Animal Reproduction Science 255 (2023) 107291

Contents lists available at ScienceDirect

Animal Reproduction Science

journal homepage: www.elsevier.com/locate/anireprosci

Effects of postpartum diseases on antral follicle count and serum concentration of Anti-Müllerian hormone in dairy cows

Laurin Schwarzmann [a], Arlene Marchand [b], Barbara Knutti [b], Rupert Bruckmaier [c], Heinrich Bollwein [a], Dragos Scarlet [a,d,*]

[a] *Clinic of Reproductive Medicine, Vetsuisse Faculty Zurich, University of Zurich, Switzerland*
[b] *Tierarztpraxis KLC, Corcelles-près-Payerne, Switzerland*
[c] *Veterinary Physiology, Vetsuisse Faculty Bern, University of Bern, Switzerland*
[d] *Institute of Veterinary Anatomy, Vetsuisse Faculty Zurich, University of Zurich, Switzerland*

ARTICLE INFO

Keywords:
AFC
AMH
Fertility
Dairy cow

ABSTRACT

The antral follicle count (AFC) and Anti-Müllerian hormone (AMH) concentration are validated markers for ovarian reserve in cattle, but their use as fertility markers is controverse. Here we assessed the effects of postpartum diseases on AFC and AMH concentration, as well as the influence of parity and breed on these parameters. Cows ($n = 513$, mostly Holstein Friesian and Brown Swiss, parity 3.0 ± 1.8) underwent a single ultrasonography examination 28–56 days after parturition and categorized as having low ($n \leq 15$ follicles), intermediate ($n = 16$–24 follicles), or high ($n \geq 25$ follicles) AFC based on objective video analysis of recorded sequences. Blood samples for AMH determination were collected at the time of examination and animals divided into low (< 0.05 ng/ml) and high AMH (≥ 0.05 ng/ml) group, respectively. No effects of postpartum diseases or breed on either AFC or AMH groups could be observed. There was a strong interaction between parity and AFC, primiparous cows having less follicles (13.6 ± 6.2 vs. 17.1 ± 7.0, $P < 0.001$) than pluriparous cows. The AFC did not affect reproductive parameters or productivity of the cows. In comparison, pluriparous cows with high AMH concentration had shorter calving to first service (86.0 ± 37.6 vs. 97.1 ± 46.7 days, $P < 0.05$) and calving to conception (123.8 ± 51.9 vs. 135.8 ± 54.4 days, $P < 0.05$) intervals, but lower milk yield (8440.3 ± 2292.9 vs. 8927.9 ± 2192.5 kg, $P < 0.05$) compared to cows with low AMH. In conclusion, no effect of postpartum diseases on AFC or AMH concentration of dairy cows could be observed. However, an interaction between parity and AFC, as well as associations of AMH with fertility and productivity in pluriparous cows, were demonstrated.

1. Introduction

The relationship between ovarian reserve and fertility is of high interest for scientists but also for practitioners, as selection of cattle for fertility early in their reproductive life would avoid unnecessary costs related to maintenance. In the past years, two markers for ovarian reserve of cattle could be validated independently from each other: the number of follicles recruited during follicular

* Correspondence to: Clinic of Reproductive Medicine, Vetsuisse Faculty Zurich, University of Zurich, Winterthurerstrasse 260, Zürich 8057, Switzerland.

E-mail address: dragos.scarlet@uzh.ch (D. Scarlet).

https://doi.org/10.1016/j.anireprosci.2023.107291
Received 8 December 2022; Received in revised form 19 March 2023; Accepted 27 June 2023
Available online 29 June 2023

development and peripheral concentrations of anti-Müllerian hormone (AMH) (Mossa and Ireland, 2019). Interestingly, although these two markers are highly positively correlated to each other (Rico et al., 2009) contradictory results were observed in dairy heifers regarding fertility, using these measurements (Jimenez-Krassel et al., 2017; Morotti et al., 2018). As productivity is directly related to fertility in cattle, finding reliable markers for reproductive performance is of utmost importance for animal selection and economy of the dairy farms.

Antral follicle count (AFC) has been long under research as a parameter for fertility in cattle and is defined as the average peak number of follicles $\geq$ 3 mm growing during consecutive follicular waves of estrous cycles (Burns et al., 2005). The AFC is highly repeatable among estrous cycles and cattle can be classified into three different groups accordingly: low ($n \leq 15$), intermediate ($n =$ 16–25), and high ($n \geq 25$) follicle numbers (Burns et al., 2005; Ireland et al., 2007). This is valid for dairy and beef cattle (Burns et al., 2005; Ireland et al., 2007), but no further comparisons among breeds have been done so far. Although AFC is generally very stable within an individual, occurrence of reproductive disease such as mastitis rapidly alters follicle development (Furman et al., 2014). This leads to a reduced number of medium and large size follicles and this effect can be carried over for at least four cycles (Lavon et al., 2011). A similar decrease in the number of medium size follicles, as well as AFC, has been observed as a consequence of clinical endometritis (Saleem et al., 2022). Animals with a low AFC were shown to have increased FSH and LH concentrations (Mossa and Ireland, 2019), but also lower progesterone concentrations and endometrial thickness, compared to animals with high AFC (Jimenez-Krassel et al., 2009). As a consequence, cattle with small ovarian reserve show a low response to superovulation (Ireland et al., 2007), and experience greater embryo mortality (Diskin and Morris, 2008). Furthermore, pregnancy rate was higher and calving to conception interval shorter in dairy cows with high AFC than in cows with low AFC (Mossa et al., 2012).

Anti-Müllerian hormone regulates the initial recruitment of primordial follicles to antral follicles and lowers FSH-sensitivity of follicles at cyclic recruitment (Gigli et al., 2005; Yang et al., 2017). It is measurable during the whole estrous cycle in cattle and is constantly in the same range for one individual (Rico et al., 2009; Monniaux et al., 2011; Baruselli et al., 2018). Anti-Müllerian hormone can be used as a diagnostic tool to estimate the population of healthy follicles in cattle (Ireland et al., 2008). A single determination of AMH concentration in dairy heifers seems to be a reliable diagnostic tool to predict herd longevity but not for fertility in the same animals (Jimenez-Krassel et al., 2015). Recently, decreased AMH concentrations were observed during perinatal period in association with the occurrence of systemic inflammation, but the effect on reproductive function still needs to be determined (Okawa et al., 2021). Both AFC and AMH are not only associated with fertility and productivity parameters, but they have also been shown to have high heritability (Walsh et al., 2014; Nawaz et al., 2018).

Considering the economic impact these parameters have on dairy industry, herein we analyzed the association between occurrence of postpartum disease and AFC and AMH, respectively. We hypothesized that AFC and AMH are reduced in cows with postpartum disease compared to healthy cows. Furthermore, we correlated above mentioned factors with reproductive efficiency and productivity in lactating dairy cows, also taking effects of parity and breed into consideration, as most studies so far included animals with similar parity of the same breed.

2. Material and methods

2.1. Animals

This study used a cohort of 513 cows originating from 22 different farms in Switzerland. The cows belonged to four different breeds: Holstein Friesian ($n = 369$), Brown Swiss ($n = 112$) and others ($n = 32$, mostly Montbèliard, except for one Jersey and two crossbreeds). Information on parity and level of milk production as determined by 305-d mature equivalent yields was available. The animals were housed either in tethered housing or in free stall barns.

2.2. Gynecological examination and AFC determination

Each animal was examined once 28–56 days postpartum. Data for body condition score and vaginal discharge were recorded. The ovaries and uteri of all cows were scanned transrectally with an ultrasound scanner (MyLab One Vet, Esaote, Köln, Germany) equipped with a multi-frequency 5–10 MHz linear array transducer. The ovaries were examined systematically, starting at the ovarian pedicle and ending at the ovarian ligament. Three video sequences were recorded for each ovary and an AFC estimation was performed at the same time by the observer. Later, one video sequence with the best quality was chosen for each ovary to objectively determine AFC. All sequences were analyzed by one observer (LS) using MyLab Desk. Based on number of recorded follicles $\geq$ 3 mm in diameter, cows were categorized as having low ($n \leq 15$ follicles), intermediate ($n = 16$–24 follicles), or high ($n \geq 25$ follicles) AFC, respectively (Burns et al., 2005).

2.3. Fertility data

Information regarding type of breeding (insemination by bull or artificial insemination), number of inseminations, and last date of breeding was recorded. Pregnancy diagnosis was performed at least twice for every cow on days 28–35 and days 50–70 after insemination by experienced veterinarians using ultrasound. If cows were open for more than 200 days after parturition, they were classified as not pregnant. Fertility parameters, i.e., first service conception rate, conception rate, calving to first service interval, days open, and number of services per conception, were calculated.

Occurrence of postpartum diseases during the first 28 days postpartum was accounted for by means of a questionnaire addressed to the farmer and by checking records of treatments for puerperal diseases. Postpartum diseases were categorized into infectious/inflammatory: retained fetal membranes: >12 h after parturition, metritis, endometritis, mastitis (fever, positive California mastitis test, signs of udder inflammation), and metabolic diseases: hypocalcemia (calcium < 2.3 mmol/l), ketosis (BHB > 1 mmol/l), abomasal displacement (clinical examination), respectively. The occurrence of an infectious/inflammatory disease was diagnosed if fever (>39.0 °C) and a change of general behavior existed. Diseased cows were treated by experienced veterinarians accordingly.

2.4. Anti-Müllerian hormone (AMH) assay

Blood samples were collected by venipuncture of the coccygeal vein at the time of AFC determination. After centrifugation at 1200xg for 10 min, serum was collected and stored at −20 °C until further analysis. Serum AMH concentration was determined with an enzyme linked immunosorbent assay, as recommended by the manufacturer (A79765, AMH Gen II ELISA, Beckman Coulter, Brea, CA, USA), as previously validated (Ireland et al., 2008). The controls provided by the same company were used for calibration (A79766, Beckman Coulter). The intra- and inter-assay coefficients of variation were 7.0 % and 4.6 %, respectively, and the minimal detectable concentration was 0.05 ng/ml. Cows presenting an AMH concentration below the limit of detection of the assay were classified into the low AMH group, whereas all cows with AMH concentration above the limit of detection were classified into the high AMH group.

2.5. Statistical analysis

Statistical analyses were conducted with the software SPSS Version 27 (SPSS Inc., Chicago, IL, USA). A one-way ANOVA, followed by a LSD multiple comparisons test if applicable, was employed to determine the effects of postpartum diseases on AMH concentration and AFC group and if significant ($P < 0.05$) differences existed among AMH and AFC groups for all variables, such as first service conception rate, conception rate, calving to first service interval, days open, number of services per conception, and level of milk production as determined by 305-d mature equivalent yields. Also, the effect of the farm on the above-mentioned parameters was tested for. The interrater reliability for AFC estimation was tested with Cohens Kappa statistic. A comparison was made between the on-site AFC estimation and the computer-assisted AFC determination. Pearson`s test was used to analyze the correlation between AMH and AFC. Data are given as mean ± standard deviation (SD).

3. Results

3.1. Age, parity, milk yield and reproductive parameters

On the day of first examination (42 ± 8 days post-partum), the age of primiparous cows ($n = 121$) was 31 ± 3 months and of pluriparous cows ($n = 392$) 67 ± 23 months, respectively. Average level of milk production as determined by 305-d mature equivalent yields was 8359 ± 2261 kg (range 1445–14746 kg). First service conception rate was 34.9 % and by the end of the study (200th day after calving) 67.4 % of the cows became pregnant. Of these, 90.5 % ($n = 313$) were artificially inseminated and 9.5 % ($n = 33$) were bred by a bull. Calving to first service interval was 88 ± 40 days and calving to conception interval was 126 ± 53 days. The average number of services per conception was 1.8 ± 0.9. From the total of 513 cows, 17.2 % presented signs of inflammatory disease (14 % of primiparous, 18 % of pluriparous), 5.1 % metabolic disease (0 % of primiparous, 6.6 % of pluriparous), and 2.7 % signs of combined inflammatory and metabolic disease (0.8 % of primiparous, 3.3 % of pluriparous), respectively. There was an effect ($P < 0.001$) of the farm of origin on the average level of milk production and on the occurrence of metabolic disease, but not on the other parameters.

3.2. Antral follicle count

There was a high variability in the AFC between individual animals (Fig. 1). The average AFC was 16.3 ± 6.9 (range 1–41 follicles). Overall, 48 % of cows had low AFC (10.5 ± 3.0, $n = 246$), 39.4 % intermediate (19.3 ± 2.8, $n = 202$), and 12.6 % high (28.7 ± 3.4, $n =$

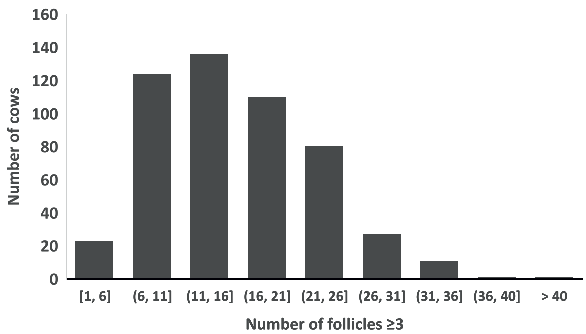

Fig. 1. Distribution of 513 cows according to their antral follicle count recorded using ovarian ultrasonography during one examination 28–56 days postpartum.

65), respectively. The interrater reliability between on-site AFC estimation and computer-assisted AFC determination was $\kappa = 0.56$, hence a moderate concordance. Primiparous cows had lower AFC (13.6 ± 6.2 vs. 17.1 ± 7.0, $P < 0.001$) than pluriparous cows (Fig. 2A). There was a strong interaction between parity and AFC group ($P < 0.001$): more primiparous cows were distributed in the low AFC group (63.6 % vs. 43.1 %) and less in the high AFC group (5.8 % vs. 14.8 %) compared to pluriparous cows (Fig. 2B). In primiparous cows calving to first service interval was shorter in those with high AFC than in cows with intermediate AFC (58.3 ± 17.7 vs. 90.2 ± 30.5 days, $P < 0.05$), but there was no difference of this parameter between cows with low AFC and the other groups (Table 1). The number of days open, as well as first service conception rate and overall conception rate (Table 1), were similar among AFC groups, independent of parity of the cows. Also, the number of services per conception was similar for all AFC groups and for all parities (Table 1). There was no difference in average level of milk production as determined by 305-d mature equivalent yields according to AFC groups, and no effect of breed or health status post-partum on the AFC could be observed (Table 1). The farm of origin influenced ($P < 0.001$) AFC and the distribution in AFC groups.

3.3. Anti Müllerian hormone

In 204 (39.8 %) cows, AMH concentration was below the detection limit of the assay (0.05 ng/ml), but the distribution of cows in low versus high AMH was not affected by parity. In pluriparous cows with high AMH, but not in primiparous cows, calving to first service interval was shorter (86.0 ± 37.6 vs. 97.1 ± 46.7 days, $P < 0.05$) and less days open (123.8 ± 51.9 vs. 135.8 ± 54.4 days, $P < 0.05$) were observed compared with low AMH cows (Table 2). However, average level of milk production as determined by 305-d mature equivalent yields was greater in low AMH cows (8927.9 ± 2192.5 vs. 8440.3 ± 2292.9 kg, $P < 0.05$) than in high AMH cows (Table 2). First service conception rate and overall conception rate were similar between low and high AMH groups, respectively, independent of parity of the cows (Table 2). Also, the number of services per conception was similar for all AFC groups and for all parities (Table 2). Anti-Müllerian hormone concentration was not influenced by breed or by health status post-partum. Serum concentration of AMH was correlated ($P < 0.001$, $r = 0.34$) with AFC in animals with measurable AMH and was influenced by the farm of origin ($P < 0.001$).

4. Discussion

In this field study we investigated the effects of postpartum disease on AFC and AMH concentration in relation to fertility and productivity. While no effect of postpartum disease on AFC or AMH could be observed, a strong interaction between parity and AFC was demonstrated. Greater number of follicles were observed in pluriparous cows. At the same time, cows with high serum AMH concentration showed better fertility but lower milk production. Furthermore, we tested whether a single subjective ultrasound evaluation during postpartum period can successfully estimate AFC and were able to demonstrate the feasibility of AFC determination in the field.

Signs of puerperal diseases occurred in 26 % of the cows enrolled in this study, in accordance with other recent studies where almost 2500 cows where analyzed (Hubner et al., 2022), but these did not affect the distribution into AFC groups or circulating AMH concentration. Although dairy cows show a drop in AMH for about 60 days after parturition compared to pre-calving time (Monniaux et al., 2013; Alward et al., 2021), no association between negative health events and AMH could be demonstrated (Alward et al., 2021). Supposedly, the AMH drop occurs as a consequence of negative energy balance which, coupled with a high concentration of

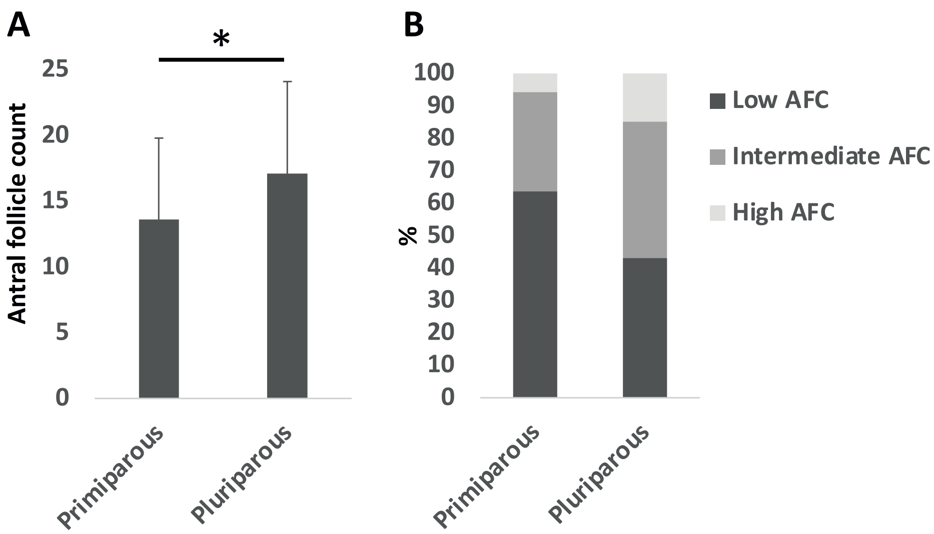

Fig. 2. Antral follicle count (AFC) in primiparous and pluriparous cows (A) and frequency distribution of cows according to their parity in low, intermediate, or high AFC groups (B). Numerical data are presented as the mean ± SD. Bar with asterisk differs at P < 0.05.

Table 1
Fertility and productivity parameters in primiparous and pluriparous cows according to their antral follicle count (AFC). Numerical data are presented as the mean ± SD. Different letters within one row differ at P < 0.05.

	Primiparous			Pluriparous		
	AFC low	AFC intermediate	AFC high	AFC low	AFC intermediate	AFC high
Calving to first service interval (days)	78.4 ± 35.0^{ab}	90.2 ± 30.5^{b}	58.3 ± 17.7^{a}	90.1 ± 41.6	92.0 ± 43.1	84.7 ± 36.0
Days open	115.9 ± 53.3	127.0 ± 49.1	106.1 ± 58.9	129.0 ± 53.1	130.1 ± 52.3	120.6 ± 55.3
First service conception rate (%)	40	38	43	32	33	40
Conception rate (%)	75	78	86	62	66	67
Services per conception	1.6 ± 0.7	1.8 ± 0.9	1.7 ± 0.8	1.7 ± 1.0	1.9 ± 1.1	1.6 ± 0.9
Milk yield (KG)	n/a	n/a	n/a	8667.3 ± 2315.0	8569.5 ± 2215.8	8624.6 ± 2297.6

n/a: not applicable.

Table 2
Fertility and productivity parameters in primiparous and pluriparous cows according to their serum AMH concentration. Numerical data are presented as the mean ± SD. Different letters within one row differ at P < 0.05.

	Primiparous		Pluriparous	
	Low AMH	High AMH	Low AMH	High AMH
Calving to first service interval (days)	85.7 ± 34.8	76.1 ± 32.1	97.1 ± 46.7^{a}	86.0 ± 37.6^{b}
Days open	120.6 ± 49.4	116.9 ± 55.3	135.8 ± 54.4^{a}	123.8 ± 51.9^{b}
First service conception rate (%)	47	33	33	34
Conception rate (%)	83	70	61	61
Services per conception	1.6 ± 0.8	1.8 ± 0.9	1.8 ± 1.1	1.8 ± 1.0
Milk yield (KG)	n/a	n/a	8927.9 ± 2192.5^{a}	8440.3 ± 2292.9^{b}

n/a: not applicable.

non-esterified fatty acids (NEFA), leads to impaired follicular growth (Lucy, 2007). Interestingly, a recent study investigating almost 2500 cows with various metabolic diseases and severity degrees was not able to find any correlation between NEFA concentration and reproductive outcome (Hubner et al., 2022). In contrast, exposure of ovarian tissue to NEFA has been shown to affect follicular environment and development (Pedroza et al., 2022), but the effect is mainly seen in preantral follicles (Figueiredo et al., 1994). The same is valid in the case of inflammatory diseases, as the number of secondary follicles is reduced in cows with acute, induced mastitis (Lavon et al., 2011), but also in naturally occurring chronic cases (Rahman et al., 2012). Moreover, an in vitro negative effect of lipopolysaccharide occurring during the course of mastitis on the primordial follicle pool could be demonstrated (Bromfield and Sheldon, 2013). Not only mastitis, but also clinical endometritis had a negative effect on follicular dynamics (Saleem et al., 2022). A strong association between decreasing AMH concentrations postpartum and high inflammation biomarker levels was recently documented (Okawa et al., 2021). However, these authors did not analyze reproductive prognosis of animals included in their study. Our results add to the existing knowledge and extend beyond it, as neither AMH nor AFC were affected by the health status of the cow in this study, regardless of type of postpartum disease. This may be due to the severeness of the disease, as previous studies analyzed a homogenous group of moderate to severe diseased animals, while animals in our study mainly suffered from mild to moderate diseases. For example, animals diagnosed with endometritis in our study did not require any extra treatment besides hormonal therapy. Another reason for not observing any effect on AFC and AMH might be related to the timepoint (28–56 days postpartum) when examinations were conducted in the current study. Toxin-induced mastitis was shown to have carryover effects on follicular function in cows (Lavon et al., 2011; Furman et al., 2014), but these could have only been observed by an extra AFC determination several weeks later.

A strong interaction between AFC and parity was found with primiparous cows having less antral follicles than pluriparous cows. Here, we see parallels with two other studies on dairy cows, where an obvious increase in AFC with age/parity was observed (Mossa et al., 2012; Martinez et al., 2016). This finding is in contradiction with reports of other studies, which demonstrated diminished ovarian reserve with age (Erickson, 1966; Erickson et al., 1976; Cushman et al., 2009). However, the latter studies were performed in beef and not dairy cows. Low AFC was previously associated with lower fertility in cattle (Mossa et al., 2012), therefore one can hypothesize that animals with less follicles are culled earlier due to reproductive failure. However, as demonstrated also in this study, conception rate is higher in primiparous than in pluriparous cows (Malhi et al., 2005) and we could not see any effect of AFC on reproductive or productive parameters. The animals included in this study originated from 22 different farms in Switzerland and an effect of the farm on AFC could be seen. In this country, dairy farms are rather small with a pasture-based management, and selection is not being done so stringent based on reproductive performance. Based on this, our results reflect the overall status of cows in this country, not only within one farm, although similar findings were observed in large farms from North America (Mossa et al., 2012) and New Zeeland (Martinez et al., 2016).

Regardless of animal`s parity, AFC did not influence reproductive or productivity parameters in this study. Normally, using AFC the number of morphologically healthy oocytes and follicles in ovaries of young adult cattle can be successfully predicted (Ireland et al., 2008). Low fertility was observed in cows with diminished ovarian reserve (Mossa et al., 2012) due to alteration of corpus luteum function and poor endometrial growth (Jimenez-Krassel et al., 2009). Interestingly, cows with high AFC were also shown to have suboptimal fertility (Jimenez-Krassel et al., 2017), similar to what is observed in women with polycystic ovarian syndrome (Webber et al., 2003). However, we could not see any effect of AFC on first service conception rate, overall conception rate, number of services per conception, days open or milk yield in cattle included in our analysis. Despite an existing agreement regarding the positive association of AFC with superovulatory response (Kawamata, 1994; Cushman et al., 1999; Singh et al., 2004) and in vitro embryo production (Taneja et al., 2000; Pontes et al., 2009), there is no general consent for other reproductive parameters. Results regarding AFC seem to largely differ between Bos taurus and Bos indicus cattle, but also within one species (Morotti et al., 2018). Moreover, AFC classification is often inconsistent among various studies, making it difficult to compare the results. A recent study could demonstrate several associations between the number of follicles with a diameter of 2 mm or greater and reproductive parameters, whereas most of the associations were lost when focusing on follicles with a diameter of 3 mm or greater (Martinez et al., 2016). Despite this, the 3 mm threshold for AFC determination was used in our study, according to previous literature (Burns et al., 2005), but also because we performed an on-site AFC estimation at the same time and follicles under 3 mm are difficult to recognize and differentiate from blood vessels.

A moderate concordance could be demonstrated in the current study between on-site AFC estimation and computer-assisted AFC determination. This is in accordance with findings of others, although a combination of ovarian size (as measured using ultrasound) and number of follicles was used in that study to categorize animals (Martinez et al., 2016). Thus on-site AFC determination could be a useful tool to identify cows with very low numbers of follicles, well-known for their reduced fertility (Mossa et al., 2012), but it can be difficult to extend the conclusion beyond this. When analyzing associations between AFC and fertility parameters, results are inconsistent. This is due to the variation in the evaluation criteria used to establish AFC categories and also due to the cut-point with only one follicle between AFC categories (Morotti et al., 2018). Especially when performing on-site AFC estimation, it is very easy to miss one small follicle and then AFC category could change.

In contrast to AFC, serum AMH concentration of the cows influenced their reproductive parameters and milk yield, but this effect could only be observed in pluriparous cows. Due to the high percentage (39.8 %) of cows included in this study with AMH concentration below the detection limit of the assay, we considered that these animals belong to the low AMH group. We then compared them to the rest of the animals, considered to belong to the high AMH group, and did not further partition cows into quartiles according to their AMH concentration as previously described (Jimenez-Krassel et al., 2015). To date, no reference values for circulating AMH concentrations in cattle have been established. This is probably due to the large variability of AMH values. In our study, measured values ranged from 0.05 ng/ml to 0.71 ng/ml, which is comparable to the results of others (Alward et al., 2021). Also, the number of animals with AMH concentration lower than 0.05 ng/ml is similar to observations by others (Jimenez-Krassel et al., 2015). Nevertheless, in the latter study AMH concentrations as low as 6.2 pg/ml were measured, while the minimum detected value in our hands was 0.05 ng/ml, closer to the instructions of the manufacturer. Pluriparous cows with high AMH in this study had a shorter calving to first service interval and less days open, but this was not the case in primiparous cows. The lack of effect of different AMH concentration on reproductive parameters and productivity was previously demonstrated in heifers (Jimenez-Krassel et al., 2015) and it was mainly attributed to the age of cattle. It was speculated that indices of ovarian function, endometrial development and oocyte quality were not markedly enough reduced in low AMH heifers in order to decrease various reproductive parameters (Mossa and Ireland, 2019). Our results showed no effect of AMH concentration on first service conception rates, number of services per conception, total pregnancy rates, regardless of parity of the cow. Interestingly, an effect of the farm of origin on AMH concentrations of the cows was observed. This could be due to selection focused either on fertility or on milk yield, as the genomic heritability of AMH was estimated to be 0.36 (Nawaz et al., 2018). In the same time, it can be due to different farm management, as variations in cows of the same breed held in different locations have been documented before (Walsh et al., 2014; Martinez et al., 2016).

5. Conclusions

Taken together, no effect of postpartum disease on AFC or AMH concentration of dairy cows enrolled in this study could be observed. There was a strong positive association between AFC and parity, but no interaction of AFC with fertility and productivity parameters. Nevertheless, pluriparous cows with high AMH concentration had a shorter calving to first service and to conception intervals, but lower milk yield compared to cows with low AMH concentration. Our results add to existing knowledge and extend the practical applicability of AFC on-site estimation together with AMH determination to select cattle with superior fertility and/or productivity.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of Competing Interest

The authors declare that they have no financial or personal relationship with other people or organizations that could inappropriately influence or bias the publication of this manuscript.

Acknowledgements

This research was supported using resources of the AgroVet-Strickhof research facility, a cooperation between Strickhof, ETH

Zurich and University of Zurich.

References

Alward, K.J., Graves, W.M., Palomares, R.A., Ely, L.O., Bohlen, J.F., 2021. Characterizing Anti-Müllerian Hormone (AMH) concentration and change over time in Holstein dairy cattle. Theriogenology 168, 83–89.
Baruselli, P., Batista, E., Vieira, L., Souza, A., 2018. Relationship between follicle population, AMH concentration and fertility in cattle. Anim. Reprod. (AR) 12, 487–497.
Bromfield, J.J., Sheldon, I.M., 2013. Lipopolysaccharide reduces the primordial follicle pool in the bovine ovarian cortex ex vivo and in the murine ovary in vivo. Biol. Reprod. 88, 98.
Burns, D.S., Jimenez-Krassel, F., Ireland, J.L., Knight, P.G., Ireland, J.J., 2005. Numbers of antral follicles during follicular waves in cattle: evidence for high variation among animals, very high repeatability in individuals, and an inverse association with serum follicle-stimulating hormone concentrations. Biol. Reprod. 73, 54–62.
Cushman, R.A., DeSouza, J.C., Hedgpeth, V.S., Britt, J.H., 1999. Superovulatory response of one ovary is related to the micro- and macroscopic population of follicles in the contralateral ovary of the cow. Biol. Reprod. 60, 349–354.
Cushman, R.A., Allan, M.F., Kuehn, L.A., Snelling, W.M., Cupp, A.S., Freetly, H.C., 2009. Evaluation of antral follicle count and ovarian morphology in crossbred beef cows: investigation of influence of stage of the estrous cycle, age, and birth weight1,2. J. Anim. Sci. 87, 1971–1980.
Diskin, M.G., Morris, D.G., 2008. Embryonic and early foetal losses in cattle and other ruminants. Reprod. Domest. Anim. 43 (Suppl 2), 260–267.
Erickson, B.H., 1966. Development and senescence of the postnatal bovine ovary. J. Anim. Sci. 25, 800–805.
Erickson, B.H., Reynolds, R.A., Murphree, R.L., 1976. Ovarian characteristics and reproductive performance of the aged cow. Biol. Reprod. 15, 555–560.
Figueiredo, J.R., Hulshof, S.C.J., Van den Hurk, R., Bevers, M.M., Thiry, M., Nusgens, B., Beckers, J.F., 1994. The physiological status of the ovarian donor affects in vitro development of isolated bovine preantral follicles. Theriogenology 42, 1303–1310.
Furman, O., Leitner, G., Roth, Z., Lavon, Y., Jacoby, S., Wolfenson, D., 2014. Experimental model of toxin-induced subclinical mastitis and its effect on disruption of follicular function in cows. Theriogenology 82, 1165–1172.
Gigli, I., Cushman, R.A., Wahl, C.M., Fortune, J.E., 2005. Evidence for a role for anti-Mullerian hormone in the suppression of follicle activation in mouse ovaries and bovine ovarian cortex grafted beneath the chick chorioallantoic membrane. Mol. Reprod. Dev. 71, 480–488.
Hubner, A., Canisso, I.F., Peixoto, P.M., Coelho Jr., W.M., Ribeiro, L., Aldridge, B.M., Menta, P., Machado, V.S., Lima, F.S., 2022. Characterization of metabolic profile, health, milk production, and reproductive outcomes of dairy cows diagnosed with concurrent hyperketonemia and hypoglycemia. J. Dairy Sci. 105, 9054–9069.
Ireland, J.J., Ward, F., Jimenez-Krassel, F., Ireland, J.L., Smith, G.W., Lonergan, P., Evans, A.C., 2007. Follicle numbers are highly repeatable within individual animals but are inversely correlated with FSH concentrations and the proportion of good-quality embryos after ovarian stimulation in cattle. Hum. Reprod. 22, 1687–1695.
Ireland, J.L., Scheetz, D., Jimenez-Krassel, F., Themmen, A.P., Ward, F., Lonergan, P., Smith, G.W., Perez, G.I., Evans, A.C., Ireland, J.J., 2008. Antral follicle count reliably predicts number of morphologically healthy oocytes and follicles in ovaries of young adult cattle. Biol. Reprod. 79, 1219–1225.
Jimenez-Krassel, F., Folger, J.K., Ireland, J.L., Smith, G.W., Hou, X., Davis, J.S., Lonergan, P., Evans, A.C., Ireland, J.J., 2009. Evidence that high variation in ovarian reserves of healthy young adults has a negative impact on the corpus luteum and endometrium during estrous cycles in cattle. Biol. Reprod. 80, 1272–1281.
Jimenez-Krassel, F., Scheetz, D.M., Neuder, L.M., Ireland, J.L., Pursley, J.R., Smith, G.W., Tempelman, R.J., Ferris, T., Roudebush, W.E., Mossa, F., Lonergan, P., Evans, A.C., Ireland, J.J., 2015. Concentration of anti-Müllerian hormone in dairy heifers is positively associated with productive herd life. J. Dairy Sci. 98, 3036–3045.
Jimenez-Krassel, F., Scheetz, D.M., Neuder, L.M., Pursley, J.R., Ireland, J.J., 2017. A single ultrasound determination of ≥25 follicles ≥3 mm in diameter in dairy heifers is predictive of a reduced productive herd life. J. Dairy Sci. 100, 5019–5027.
Kawamata, M., 1994. Relationships between the number of small follicles prior to superovulatory treatment and superovulatory response in Holstein cows. J. Vet. Med. Sci. 56, 965–967.
Lavon, Y., Leitner, G., Moallem, U., Klipper, E., Voet, H., Jacoby, S., Glick, G., Meidan, R., Wolfenson, D., 2011. Immediate and carryover effects of Gram-negative and Gram-positive toxin-induced mastitis on follicular function in dairy cows. Theriogenology 76, 942–953.
Lucy, M.C., 2007. Fertility in high-producing dairy cows: reasons for decline and corrective strategies for sustainable improvement. Soc. Reprod. Fertil. Suppl. 64, 237–254.
Malhi, P.S., Adams, G.P., Singh, J., 2005. Bovine model for the study of reproductive aging in women: follicular, luteal, and endocrine characteristics. Biol. Reprod. 73, 45–53.
Martinez, M.F., Sanderson, N., Quirke, L.D., Lawrence, S.B., Juengel, J.L., 2016. Association between antral follicle count and reproductive measures in New Zealand lactating dairy cows maintained in a pasture-based production system. Theriogenology 85, 466–475.
Monniaux, D., Baril, G., Laine, A.L., Jarrier, P., Poulin, N., Cognié, J., Fabre, S., 2011. Anti-Mullerian hormone as a predictive endocrine marker for embryo production in the goat. Reproduction 142, 845–854.
Monniaux, D., Drouilhet, L., Rico, C., Estienne, A., Jarrier, P., Touzé, J.L., Sapa, J., Dupont, J., Dalbiés-Tran, R., Fabre, S., 2013. Regulation of anti-Mllerian hormone production in domestic animals. Reprod. Fertil. Dev. 25, 1–16.
Morotti, F., Zangirolamo, A.F., da Silva, N.C., da Silva, C.B., Rosa, C.O., Seneda, M.M., 2018. Antral follicle count in cattle: advantages, challenges, and controversy. Anim. Reprod. (AR) 14, 414–420.
Mossa, F., Ireland, J.J., 2019. Physiology and endocrinology symposium: anti-Müllerian hormone: a biomarker for the ovarian reserve, ovarian function, and fertility in dairy cows. Funct. Fertil. J. Anim. Sci. 97, 1446–1455.
Mossa, F., Walsh, S.W., Butler, S.T., Berry, D.P., Carter, F., Lonergan, P., Smith, G.W., Ireland, J.J., Evans, A.C., 2012. Low numbers of ovarian follicles ≥3 mm in diameter are associated with low fertility in dairy cows. J. Dairy Sci. 95, 2355–2361.
Nawaz, M.Y., Jimenez-Krassel, F., Steibel, J.P., Lu, Y., Baktula, A., Vukasinovic, N., Neuder, L., Ireland, J.L.H., Ireland, J.J., Tempelman, R.J., 2018. Genomic heritability and genome-wide association analysis of anti-Müllerian hormone in Holstein dairy heifers. J. Dairy Sci. 101, 8063–8075.
Okawa, H., Monniaux, D., Mizokami, C., Fujikura, A., Takano, T., Sato, S., Shinya, U., Kawashima, C., Yamato, O., Fushimi, Y., Vos, P.L.A.M., Taniguchi, M., Takagi, M., 2021. Association between Anti-Müllerian hormone concentration and inflammation markers in serum during the peripartum period in dairy cows. Animals 11, 1241.
Pedroza, G.H., Lanzon, L.F., Rabaglino, M.B., Walker, W.L., Vahmani, P., Denicol, A.C., 2022. Exposure to non-esterified fatty acids in vitro results in changes in the ovarian and follicular environment in cattle. Anim. Reprod. Sci. 238, 106937.
Pontes, J.H., Nonato-Junior, I., Sanches, B.V., Ereno-Junior, J.C., Uvo, S., Barreiros, T.R., Oliveira, J.A., Hasler, J.F., Seneda, M.M., 2009. Comparison of embryo yield and pregnancy rate between in vivo and in vitro methods in the same Nelore (Bos indicus) donor cows. Theriogenology 71, 690–697.
Rahman, M.M., Mazzilli, M., Pennarossa, G., Brevini, T.A., Zecconi, A., Gandolfi, F., 2012. Chronic mastitis is associated with altered ovarian follicle development in dairy cattle. J. Dairy Sci. 95, 1885–1893.
Rico, C., Fabre, S., Médigue, C., di Clemente, N., Clément, F., Bontoux, M., Touzé, J.L., Dupont, M., Briant, E., Rémy, B., Beckers, J.F., Monniaux, D., 2009. Anti-mullerian hormone is an endocrine marker of ovarian gonadotropin-responsive follicles and can help to predict superovulatory responses in the cow. Biol. Reprod. 80, 50–59.
Saleem, M., Yousuf, M.R., Ghafoor, A., Riaz, A., 2022. Influence of endometritis on the follicular dynamics, recovery, quality, gene expression, nuclear maturation and in-vitro developmental competence of oocytes in Sahiwal cattle. Reprod. Domest. Anim.
Singh, J., Domínguez, M., Jaiswal, R., Adams, G.P., 2004. A simple ultrasound test to predict the superstimulatory response in cattle. Theriogenology 62, 227–243.

Taneja, M., Bols, P.E., Van de Velde, A., Ju, J.C., Schreiber, D., Tripp, M.W., Levine, H., Echelard, Y., Riesen, J., Yang, X., 2000. Developmental competence of juvenile calf oocytes in vitro and in vivo: influence of donor animal variation and repeated gonadotropin stimulation. Biol. Reprod. 62, 206–213.
Walsh, S.W., Mossa, F., Butler, S.T., Berry, D.P., Scheetz, D., Jimenez-Krassel, F., Tempelman, R.J., Carter, F., Lonergan, P., Evans, A.C.O., Ireland, J.J., 2014. Heritability and impact of environmental effects during pregnancy on antral follicle count in cattle. J. Dairy Sci. 97, 4503–4511.
Webber, L.J., Stubbs, S., Stark, J., Trew, G.H., Margara, R., Hardy, K., Franks, S., 2003. Formation and early development of follicles in the polycystic ovary. Lancet 362, 1017–1021.
Yang, M.Y., Cushman, R.A., Fortune, J.E., 2017. Anti-Müllerian hormone inhibits activation and growth of bovine ovarian follicles in vitro and is localized to growing follicles. Mol. Hum. Reprod. 23, 282–291.