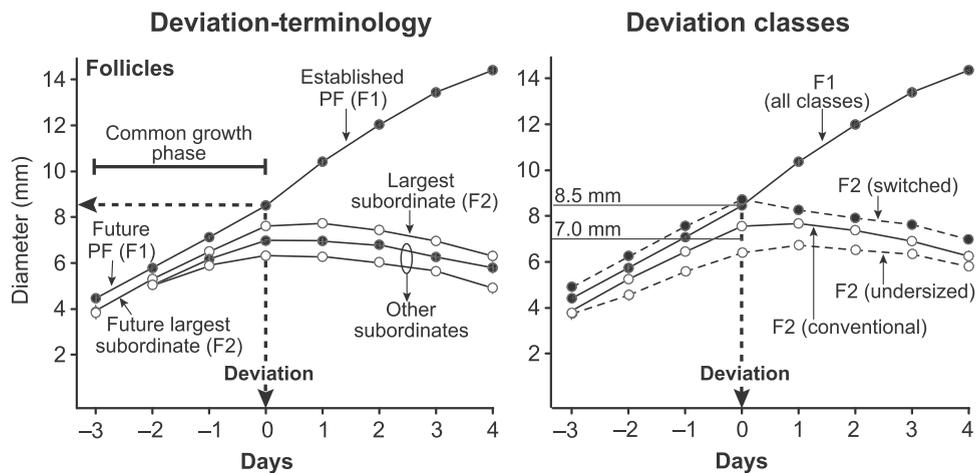


Fig. 1. Diameter illustrations for deviation terminology and for F2 switched as 1 of 3 deviation classes.

pattern) and the opposite ovary does not contain either a PF or CL (devoid pattern). The PF-to-CL relationship is contralateral when the PF and CL are in opposite ovaries (Ginther et al., 2015a). A slant bar is used to indicate both pattern and side (e.g., PF – CL/RO). An ovary with a pattern/side that includes a PF indicates the side of ovulation.

A predilection for ovulation from RO has been reported in many farm and laboratory species and primates (reviewed by Karamishabankareh et al., 2015) but the mechanism accounting for the greater frequency of RO ovulation is not known for any species. The side of ovulation in heifers may be modified during the common growth phase in wave 3 of three-wave IOI by a switch in subsequent dominance to a smaller follicle when the larger follicle is adjacent to the regressing CL (Ginther, 2018a; Ginther et al., 2014a, 2016b). Thereby, a follicle that was destined to develop into a PF in the RO can switch to a follicle in the LO in ovulatory wave 3.

During the predeviation period, there are more follicles that develop to be at least 5- or 6-mm in the RO than in the LO (Ginther and Hoffman, 2014, 2016), and the RO has the PF – CL pattern more frequently than the PF pattern (Ginther and Hoffman, 2016). In a recent study (Ginther and Dangudubiyam, 2018) there were indications that the RO predilection for ovulation in heifers is a consequence of a predilection for more 6-mm predeviation follicles in the RO based on the indirect findings that (1) a group of animals (heifers) with a predilection for RO ovulation also had more predeviation follicles in the RO and (2) another group of animals (mares) that did not have asymmetry in side of ovulation also did not have asymmetry in number of predeviation follicles.

In the present study, the number of 6-mm predeviation follicles per ovary was compared among the subsequent four intraovarian patterns (PF – CL, devoid, PF, CL) of the ovulatory wave in two-wave and three-wave IOI. Hypothesis 1 was that the number of 6-mm predeviation follicles developing during the ovulatory wave is greater for RO. In previous studies, there was not consideration of the ovulatory wave. Hypothesis 2 was that the number of predeviation follicles is greater for the ovary in which the preovulatory follicle subsequently develops. Previous studies, did not consider the association between number of follicles before deviation and development of the PF after deviation. In addition, the report that ovulation from the RO in heifers is more frequent only when the RO contains the PF and regressed CL (Ginther and Dangudubiyam, 2018) was considered for confirmatory purposes and to provide a continuous perspective on factors affecting ovulation from the RO from the period of predeviation to the time of ovulation.

2. Materials and methods

Previous routine records of daily ultrasonic imaging from the past 6 years in an experimental herd of 40 heifers were used. Replacements to the herd maintained an age of about 16 to 28 months during the 6 years. Previously published findings from the same records were not duplicated in this report. The heifers were handled in accordance with the US Department of Agriculture Guide for Care and Use of Agricultural Animals in Research. *Bos taurus* dairy heifers (Holsteins) were used and had never been bred. All IOI were natural in that treatments for synchronizing the time of ovulation among animals or altering length of the IOI were not used. Records from 145 IOI and the associated ovulatory follicular wave were selected that had all of the following criteria: (1) IOI with a single ovulation at the beginning and at the end of the IOI, (2) known number of follicular waves per IOI (two or three), (3) known number of 6-mm predeviation follicles per ovary, and (4) known intraovarian patterns. Follicles were measured using ultrasonic imaging with transrectal 7.5 MHz transducers by placing the cursors of the scanner at the distinctive periphery of the follicle's antrum so that antral diameter represented follicle diameter (Ginther, 1998).

The number of follicles per ovary that developed to at least 6 mm during the common growth phase included the day of the beginning of deviation but not thereafter. The subsequent PF was included in the number of 6-mm follicles, but one tally considered only future subordinate follicles by excluding one follicle to represent the contribution of the subsequent PF to the total count. Analyses considered differences in number of 6-mm follicles between the RO and LO, between two-wave and three-wave IOI, and among the four intraovarian patterns. The following relationships were considered: (1) side of ovulation in wave 2 of two-wave IOI

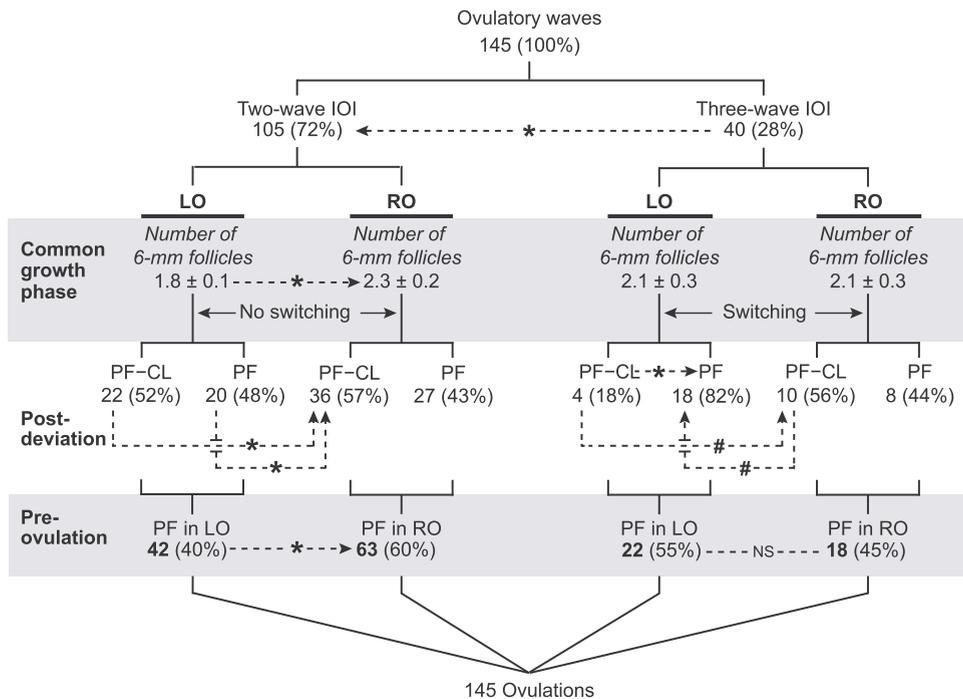


Fig. 2. Schematic for ovulatory waves showing number of two-wave and three-wave IOI, number of predeviation follicles per ovary, intraovarian patterns containing the PF (ovulation), and PF in right or left ovary (RO, LO). Switching in three-wave IOI occurs when the largest follicle during the common growth phase becomes F2 and the second largest follicle becomes F1. An asterisk (*) ($P < 0.05$) and a hatch mark (#) ($P < 0.1$) with the connecting broken lines indicate the probability for a difference between two numbers or percentages; the probability for a difference between PF-CL/LO and PF-CL/RO in two-wave IOI was $P < 0.06$. NS, not significant.

and wave 3 of three-wave IOI, (2) effect of ovary that had more compared to fewer 6-mm follicles in a pair of ovaries on pattern/sides (PF – CL/RO, PF – CL/LO, PF/RO, PF/LO), (3) frequency of intraovarian PF – CL and devoid patterns (ipsilateral relationship) and PF and CL patterns (contralateral relationship), (4) frequency of RO compared to LO ovulation for PF – CL compared to PF intraovarian patterns, and (5) repeatability in side of ovulation at beginning of IOI and at end of IOI as indicated by the PF – CL pattern. Side of ovulation at beginning of IOI was indicated by side of CL at end of IOI.

Data that were not normally distributed based on the Shapiro-Wilk test were resolved by transformation to natural logarithms or ranks. The analyses used the Statistical Analysis System (SAS) using a mixed procedure with a repeated statement to minimize autocorrelation (Version 9.4; SAS Institute Inc., Cary, NC, USA). When a factor or interaction was significant, Tukey's honestly significant difference test was used for further comparisons. Fisher's exact test was used to compare frequency of relationships between ovulatory waves 2 and 3 and among intraovarian patterns. Chi-square goodness of fit was used to test for differences in equality of frequencies between different waves or intraovarian patterns. A probability of $P \leq 0.05$ indicated significance, and a probability between $P > 0.05$ and $P \leq 0.10$ indicated significance was approached. Differences that approached significance were included on a tentative basis for potential consideration in future studies. Data are presented as the mean \pm SEM unless otherwise indicated.

3. Results

The number of 6-mm follicles during the common growth phase (Fig. 2; Fig. 3, left panel) and the frequencies of two-wave and three-wave IOI, location of the PF in the same ovary as the CL (PF – CL pattern) and in the ovary opposite to the CL (PF pattern), and location of PF (PF-CL and PF patterns) in RO and LO (side of ovulation) are depicted for the 145 ovulatory waves (Fig. 2). The frequency of two-wave IOI was greater ($P < 0.001$) than for three-wave IOI. An interaction of side and wave on number of 6-mm follicles approached significance ($P < 0.10$). The number of follicles during the common growth phase was greater ($P < 0.01$) in the RO than LO in ovulatory wave 2 with no effect of side and number of follicles in ovulatory wave 3.

The frequency of PF-CL/RO pattern/side approached being greater than the frequency of the PF-CL/LO pattern/side within each of two-wave ($P < 0.06$) and three-wave ($P < 0.10$) IOI (Fig. 2). Combined for ovulatory waves 2 and 3, frequency of the PF – CL pattern was greater ($P < 0.02$) for the RO (46/72, 64%) than for the LO (26/72, 36%) (Fig. 4, right panel). In two-wave IOI, the frequency of the PF – CL pattern was not different from the PF pattern for either the LO or RO, but in three-wave IOI the PF pattern was greater than the PF – CL pattern for the LO. The frequency of the PF – CL pattern in RO (36/56, 64%) was greater ($P < 0.03$) than the PF pattern in LO (36%) in two-wave IOI. In three-wave IOI the frequency of the PF pattern in LO (18/28, 64%) approached being greater ($P < 0.13$) than the PF – CL pattern in RO (36%). Side of PF (same as ovulation) was greater ($P < 0.04$) for the RO

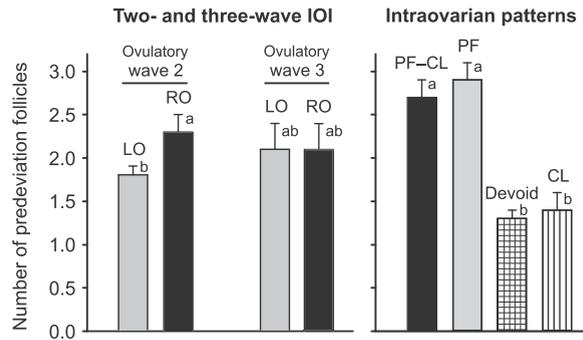


Fig. 3. Mean ± SEM number of predeviation 6-mm follicles in left and right ovaries (LO, RO) during the common growth phase for ovulatory waves 2 and 3 (left panel), and in intraovarian patterns with and without a PF (right panel) combined for ovulatory waves 2 and 3. ab = means within each panel with no common letters are different ($P < 0.05$); $n = 145$.

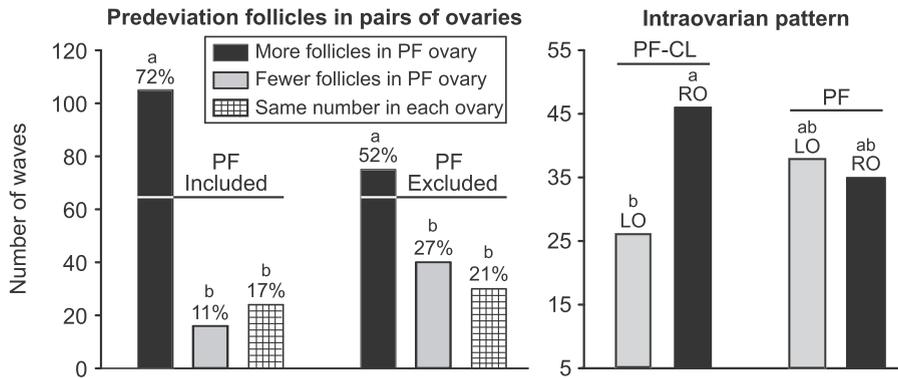


Fig. 4. Mean percentages for number of ovulatory waves ($n = 145$) with more, fewer, or same number of 6-mm follicles in the subsequent PF ovary during the common growth phase (left panel) and number of waves with PF-CL and PF patterns for left and right ovaries (LO, RO) combined for ovulatory waves 2 and 3 (right panel). ab = means within each set in left panel and for all patterns in right panel with no common letter are different ($P < 0.05$).

when there was a two-wave IOI but not when there was a three-wave IOI.

Repeatability in side of ovulation between the beginning and end of the IOI was not detected based on the similar frequency of the PF – CL pattern (72/145 ovulatory waves, 50%) and PF pattern (73/145, 50%). There was not a significant repeatability for the 105 ovulatory waves when there was a two-wave IOI (55% repeated). For the 40 three-wave IOI, the PF – CL pattern (14/40, 35%) tended to be less ($P < 0.06$) than for the PF pattern (26/40, 65%). The frequency of the PF-CL pattern in ovulatory wave 2 (58/105, 45%) was greater ($P < 0.003$) than for ovulatory wave 3 (14/40, 35%).

The effects of side (RO, LO), wave (two-wave IOI, three-wave IOI), and intraovarian pattern (PF – CL, devoid, PF, CL) on number of 6-mm follicles during the common growth phase were evaluated using a three-way factorial analysis. There were no main effects of side or wave or interactions of intraovarian pattern with side or wave (not shown). There was a main effect of intraovarian pattern ($P < 0.0001$) on number of follicles with no interactions between pattern and any other factor in each of the three-way factorials that included pattern. The main effect was from a similar number of follicles between the PF-CL and PF patterns and between the devoid and CL patterns with a greater number in the PF-CL and PF patterns (Fig. 3, right panel).

The PF (PF – CL and PF patterns) developed in the ovary with more 6-mm follicles during the common growth phase in more ($P < 0.0001$) waves than when the PF developed in the ovary with fewer 6-mm follicles or in each ovary of a pair with an equal number of follicles (Fig. 4, left panel). Similarly, in the ovary with more follicles (future subordinate follicles) after excluding one follicle to remove the effect of the follicle that became the PF, the PF developed in more ($P < 0.001$) waves than when the PF was in an ovary with fewer follicles.

4. Discussion

Discussion of the effect of number of 6-mm predeviation follicles on the long-time and repeatedly confirmed greater frequency of RO than LO ovulation in cattle will first consider the profound differences in frequency between ovulatory waves 2 and 3. The greater frequency of two-wave than three-wave IOI has been reported in dairy (Ginther et al., 1989) and beef (Ahmad et al., 1997; Jaiswal et al., 2009) *Bos taurus* heifers and in the present experimental dairy herd when there was a feeding regimen similar to the regimen of the present study (Ginther and Danguubiyam, 2018; Ginther et al., 2014b). The greater frequency of two-wave IOI than three-wave

IOI accounts for the greater frequency of RO ovulation in reports (reviewed by Karamishabankareh et al., 2015) that did not consider number of waves per IOI.

Hypothesis 1. That the number of 6-mm predeviation follicles developing in the ovulatory wave is greater for RO was only partly supported. The hypothesis was supported for ovulatory wave 2 as a result of the greater number of predeviation 6-mm follicles in RO than in LO. The hypothesis was not supported for ovulatory wave 3 as a result of a similar number of predeviation follicles between RO and LO. The present and reported findings of a greater frequency of RO ovulation in ovulatory wave 2 can be attributed to more predeviation follicles in RO. Similarity in frequency of ovulation between RO and LO in ovulatory wave 3 can be attributed to the similarity between ovaries in number of predeviation follicles. The positive and negative effects of number of predeviation follicles on side of ovulation in ovulatory waves 2 and 3, respectively, are consistent with previous results in heifers and mares (Ginther and Dangudubiyam, 2018). Heifers have a predilection for both more predeviation follicles in the RO and for ovulation from RO whereas mares have symmetry in side of number of predeviation follicles and in side of ovulation.

The finding that an RO predilection for number of predeviation follicles precedes the RO predilection for ovulation raises the question whether RO predilection for more follicles represents an inherent greater oocyte reserve that begins in the fetal RO. The difference in fetal oocyte reserve between the RO and LO has received limited research attention and specific studies are needed. Limited information or considerations relating to an inherently greater follicle development in the RO are as follows: (1) In calves in the first few weeks of life, the RO compared to the LO had significantly greater fluid volume, more follicles 4 to 13 mm, and greater weight (Casida et al., 1935); no reports were found on differences in follicle dynamics between the RO and LO for the bovine fetus or newborn calf. (2) In humans, the RO has a predilection for ovulation, and the right fetal gonad is more developed than the left gonad as indicated by weight and by protein and DNA content (Mittwoch and Kirk, 1975). (3) The many laboratory and farm species with a greater ovulation frequency from the RO (reviewed by Karamishabankareh et al., 2015) is consistent with the assumption of differences between the RO and LO in fetal oocyte reserve and possibly in fetal vascular ovarian anatomy. (4) The reports of RO asymmetry for many mammalian species decreases the likelihood of an influence of other abdominal organs on RO predilection for ovulation considering the many anatomical differences in abdominal organs among species.

Hypothesis 2. That number of predeviation follicles is greater for the ovary in which the preovulatory follicle subsequently develops was supported. There were approximately twice as many follicles in ovaries that later contained the PF (PF – CL and PF patterns) than for the opposite ovaries that did not develop a PF (devoid and CL patterns). In addition, the PF developed in the ovary with more 6-mm follicles in more ($P < 0.0001$) waves than when the PF developed in the ovary with fewer 6-mm follicles. The frequency of ovulation as indicated by side of the PF was similar between each ovary of a pair when the number of predeviation follicles was similar between ovaries. Even after excluding the follicle that subsequently developed the PF from the tally of number of 6-mm predeviation follicles, more of the remaining follicles (future subordinates) were present in the ovary in which the subsequent PF developed. Although not considered in the hypothesis, this observation provides additional support for the greater predeviation follicular development in the ovary where the subsequent PF developed.

The RO but not the LO had a predilection for more follicles during the common growth phase, and the presence of more follicles in the RO increased the frequency of development of the PF, thereby accounting for the RO predilection for ovulation. During the waves when anovulation was the outcome, the ovary with the greater number of follicles in heifers is associated with the ovary in which there is development of the dominant follicle and not in the ovary where there is development of the CL (Ginther and Hoffman, 2014, 2016). This is consistent with the present finding that the number of predeviation follicles influenced the side in which the subsequent PF developed and not the side of the extant CL which formed before deviation.

The future ovarian patterns that contained the PF (PF – CL and PF patterns) were developed during predeviation and were manifested during post-deviation. The difference between two- and three-wave IOI in the percentage of PF – CL compared to PF patterns during post-deviation is attributable to a reported regression of the largest follicle in ovulatory wave 3 during the common growth phase when the follicle is adjacent to the regressing CL (switching) (Ginther, 2018a; Ginther et al., 2015b; Siddiqui and Ginther, 2014). The common growth phase and luteolytic period may occur in synchrony in ovulatory wave 3. In ovulatory wave 2, luteolysis occurs well after the common growth phase (Ginther et al., 2014a). The greater frequency of the ipsilateral PF-to-CL relationship (PF – CL pattern) as shown in ovulatory wave 2, therefore, was disrupted in ovulatory wave 3 resulting in a switch from ipsilateral to a contralateral relationship (PF pattern and CL pattern). Thereby, the destiny of a follicle to become the subsequent PF may switch from one ovary to the other in ovulatory wave 3. The switching of the PF from RO to LO or PF – CL pattern to PF pattern accounted for the percentage of PF – CL patterns of 64% in RO and PF patterns of 36% in LO in ovulatory wave 2 to a percentage of the PF – CL pattern of 36% in RO and PF patterns of 64% in LO in ovulatory wave 3. Switching also accounts for the greater frequency of the PF than PF – CL pattern in the LO of ovulatory wave 3 but not in ovulatory wave 2. The percentages of the PF – CL and PF patterns are best assessed in ovulatory wave 2 owing to the overriding switching mechanism in ovulatory wave 3.

The greater frequency of the PF – CL/RO pattern/side than the PF – CL/LO pattern/side was indicated in the present study by the tendency (approached significance) for a greater frequency of the PF – CL pattern in the RO than in the LO for each of ovulatory waves 2 and 3. When waves 2 and 3 were combined, the PF – CL pattern was more frequent in RO than in LO. In a previous study with a larger number of ovulatory waves ($n = 500$), the PF – CL pattern was more frequent from the RO than LO in each of ovulatory waves 2 and 3 (Ginther and Dangudubiyam, 2018). Ovulations were more frequent from the RO than LO only when the PF was in the same ovary as the regressing CL (PF – CL/RO pattern/side).

The extant CL is from the ovulation at the beginning of the IOI, and therefore the PF – CL pattern is more likely to develop in the RO than LO in each of waves 2 and 3. In addition, if there is a CL present this may favor development of the PF in the ovary containing

the CL as a result of the two-way positive effect on both structures when these are adjacent in an ovary during the common growth phase (reviewed in Ginther et al., 2016c). There is greater vascular perfusion of both the CL and the subsequently developed and established PF when the ovary contains both structures (Domingues and Ginther, 2018; Ginther et al., 2016c) which may at least partly account for enhanced PF development and preparation for ovulation for the PF – CL pattern. Greater vascular perfusion occurs specifically for the PF wall during 1 and 2 days before ovulation when the regressed CL is in the same ovary as the PF as compared to when the CL and PF are in opposite ovaries (Ginther et al., 2014c).

Non-detection of repeatability in side of ovulation as indicated by the PF – CL pattern in ovulatory wave 2 and a decrease in repeatability in ovulatory wave 3 apparently have not been previously reported. The PF – CL pattern was used to indicate repeated ovulation from the same ovary between the beginning (indicated by CL) and end (indicated by PF) of the IOI. The lesser repeatability for ovulatory wave 3 was indicated by the lesser frequency of the PF – CL pattern than the PF pattern. This is attributable to switching from the PF – CL pattern to the PF pattern when the largest predeviation follicle was adjacent to the regressing CL as discussed previously.

In conclusion, the greater frequency of RO ovulation in cattle was associated with a greater number of follicles in the RO early in the ovulatory wave (before diameter deviation; hypothesis 1). Owing to the greater number of 6-mm follicles in RO, the largest follicle per wave more often developed in the RO and became the PF (hypothesis 2) and did so in ovulatory wave 2. In ovulatory wave 3, the largest follicle during predeviation sometimes did not continue to develop into the subsequent PF reportedly owing to its regression when in the ovary with the regressing CL. The greater frequency of ovulation from RO occurred only when the PF and regressing CL were in the same ovary. The extant CL is from the ovulation at the beginning of the IOI and, therefore, the PF – CL pattern was more likely to develop in the RO than LO in each of waves 2 and 3. In addition, the presence of a CL may favor development of the PF in the same ovary because of the two-way positive effect of both structures when these structures are adjacent in an ovary. More frequent ovulation from the RO was attributable to the following intraovarian considerations: (1) more predeviation follicles in the RO, (2) development of the PF in the ovary with more follicles, and (3) greater frequency of the PF – CL intraovarian pattern in RO.

Conflicts of interest

The authors declare that there are no conflicts of interest.

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References

- Ahmad, N., Townsend, E.C., Dailey, R.A., Inskip, E.K., 1997. Relationships of hormonal patterns and fertility to occurrence of two or three waves of ovarian follicles, before and after breeding, in beef cows and heifers. *Anim. Reprod. Sci.* 49, 13–28.
- Casida, L.E., Chapman, A.B., Rupel, I.W., 1935. Ovarian development in calves. *J. Agric. Res.* 50, 953–960.
- Domingues, R.R., Ginther, O.J., 2018. Angioco coupling between the dominant follicle and corpus luteum during waves 1 and 2 in *Bos taurus* heifers. *Theriogenology* 114, 109–115.
- Ginther, O.J., 1998. *Ultrasonic Imaging and Animal Reproduction: Book 3, Cattle*. Equiservices Publishing, Cross Plains, WI.
- Ginther, O.J., 2016. The theory of follicle selection in cattle. *Domest. Anim. Endocrinol.* 57.
- Ginther, O.J., 2018a. Spontaneous switching of future dominance to a smaller follicle: commonality among monovular species. *Biol. Reprod.* 99, 1129–1136.
- Ginther, O.J., 2018b. Variations in follicle diameter deviation and a growth spurt in the dominant follicle at deviation in *Bos taurus* heifers. *Anim. Reprod. Sci.* 188, 155–164.
- Ginther, O.J., Danguubiyam, S.V., 2018. Factors affecting side of ovulation in heifers and mares—a comparative study. *Anim. Reprod. Sci.* 199, 72–78.
- Ginther, O.J., Hoffman, M.M., 2014. Intraovarian effect of dominant follicle and corpus luteum on number of follicles during a follicular wave in heifers. *Theriogenology* 82, 169–175.
- Ginther, O.J., Hoffman, M.M., 2016. Interactions of side (left and right ovary) with the number of follicles per ovary and with the intraovarian relationships between dominant follicle and corpus luteum in heifers. *Theriogenology* 86, 907–913.
- Ginther, O.J., Knopf, L., Kastelic, J.P., 1989. Temporal associations among ovarian events during bovine oestrous cycles with two and three follicular waves. *J. Reprod. Fertil.* 87, 223–230.
- Ginther, O.J., Wiltbank, M.C., Fricke, P.M., Gibbons, J.R., Kot, K., 1996. Selection of the dominant follicle in cattle. *Biol. Reprod.* 55, 1187–1194.
- Ginther, O.J., Rakesh, H.B., Bashir, S.T., Hoffman, M.M., 2014a. Relationship between days of the luteolytic period and locations of the preovulatory follicle and CL in interovulatory intervals with two or three follicular waves in heifers. *Theriogenology* 81, 787–796.
- Ginther, O.J., Rakesh, H.B., Hoffman, M.M., 2014b. Complex interrelationships among corpus luteum, preovulatory follicle, number of follicular waves, and right or left ovaries in heifers. *Theriogenology* 81, 481–489.
- Ginther, O.J., Siddiqui, M.A.R., Baldrighi, J.M., Hoffman, M.M., 2014c. Effect of intraovarian proximity between dominant follicle and corpus luteum on dimensions and blood flow of each structure in heifers. *Theriogenology* 82, 875–883.
- Ginther, O.J., Siddiqui, M.A.R., Baldrighi, J.M., Hoffman, M.M., 2015a. Conversion of intraovarian patterns from preovulation to postovulation based on location of dominant follicle and corpus luteum in heifers. *Theriogenology* 83, 153–161.
- Ginther, O.J., Siddiqui, M.A.R., Baldrighi, J.M., Hoffman, M.M., 2015b. Intraovarian factors associated with switching of a future dominant follicle to a subordinate follicle during induced luteolysis in heifers. *Theriogenology* 83, 786–796.
- Ginther, O.J., Baldrighi, J.M., Siddiqui, M.A.R., Araujo, E.R., 2016a. Complexities of follicle deviation during selection of a dominant follicle in *Bos taurus* heifers. *Theriogenology* 86, 2012–2019.
- Ginther, O.J., Baldrighi, J.M., Siddiqui, M.A.R., Bashir, S.T., Rakesh, H.B., 2016b. Mechanism for greater frequency of contralateral than ipsilateral relationships between corpus luteum and ovulatory follicle for wave 3 in heifers. *Theriogenology* 85, 361–367.
- Ginther, O.J., Siddiqui, M.A.R., Baldrighi, J.M., 2016c. Functional angioco coupling between follicles and adjacent corpus luteum in heifers. *Theriogenology* 86, 465–471.

- Gomez-León, V.E., Ginther, O.J., Araujo, E.R., Guimrães, J.D., Wiltbank, M.C., 2019. Hormonal mechanisms regulating follicular wave dynamics I: comparison of follicle growth profiles under different physiological conditions in heifers. *Theriogenology* 123, 194–201.
- Jaiswal, R.S., Singh, J., Marshall, L., Adams, G.P., 2009. Repeatability of 2-wave and 3-wave patterns of ovarian follicular development during the bovine estrous cycle. *Theriogenology* 72, 81–90.
- Karamishabankareh, H., Hajarian, H., Shahsavari, M., Moradinejad, R., 2015. *In vivo* and *in vitro* study of the function of the left and right bovine ovaries. *Theriogenology* 84, 724–731.
- Mittwoch, U., Kirk, D., 1975. Superior growth of the right gonad in human foetus. *Nature* 257, 791–792.
- Pierson, R.A., Ginther, O.J., 1987. Follicular populations during the estrous cycle in heifers. II. Influence of right and left sides and intraovarian effects of the corpus luteum. *Anim. Reprod. Sci.* 14, 177–186.
- Rajakoski, R., 1960. The ovarian follicular system in sexually mature heifers with special reference to seasonal, cyclical, and left-right variations. *Acta Endocrinol. (Copenhagen)* 52, 1–68.
- Siddiqui, M.A.R., Ginther, O.J., 2014. Switching of largest follicle from dominant to subordinate status when follicle and CL are in same ovary in heifers. *Theriogenology* 82, 259–265.