Evaluation of a wireless pulse oximeter to measure arterial oxygen saturation and pulse rate in newborn Holstein Friesian calves

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Abstract. *Pulse oximetry is a well-established technique in nowadays human and veterinarian medicine. Also in the farm animal sector, it could be a useful tool to detect critical conditions of the oxygen supply and the cardiovascular system of the patient. However, its use in ruminant medicine is still limited to experimental application. The objective of this study was to evaluate the accuracy of a Radius-7 Wearable Pulse Oximeter (Masimo Corporation, Irvine, CA) for monitoring the vital parameters of Holstein Frisian calves. The sensor of the pulse oximeter was placed in the interdigital space of the calf's front leg. The arterial oxygen saturation (SO_2) of 40 newborn calves was measured and compared with the corresponding results from a portable blood gas analyzer which served as reference method. The arterial blood sample was taken from the medial intermediate branch of the caudal auricular artery. The pulse rate was measured on 10 calves aged 0 to 7 days with the pulse oximeter and a heart rate belt simultaneously and their level of agreement was evaluated. Spearman correlation coefficient was 93.8 % for the SO_2 parameter between the pulse oximeter and the blood gas analyzer and 97.7 % for the pulse rate between the pulse oximeter and the heart rate belt. The pulse oximeter overestimated the SO_2 by 2.95 ± 6.39 % and underestimated the pulse rate by -0.41 ± 3.18 bpm compared with the corresponding reference methods. This pulse oximeter seems to be suitable for continuous monitoring of SO_2 and pulse of Holstein-Friesian calves.*

Keywords. *Calf, pulse oximetry, vital parameter, monitoring.*

Introduction

Pulse oximetry is a well-established technique in human and veterinary medicine. In farm animals, it could be a useful tool, too for the detection of critical conditions relating to oxygen supply and the cardiovascular system. One issue is that there are no devices on the market available which allow a practical and easy application of this technique, including attachment of the device to the animals as well as wireless transmission of the data to a display.

So far, commonly used techniques for detection of vital parameters, such as the auscultation of the heart or the palpation of the pulse, provide information only at the time of examination but do not allow continuous monitoring over a period of time. Therefore, pulse oximetry monitoring could be appropriate for early detection of hypoxia, especially in calves during high risk situations, such as during and after birth and in anaesthetized animals or patients suffering from pulmonary disease. Critical conditions could be detected at an early stage so that appropriate treatment could be initiated. All this requires a pulse oximeter validated for the use in calves and a practicable method for attaching the sensor. A stable physical connection between the sensor and the hoof is required, which is necessary for reliable measurements. A simple method for attaching the sensor that requires little practice is essential, too. The sensor used in this study was previously tested by the manufacturer on adult humans.

The objective of this study was to evaluate the accuracy of a pulse oximeter (Radius-7 Wearable Pulse CO-Oximeter, Masimo Corporation, Irvine, USA) for measuring arterial oxygen saturation (SpO_2) and pulse rate of newborn Holstein-Friesian calves. Results were compared with the corresponding measures from a portable blood gas analyzer and a heart rate belt, respectively.

Materials and Methods

Experimental Design

The study was approved by the institutional ethics and animal welfare committee and the national authority according to §§ 26 of Animal Experiments Act, Tierversuchsgesetz 2012 – TVG 2012 (GZ 68.205/0114-WF/V/3b/2015), as well as by the Slovakian Regional Veterinary Food Administration.

The study was conducted between May and August 2016 on a Slovakian dairy farm housing approximately 2,700 Holstein-Friesian cows and on the Teaching and Research Farm of the University of Veterinary Medicine, Vienna, Austria, housing 70 dairy cows (Simmental, Holstein Friesian and Brown Swiss). On both farms, calving took place in straw-bedded calving pens. Calves were separated from their dam within 1 h of birth and housed in individual calf hutches. The wireless Radius-7 pulse oximeter was used to measure the arterial oxygen saturation (SpO_2) and the pulse rate in Holstein-Friesian calves.

The eligibility of the pulse oximeter for measuring SpO_2 in calves was evaluated on 40 newborn calves, which were tested within 30 min of birth. For this, a transflectance sensor (M-LNCS TF-I A, Masimo Corporation, Irvine, USA) was placed on the pars axialis of the hoof on one front leg of the calf. The sensor was attached to the hoof by using a home-made hoof-shaped black latex-cover, which was slipped over the claw (Figure 1).

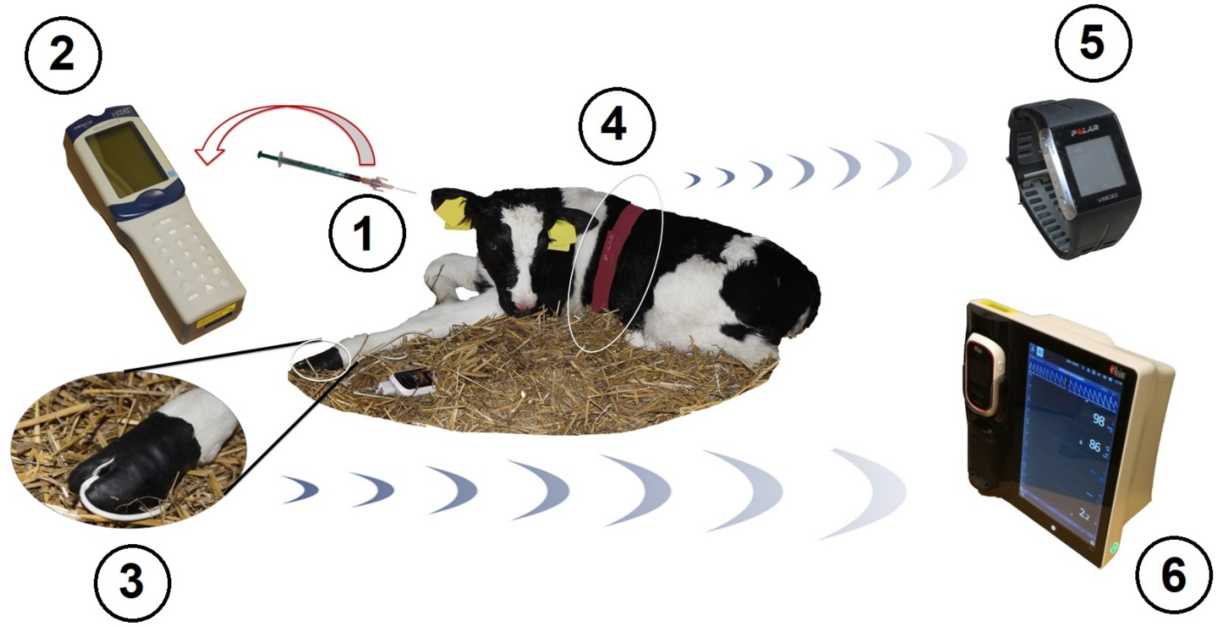

Fig 1. Technical equipment of the pulse oximeter and the heart rate belt and attachment of the devices to the calf.
1) Arterial blood sample
2) Bood gas analyzer (VetScan iStat1; Abaxis Inc., Union City, USA)
3) Latex hoof cover with transflectance sensor (M-LNCS TF-I A; Masimo Corporation, Irvine, USA) located in the interdigital space of the calf and cable link to the wearable pulse oximeter (Radius-7 Wearable Pulse CO-Oximeter; Masimo Corporation, Irvine, USA).4) Heart rate belt (Polar Equine Belt; Polar Electro Oy, Kempele, Finland)
5) Wearable clock-like device (Polar V800, Polar Electro Oy)
6) Masimo Root (Masimo Corporation, Irvine, USA) with digital display for visualizing the measured parameters.

This reusable cover was manufactured using a cast taken from the hoof of a newborn calf. The sensor was connected by cable to a wearable pulse oximeter for wireless transmission of data via Bluetooth to the Masimo Root device (Masimo Root, Masimo Corporation, Irvine, USA). The measured SpO_2 levels, as well as the pulse rate, were visualized on the digital screen of the device and corresponding data were saved every 2 s on the root device. The arterial oxygen saturation of the calf was additionally determined using a blood gas analyzer (VetScan iStat1; Abaxis Inc., Union City, USA) that has been previously evaluated in newborn calves (Bleul and Gotz 2014) and served as reference method. After attaching the pulse oximeter to the calf, an arterial blood sample was obtained from the medial intermediate branch of the caudal auricular artery using a heparinized syringe with a 23G needle (Gaslyte arterial blood sampler; Vital Signs Inc., Englewood, CO). Within 2 min after the blood sample was taken, it was analyzed using the portable blood gas analyzer. The analyzed oxygen saturation levels were recorded on a data-capture form. Mean pulse oximetry data during the last 20 s of blood sampling were used for comparison of SpO_2 (pulse oximeter) and SaO_2 (blood gas analyzer).

Ten Holstein-Friesian calves at the age of 0 to 7 d were used to validate the measured pulse rate of the oximeter. For this, the sensor of the pulse oximeter was connected to each calf as described above. All calves were in a relaxed lying position while the measurements were performed. Simultaneously, a heart rate belt (Polar Equine Belt; Polar Electro Oy, Kempele, Finland) was secured around the thorax of the calf and served as the reference method. The duration of the measurement period varied between calves and was dependent on the duration the calf was lying down. The belt provided beat-to-beat interval data, which were sent via bluetooth to a wearable clock-like device (Polar V800, Polar Electro Oy) where they were processed, displayed and stored. The correction tool of Kubios HRV software (version 2.2; Biosignal Analysis and Medical Imaging Group, Kuopio, Finland) was used to correct the data for artifacts and then converted to heart rate values (beats per minute; bpm). Data generated by the pulse oximeter and the heart-rate belt system were split into intervals of 20 s and the average bpm for each interval was calculated. This was done to minimize the influence of potential outliers. Every interval overlapped for 10 s with the previous and the subsequent intervals. In this way, 1,090 measurement pairs were calculated and statistically analyzed.

Statistical Analyses

Sample size was calculated using G*Power (version 3.1.9.2; University of Kiel, Germany) and further statistical evaluations were performed using SPSS Statistics for Windows (version 23.0; IBM Deutschland GmbH, Ehningen, Germany), BiAS for Windows (version 11.03; Epsilon-Verlag, Darmstadt, Germany) and Microsoft Excel 2010 (version 14.0.7180.5002; Microsoft Corporation, Redmond, USA). The level of significance was set at $P = 0.05$ for all statistical tests. Spearman's rho (ρ) correlation coefficients were calculated to compare the measurements of the pulse oximeter with the results from the blood gas analyzer (SaO_2) and the heart rate belt (for the pulse rate). Bland and Altman (1986) analyses were performed to investigate agreement between the test results from the pulse oximeter and the blood gas analyzer, as well as between the pulse oximeter and the heart rate belt. The cumulative sum test (Cusum) was performed to check data for linearity. Potential systematic and proportional differences in the data sets were evaluated using the method recommended by Passing and Bablok (1983).

Results

The range of arterial oxygen saturations in the 40 tested calves was between 15% and 98% determined by the blood gas analyzer and between 15% and 97% when using the pulse oximeter. The Spearman correlation coefficient (ρ) for the results of the reference test and the pulse oximeter was 93.8% ($P < 0.01$).

The average period of time for observation of the pulse rate of the calves was 18 min (minimum 14 min, maximum 29 min). The pulse rate ranged between 94 and 185 bpm measured with the belt and between 93 and 180 bpm measured with the pulse oximeter. The corresponding Spearman correlation coefficient for all calves was 97.7% ($P < 0.01$).

According to Bland-Altman analyses, the pulse oximeter overestimated the mean SaO_2 levels measured with the blood gas analyzer by 2.95 ± 6.39%, whereas the mean pulse rate was underestimated (negative bias) by the pulse oximeter by -0.41 ± 3.18 bpm compared with the heart rate belt.

The Cusum test detected no significant deviation from linearity for both, the oxygen saturation ($P = 0.85$) and the pulse rate ($P = 0.09$) testing methods, showing the Passing-Bablok method to be reliable for statistical analyses. The Passing-Bablok analyses (Table 1) showed that neither proportional nor systematic differences were detected for either the oxygen saturation or the pulse measurements.

Table 1. Differences between oxygen saturation measured with the Masimo pulse oximeter and the reference method (blood gas analyzer) and pulse rates measured with the pulse oximeter and the heart rate belt using the Passing-Bablok and Bland-Altman analyses.

	Arterial oxygen saturation Pulse oximeter vs. blood gas analyzer	Pulse rate Pulse oximeter vs. heart rate belt
Spearman correlation coefficient ρ (%)	93.8	97.7
Passing-Bablok		
Slope (*b*)	1.00	1.00
CI_{95}[1] for *b*	0.95 to 1.06	0.99 to 1.00
Intercept (*a*)	2.00	0.60
CI_{95} for *a*	-1.44 to 3.52	-1.71 to 1.73
Bland-Atman		
Bias ± SD	2.95 ± 6.39	-0.41 ± 3.18

[1]CI_{95} = 95% Confidence interval.

Additional descriptive parameters for oxygen saturation measurements as well as for pulse rate measurements are presented in Table 2 and Table 3, respectively

Table 2. Descriptive statistics of the arterial oxygen saturation tested in 40 calves performed immediately after birth using the Masimo pulse oximeter and using the VetScan iStat1 blood gas analyzer.

Parameter	Arterial oxygen saturation	
	Pulse oximeter	Blood gas analyzer
Number of samples	40	40
Mean ± SE (%)	54.85 ± 4.92	51.90 ± 4.92
Median ± Interquartile range (%)	42.00 ± 64.50	37.50 ± 62.50

Table 3. Descriptive statistics of the pulse rate of 10 calves aged between 0 to 7 d measured with the Masimo pulse oximeter and the Polar equine belt

Parameter	Pulse rate	
	Pulse oximeter	Heart rate belt
Number of averaged 20s-intervalls	1090	1090
Mean ± SE (bpm)	123.5 ± 0.4	123.9 ± 0.4
Median ± Interquartile range (bpm)	122.4 ± 16.2	122.6 ± 16.6

Discussion

As the interdigital space can be reached earlier during the calving process compared with other possible sites (i.e. the nose or ear), the interdigital space was chosen as fixation site with regard to a future use of the device for monitoring vital parameters of calves during stage II of labor.

As soon as the calf attempted to stand, the measurements were stopped because strong movements can lead to artifacts and inaccurate data (Jurban 2015). Thus, the results of this study can be considered as valid only for calm calves which are lying down. To prevent ambient light and pigmentation of the tissue on which the sensor is placed, from having a negative effect on the accuracy of the measurements (Fluck et al. 2003; Bickler et al. 2005), only calves with faintly pigmented hoofs were used for this study and the hoof cover was made from opaque latex material. Further studies should evaluate the influence of parameters such as movement of the calf during measurement, hoof pigmentation, as well as breed and age of the animal.

In this study, a stable signal was provided by the pulse oximeter and by the heart rate belt for all calves.

According to other studies that evaluated pulse oximeter in calves (Bleul and Kähn 2008) and horses (Koenig et al. 2003) the biases varied between -3.9 ± 7.4% to 3.6 ± 3.2. Reported biases in dogs ranged from -0.83 ± 2.60% to 1.52 ± 1.62%, and for cats from -4.26 ± 9.81% to 2.32 ± 5.07%, depending on the type of the pulse oximeter used (Matthews et al. 2003). For pulse oximeters in human medicine, biases of < 2% and standard deviations of < 3% were reported when tested in healthy adults with SaO_2 > 90% (Nickerson et al. 1988). However, worse accuracies were observed in patients with lower SaO_2 levels (Severinghaus et al. 1989; Hannhart et al. 1991). A slight tendency for decreasing accuracy at lower SaO_2 levels was also detected in our study. Compared with the accuracy of pulse oximetry evaluated in human medicine, the bias we detected in calves was only marginally higher, although 60% of the animals had a SaO_2 of ≤ 70%.

Conclusion

The accuracy of this method is considered as acceptable for continuous monitoring of farm animals under field conditions. The utility, although, might be affected in terms of potential threshold levels for critical conditions as suggested by others (Dildy 2001; Bleul et al. 2008). Further research should evaluate if the threshold value of e.g. 30% saturation can be considered as valid for this type of pulse oximeter and sample site as well or if it is necessary to increase it according to the bias we detected.

To sum up, using the interdigital space as attachment site for the sensor, in combination with the latex hoof cover, resulted in good attachment of the sensor and no signal loss. Further studies are required to evaluate the stability of sensor attachment and the signal quality in animals under more challenging conditions, such as standing and walking, as well as in bovine fetuses during parturition. The performance of the pulse oximeter is considered to be suitable for measuring the pulse rate and SpO_2 levels in motionless calves when the sensor is attached to the slightly pigmented front hoof of calves.

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