The effect of dam and calf measurements on overall and fetopelvic dystocia prediction in Holstein heifers.

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SUPPLEMENTARY FILE

Materials and Methods

Study farms and feeding

At the time of the study the four farms housed on average 350 lactating and dry cows (min. 200 - max. 500) and 55 heifers aged over 6 months (min. 35 - max. 105). The annual herd milk yield average was 10169 kg (min. 9211 - max. 12066). Cows were fed a Total Mixed Ration (**TMR**) consisting mainly of corn silage, alfalfa, straw, corn and soybean meal, vitamins and minerals supplementation adjusted for age and stage of lactation. In all farms, lactating cows were housed in free stalls with cubicles.

Care of the neonate

Shortly after parturition, newborn calves were separated from their dam, dried with a single-use paper towel, and housed in individual boxes until weaning, where they received ear tags, disinfection of the umbilical cord with antibiotic aerosol spray (Terramycine Aerosol Spray®, Pfizer Inc, NY, USA) and were fed the first meal of colostrum, maximum two hours after calving; two liters were given within the first two hours and a total of 4 liters within six hours after calving. Day two to three, calves received selenium intramuscularly or subcutaneously 0.055 - 0.067 mg/kg (2.5 - 3 mg/45 kg). Two meals of milk were fed every 12 hours; milk quantity was based on the age of each calf. From day three, calves had ab libitum access to water and from day seven to ten they were fed pelleted calf's starter and alfalfa hay until weaning, on day 75.

Supplementary Table S1. Definitions of parameters recorded by herdsman regarding parturition.

Parameter	Definition
Presentation	1 = anterior
	2 = posterior
Position	1 = dorso-sacral
	2 = other (specify)
Posture	1 = extended
	2 = flexed (specify body part/joint)
Duration [a]	1 = 10-30 minutes
	2 = 30-60 minutes
	3 = 60-120 minutes
	4 > 120 minutes
Dystocia	0 = spontaneous calving
	1 = dystocia [b]

[a] = since the rapture of the fetal membranes or limbs appearance through the vulva

[b] = calving difficulty one hour after appearance of the amnion with abnormal findings or two hours with normal findings. Heifers were examined in lateral recumbency if possible, otherwise they were restrained in headlocks.

Supplementary Table S2. Definitions of parameters recorded by herdsman in case of dystocia.

Parameter	Definition
Dystocia etiology	1 = fetal oversize
	2 = small pelvis
	3 = fetomaternal disproportion
	4 = malpresentation, malposition, malposture
	5 = incomplete dilation of cervix
	6 = incomplete dilation of vulva
	7 = uterine inertia
	8 = more than one cause
Person of assistance	1 = farm staff
	2 = herdsman
	3 = veterinarian
Score of assistance	1 = low severity [a]
	2 = medium severity [b]
	3 = high severity [c]
Type of assistance	1 = one person
	2 = two or more persons
	3 = veterinarian assistance / caesarean section
	4 = mechanical calf puller

[a] = completion of a dystocic parturition with one person with no complications

[b] = one person with calf puller or two persons without calf puller

[c] = two persons with calf puller, or veterinarian help was asked

Construction of the metal caliper and herd data

For the construction of the caliper a metallic ruler, one meter long, with one-millimeter increments, was adapted on a rectangular stainless-steel tube. A 30-centimeter metallic arm was stabilized vertically at the beginning of the ruler at the point of zero centimeters. A second metallic arm vertically placed on the construction of the ruler-tube was freely moving along it, for the distance's measurement between these two arms.

Supplementary Table S3. Heifers' body measurements with abbreviations and definitions.

Pelvic measure	Abbr.	Unit	Anatomic borders
Hip width	TcTcH	cm	Most lateral point of the two tuber coxae
Hip length	TcTi	cm	Most cranial point of the tuber coxae until the most caudal point of ipsilateral tuber ischiadicum
Pin bones width	TiTiH	cm	Most lateral point of the two tuber ischiadici
Chest circumference	CCH	cm	Circumference of the thorax in the region of cranial sternum
Body Condition Score	BCS	1-5	
Body weight (estimated)	BW	kg	

Data regarding heifer's birth date, date of last insemination, characteristics of the served semen and expected calving date were also exported from the records of each farm.

Calves' measurements

With the staff's aid, calves were taken out of the boxes and were steadily held on a standing position on a concrete floor, while the measurements were performed by the lead author. Head circumference, chest circumference, fetlock joint circumference of the right forelimb, body length with and without neck were measured with a 150-centimeter measuring tape with

one-millimeter increments (Hoechstmass®, Germany). Fetlock joint width of the right forelimb, hip width, pin width was measured with a 0-300 mm metallic caliper (Inter®, product code: 50774127, China). Body weight was calculated with an electronic scale with maximum weighing capacity 150 kg and 50g increments (OEM, product code: 0003681, China). Calves' anatomic parameters included in the study were based on the findings of Becker *et al.* (2011), Gundelach *et al.* (2009), Hiew *et al.* (2016) and Kolkman *et al.* (2010). All measurements were performed twice, and the mean was used for further analysis.

Supplementary Table S4. Calves' body measurements with abbreviations and definitions.

Body measurement	Abbr.	Unit	Anatomic borders
Head circumference	HC	cm	Maximum circumference of the head on the level of orbitae
Body length	CRL	cm	Linear distance along vertebral column from protuberantia occipitalis externa to first coccygeal vertebra
Chest circumference	CCC	cm	Maximum circumference in the region of cranial sternum
Hip width	TcTcC	cm	Most lateral point of the two tuber coxae
Pin bones width	TiTiC	cm	Most lateral point of the two tuber ischiadici
Fetlock joint circumference	FJC	cm	Maximum circumference in the middle of the fetlock joint of the right forelimb
Fetlock joint width	FJW	cm	Maximum width of the fetlock joint of the forelimb
Body weight	BWC	kg	

Sex, state at birth (dead or alive), viability (live for ≤ or more than 48 hours), and cause of death, were also recorded. Pathological and/or microbiological examinations were not performed in any case.

Results

None of the heifers had a twin pregnancy and all calvings were included for further analysis. The average age of successful insemination for the study animals was 530 days (17.4 months) ranging (min. – max.) from 380 – 1097 days (12.5 – 36.1 months). One heifer was bred prematurely at the age of 10.7 months. The age at first calving (**AFC**) was 806 days (612 – 1377) or 26.5 months (20.1 – 45.3). Pregnancy duration (**PrDur**) averaged 276 days (259 – 308 days). Only two cows were recorded to give birth in posterior presentation and in all calvings a dorso-sacral position was evident. Fifteen (35.7%), 10 (23.8%) and 17 (40.5%) of dystocias were assisted by farm personnel, farm owner and veterinarian, whereas 33.3%, 50% and 16.7% were classified of low, medium, and high severity, respectively. Regarding type of assistance 23.8% were assisted by one person, 38.1% by two persons and in 38.1% of cases a calf puller was used. No caesarean section was performed. One calf was born dead and two more died within 48 hours, one due to diarrhea syndrome and the other due to unspecified reasons.

Supplementary Table S5. Mean ± SD of heifers' factors included in the statistical analysis

Parameter	Mean ± SD
AFC	801.3 ± 127.0
PrDur	274.2 ± 23.7
BCS	3.2 ± 0.4
TcTcH	51.9 ± 3.1
TcTi	54.5 ± 2.8
TiTiH	35.7 ± 2.9
CCH	194.2 ± 9.8
PA	367.3 ± 43.5
PC	72.8 ± 3.8
VOL	8652.1 ± 1041.4
Diar	21.4 ± 1.6
Hmin	18.0 ± 1.6

AFC: Age first calving; PrDur: Pregnancy duration; TcTcH: Heifer's hip width; TcTi: Hip length; TiTiH: Heifer's pin bones width; CCH: Heifer's chest circumference; PA: Pelvic inlet area; PC: Pelvic inlet circumference; VOL: Pelvic volume; Diar: Right diagonal of pelvic inlet; Hmin: minimum height

Supplementary Table S6. Mean ± SD of calves' factors included in the statistical analysis

Parameter	Mean ± SD
HC	48.3 ± 1.9
CRL	83.8 ± 5.6
CCC	77.6 ± 4.0
TcTcC	16.4 ± 0.8
TiTiC	11.1 ± 1.0
FJC	17.3 ± 0.8
FJW	5.3 ± 0.3
BWC	38.5 ± 4.0

HC: Head circumference; CRL: Crown rump length; CCC: Calf's chest circumference; TcTcC: Calf's hip width; TiTiC: Calf's pin bones width; FJC: Fetlock joint circumference; FJW: Fetlock joint width; BWC: Calf's birth weight

Supplementary Table S7. Heifers' factors included in the statistical analysis regarding fetopelvic disproportion dystocia.

Parameter	Level	n	FPD[a] (%)	OR[b] (95% CI[c])	P-value
AFC	<734	99	1.0	0.2 (0.003-2.2)	0.03
	734-847	199	8.0	2.1 (0.7-6.4)	
	>847	99	4.0	Ref.	
PrDur	<275	151	3.3	0.5 (0.2-1.5)	0.38
	275-280	187	6.4	Ref.	
	>280	58	6.9	1.1 (0.3-3.5)	
BCS	<3	111	8.1	2.3 (0.9-6.1)	0.24
	3-3.5	214	3.7	Ref.	
	>3.5	76	5.3	1.4 (0.4-4.9)	
TcTcH	<49.95	98	7.1	1.6 (0.6-4.1)	0.32
	≥49.95	304	4.6	Ref.	
TcTi	<53	98	9.2	2.4 (1.0-6.0)	0.04
	≥53	304	4.0	Ref.	
TiTiH	<33.7	94	5.3	1.0 (0.4-2.9)	0.96
	≥33.7	308	5.2	Ref.	
CCH	<188	96	5.2	1.0 (0.4-2.8)	0.98
	≥188	303	5.3	Ref.	
PA	<333.2	100	8.0	1.9 (0.8-4.7)	0.16
	≥333.2	297	4.4	Ref.	
PC	<69.86	100	8.0	1.9 (0.8-4.7)	0.16
	≥69.86	297	4.4	Ref.	
VOL	<7799.2	101	7.9	1.9 (0.8-4.7)	0.16
	≥7799.2	301	4.3	Ref.	
Diar	<20.24	101	7.9	1.9 (0.8-4.7)	0.16
	≥20.24	301	4.3	Ref.	
Hmin	<16.84	101	7.9	1.9 (0.8-4.7)	0.16
	≥16.84	301	4.3	Ref.	

[a] FPD=Fetopelvic dystocia; [b] OR=Odds ratio; [c] CI= Confidence interval

AFC: Age first calving; PrDur: Pregnancy duration; TcTcH: Heifer's hip width; TcTi: Hip length; TiTiH: Heifer's pin bones width; CCH: Heifer's chest circumference; PA: Pelvic inlet area; PC: Pelvic inlet circumference; VOL: Pelvic volume; Diar: Right diagonal of pelvic inlet; Hmin: minimum height

Supplementary Table S8. Calves' factors included in the statistical analysis regarding overall dystocia.

Parameter	Level	n	OD (%)	OR[a] (95% CI[b])	P-value
Sexed semen	No	144	13.2	1.5 (0.8-2.9)	0.21
	Yes	252	9.1	Ref.	
Sex	Male	113	13.3	1.5 (0.8-2.9)	0.25
	Female	288	9.4	Ref.	
HC	≥49.5	92	9.8	0.9 (0.4-2.0)	0.81
	<49.5	310	10.7	Ref.	
CRL	≤87.13	300	11.7	1.8 (0.8-4.1)	0.19
	>87.13	100	7.0	Ref.	
CCC	>80	96	13.5	1.5 (0.7-3.0)	0.27
	≤80	304	9.5	Ref.	
TcTcC	>16.95	96	9.4	0.9 (0.4-1.9)	0.69
	≤16.95	305	10.8	Ref.	
TiTiC	>11.65	96	8.3	0.7 (0.3-1.6)	0.43
	≤11.65	304	11.2	Ref.	
FJC	>18	49	16.3	1.8 (0.8-4.2)	0.15
	≤18	352	9.7	Ref.	
FJW	>5.45	100	11.0	1.1 (0.5-2.2)	0.84
	≤5.45	301	10.3	Ref.	
BWC	≥42	86	12.8	1.3 (0.6-2.7)	0.47
	<42	308	10.1	Ref.	

[a] OD=Overall dystocia; [b] OR=Odds ratio; [c] CI= Confidence interval

HC: Head circumference; CRL: Crown rump length; CCC: Calf's chest circumference; TcTcC: Calf's hip width; TiTiC: Calf's pin bones width; FJC: Fetlock joint circumference; FJW: Fetlock joint width; BWC: Calf's birth weight

Supplementary Table S9. Ratios included in the statistical analysis regarding overall dystocia.

Parameter	Level	n	OD (%)	OR[a] (95% CI[b])	P-value
PA/CCC	<4.33	98	15.3	1.8 (0.9-3.6)	0.08
	≥4.33	297	9.1	Ref.	
PC/CCC	<0.9	91	18.7	2.6 (1.3-5.0)	0.005
	≥0.9	304	8.2	Ref.	
VOL/FJC	<460.9	101	20.8	3.5 (1.8-6.7)	<0.0001
	≥460.9	300	7.0	Ref.	
VOL/HC	<164.23	100	17.0	2.3 (1.2-4.4)	0.01
	≥164.23	302	8.3	Ref.	
Hmin/HC	<0.35	105	16.2	2.1 (1.1-4.1)	0.03
	≥0.35	297	8.4	Ref.	

[a] OD=Overall dystocia; [b] OR=Odds ratio; [c] CI= Confidence interval

PA: Pelvic inlet area; PC: Pelvic inlet circumference; VOL: Pelvic volume; Hmin: Minimum height; HC: Head circumference; CCC: Calf's chest circumference; FJC: Fetlock joint circumference

Supplementary Table S10. Ratios included in the statistical analysis regarding fetopelvic disproportion dystocia.

Parameter	Level	n	OD (%)	OR[a] (95% CI[b])	P-value
PA/CCC	<4.33	98	7.1	1.6 (0.6-4.0)	0.35
	≥4.33	297	4.7	Ref.	
PC/CCC	<0.9	91	11.0	3.3 (1.3-8.0)	0.006
	≥0.9	304	3.6	Ref.	
VOL/FLJ	<460.9	101	9.9	2.9 (1.2-7.0)	0.02
	≥460.9	300	3.7	Ref.	
VOL/HC	<164.23	100	7.0	1.5 (0.6-4.0)	0.36
	≥164.23	302	4.6	Ref.	
Hmin/HC	<0.35	105	8.6	2.2 (0.9-5.4)	0.07
	≥0.35	297	4.0	Ref.	

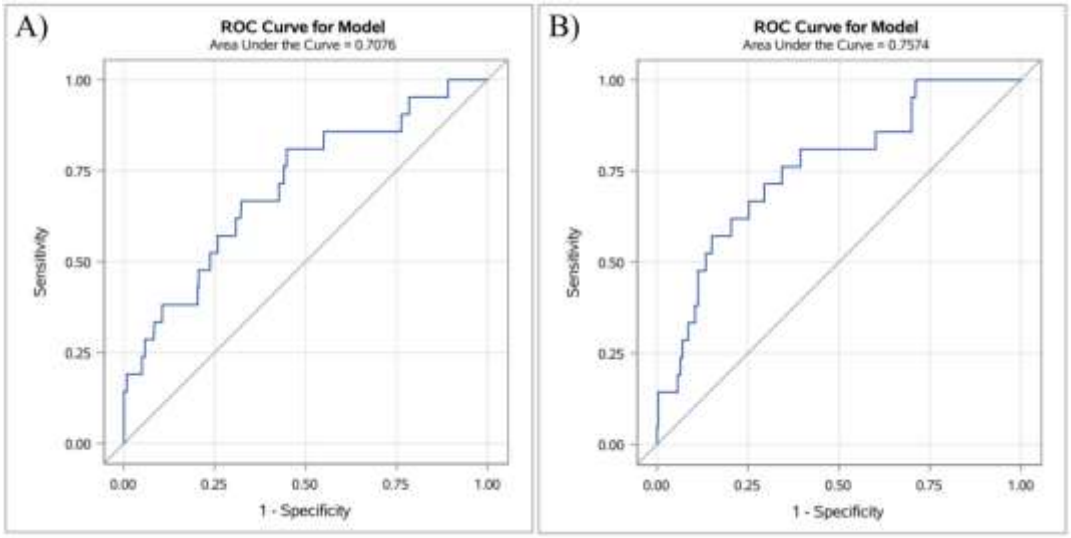
[a] FPD=Fetopelvic dystocia; [b] OR=Odds ratio; [c] CI= Confidence interval

PA: Pelvic area inlet; PC: Pelvic inlet circumference; VOL: Pelvic volume; Hmin: Minimum height; HC: Head circumference; CCC: Calf's chest circumference; FJC: Fetlock joint circumference

Supplementary Table S11. Comparison of pelvic dimensions (Mean ± SD) between heifers experiencing dystocia due to vulval stenosis (VS, n=16) and the rest of the study animals (NVS, n=386).

Parameter	VS	NVS	P-value
TcTcH	49.9 ± 2.7	52.0 ± 3.1	0.009
TcTi	53.2 ± 2.1	54.6 ± 2.9	0.05
TiTiH	34.0 ± 2.7	35.8 ± 2.9	0.02
PA	339.8 ± 28.5	368.4 ± 43.7	0.01
PC	70.4 ± 2.4	72.9 ± 3.8	0.001
VOL	7950.4 ± 849.1	8681.2 ± 1039.3	0.006

TcTcH: Heifer's hip width; TcTi: Hip length; TiTiH: Heifer's pin bones width; PA: Pelvic inlet area; PC: Pelvic inlet circumference; VOL: Pelvic volume;



Supplementary Fig. S1. ROC curves for feto-pelvic dystocia based on the combination of heifer pelvic length (TcTiH) and calf's fetlock joint circumference (FJC) (A) or body weight (B).

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