Assessment of two wireless reticulo-rumen pH sensors for dairy cows

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eCow bolus (top) and Smaxtec bolus (bottom) record continuously the pH in the reticulo-rumen of cows.
(Photo: Fredy Schori, Agroscope)

Abstract

Wireless reticulo-rumen pH sensors have to work reliably and provide accurate measurements for the early detection of subacute ruminal acidosis. To test these properties, the functionality and measurement accuracy of two reticulo-rumen pH sensors (eCow and Smaxtec) were investigated over the stated service life of 150 days. Three lactating, rumen fistulated dairy cows each carried in the rumen two boluses of both manufacturer over a period of 154 days. On day one, after activation and calibration, the boluses were placed for at least 2 hours in temperature-controlled (39 °C) buffer solutions of pH 4 and then of pH 7. Every 14 days, the challenges of the boluses with the buffer solutions were repeated. Between the challenges, the boluses stayed in the rumen of the dairy cows. The average service life of the six eCow boluses during the measurement period was 82 days (28 to 126 d). In contrast, all Smaxtec boluses recorded pH at exactly 150 days. Reading out the records of the eCow boluses was tricky compared to the Smaxtec boluses. For both buffer solutions, the average pH differences between the reference measures and eCow or Smaxtec records amounted to 0.09 (standard deviation (SD) 0.48) or –0.29 (SD 0.22), respectively. For eCow boluses, the 95 % confidence interval (CI) of the mean pH difference indicated no systematic error (–0.02 to 0.19). In contrast, the CI of the mean pH difference (–0.33 to -0.25) suggested a systematic negative bias with Smaxtec boluses. To be of real use, eCow boluses need to function more reliably, and Smaxtec boluses have to measure more precisely.

Key words: eCow, Smaxtec, sensor, pH, dairy cows.

Introduction

Cereal-rich diets for dairy cows can impair gastrointestinal health by causing subacute ruminal acidosis (SARA; Plaizier *et al.*, 2018). Even highly digestible ryegrass may result in SARA. O'Grady *et al.* (2008) concluded that, based on spot-measured rumen pH, SARA is prevalent in grazing Irish dairy cattle. Among other effects, SARA can disrupt nutrient utilization, impair the functionality of gastrointestinal microbiota, and reduce the absorptive and barrier capacities of the gastrointestinal epithelia (Plaizier *et al.*, 2018). Furthermore, SARA may be an aetiological factor for a number of other diseases (Enemark, 2008). As the signs of SARA are subtle and often temporally separated from the inciting event, the diagnosis is difficult (Enemark, 2008). For an accurate diagnosis of SARA, a combination of clinical examinations of cows as well as an analysis of herd management and feed quality is required. Diagnosis solely based on reticulo-rumen pH is inaccurate, according to Plaizier *et al.* (2018). Notwithstanding, continuous measurements of ruminal or reticular pH may help to detect SARA (Sato *et al.*, 2012). Consequently, it would be possible to detect SARA faster in at risk animals and to adapt feed ration

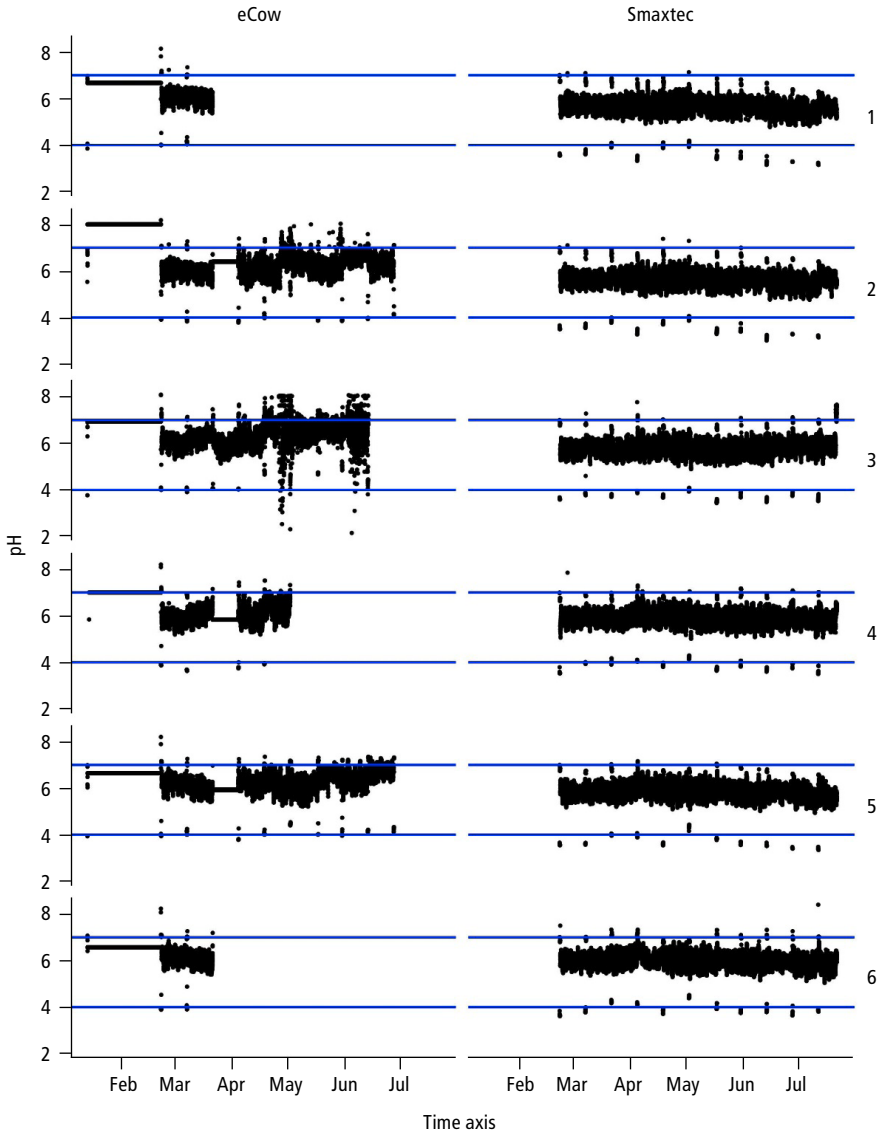

Figure 1 | Measurements of pH with six eCow and six Smaxtec boluses (the blue lines correspond to the declared pH values of the buffer solutions used during the challenges, and the numbers on the right-hand side of the figure correspond to the internal bolus numbers).

and/or feeding management in a timely manner. Wireless reticulo-rumen pH sensors may serve as a useful tool in the detection of SARA. A prerequisite for this is that they work reliably and provide accurate measurements over a certain period of time. To check manufacturer specifications in this respect, the functionality and measurement accuracy of two reticulo-rument pH sensors were examined and compared over their stated service life of 150 days.

Animals, materials and methods

The experimental procedures were approved by the Food Safety and Veterinary Office of the Canton of Fribourg (2015_61_FR). For the assessment, six new eCow (eCow Devon Ltd., Kirkcaldy, Scotland) and six new Smaxtec boluses (Smaxtec GmbH, Graz, Austria) were used. In the experiment, three rumen fistulated Holstein or Red-Holstein dairy cows in their fourth, sixth, and seventh lactations were involved. During the experiment, they produced, on average, 27.2 (±4.2 (SD)) kg milk per day and weighed 718 (±29.9 (SD)) kg. Each cow carried two boluses from both manufacturer in a holding device in their rumen over 154 days, from February to July 2016. The cows, kept in a free stall barn, were fed at the beginning with grass silage, maize silage, and hay. Additionally, from mid-March, they had partial access to pasture. The forage ration was supplemented with concentrates to cover the estimated requirements of dairy cows (Jans *et al.*, 2017). On day one of the study, after activation and calibration as required by the manufacturers, the boluses were placed in a temperature-controlled buffer solution of pH 4 for at least 2 hours. This procedure was repeated with a buffer solution of pH 7. Subsequently, the boluses were put in the holding device, which was attached with a cord to the fistula stopper. This device was inserted into the rumen via the rumen fistula. The cows where the boluses were introduced changed sys-

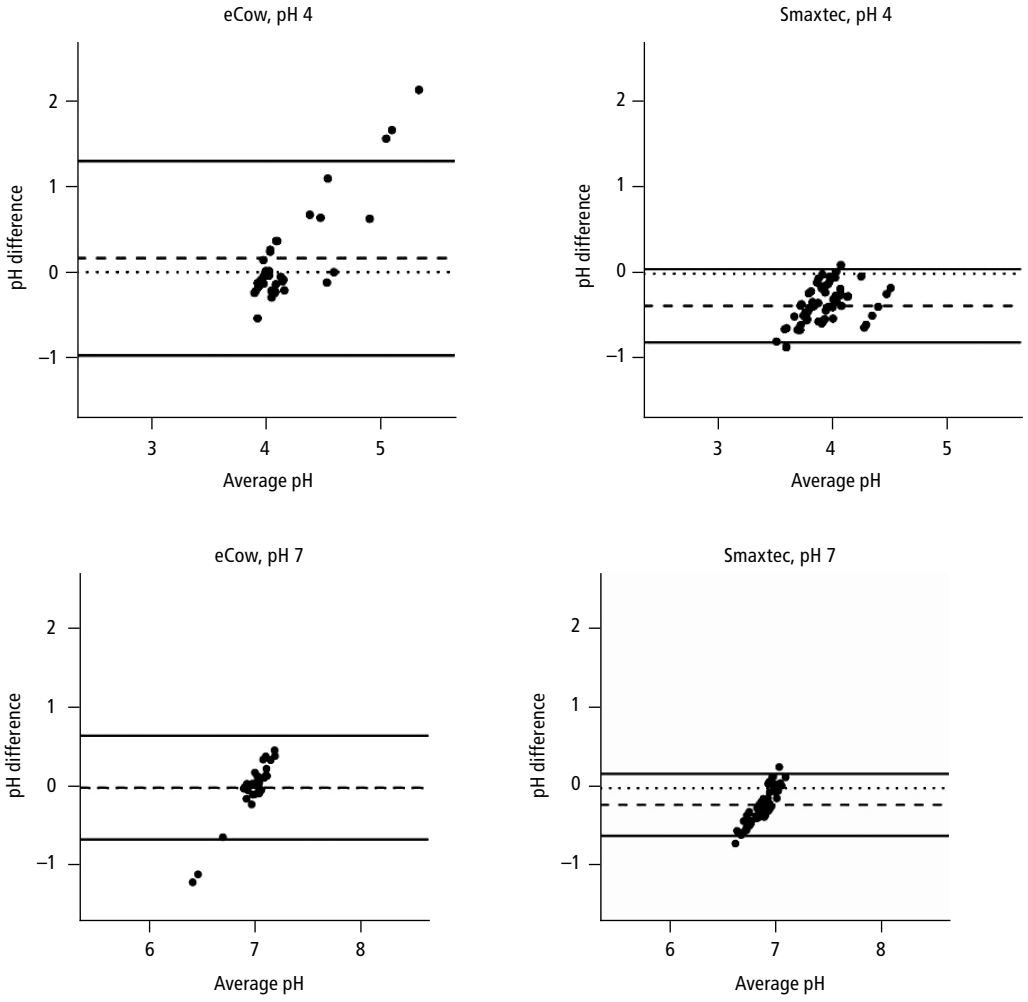

Figure 2 | Bland-Altman plots for the eCow and Smaxtec boluses at buffer solution pH 4 and pH 7. The solid lines indicate the lower and upper limits of agreement, while the dashed lines indicate the mean of the pH differences.

tematically. Each time before the boluses were placed in the buffer solutions, they were thoroughly rinsed with demineralized water. The challenges of the boluses with buffer solutions of pH 4 and 7 were repeated every 14 days. The pH of the buffer solutions was measured before and after the fortnightly control periods using a pH meter (HI98128, Hanna Instruments Inc., Smithfield, United States of America, resolution of 0.01). During the challenges, the buffer solutions were kept in a temperature–controlled water bath. The mean temperature of the buffer solutions, which was measured using the Smaxtec boluses, was 39 (±1.2 (SD)) °C. During the challenge period outside the rumen, attention was paid to ensure the storage in tempered liquid to avoid the sensors from drying out.

The statistical analyses of the pH differences between bolus measure and buffer solutions were carried out using R (R Core Team, 2021). The Bland-Altman plots, the limits of agreement, and the 95 % confidence interval (CI) of the mean were generated based on Giavarina (2015). Only for the Smaxtec bolus data a more in-depth evaluation was conducted using a linear mixed model (R package "lmerTest", Kuznetsova *et al.*, 2017). The fixed factors of the linear mixed model were buffer solution (pH 4 and 7) and the dates of the challenges (11 challenges, because after 150 days the pH measurements of the Smaxtec boluses stopped automatically). The individual boluses were used as a random factor of the linear mixed model.

Results and discussion

The experimental design was chosen to expose the boluses to the harsh rumen environment during the stated lifetime and to carry out comparative measurements of pH fortnightly under standardized conditions. One manufacturer questioned this approach, but Scheider *et al.* (2010) did the same, with a significantly shorter measurement duration, and obtained a correlation coefficient of 0.998 between the pH of the buffer solutions and the sensor measurements. To be fair, it should be mentioned that the study was conducted in 2016, and in the meantime, the devices might have been improved; however, they would still have to be proven, particularly in view of the inherent problems of pH measurement without regular recalibration. In fact, the eCow model was redesigned (https://www.wolf-hound.com/for-researchers).

The average service life of the six eCow boluses during the measurement period was 82 days, although two of them worked for only 28 days. The eCow boluses had been delivered in a started state in mid-January; they were supposed to stay in sleep mode below 32 °C and were kept at room temperature until deployment on February 22nd. As can be concluded from Figure 1, they did not remain in sleep mode but were recording data, presumably due to false temperature readings, which stayed above 32 °C during the whole period. Moreover, reading out the records of the eCow boluses was challenging and time consuming with the hand-held data

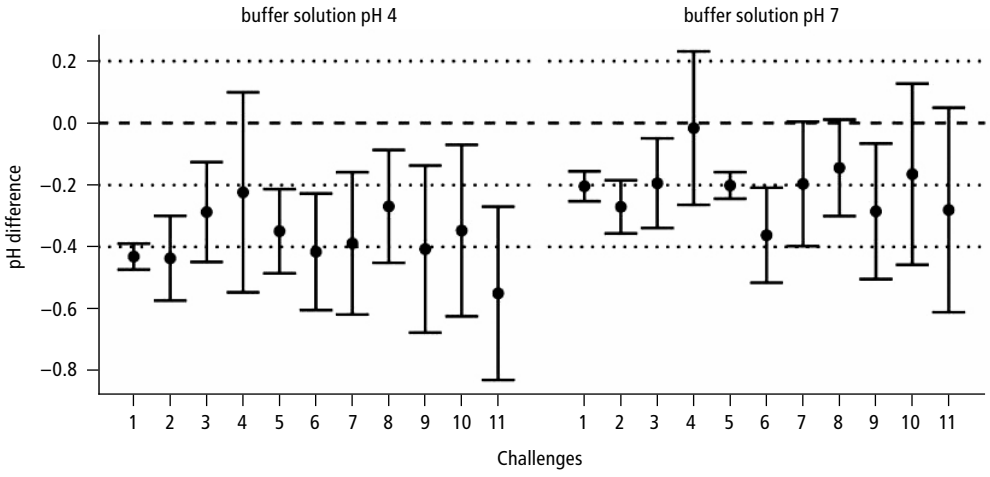

Figure 3 | Mean and standard deviation of the difference between the pH measurements of the Smaxtec boluses (n = 6) and the reference pH measurement method of the buffer solutions during the fortnightly challenges (x-axis: 1 is the challenge at day 1, 2 is the challenge at day 15 … 11 is the challenge at day 141; the dotted lines are the measurement accuracy, as specified by the manufacturer, up to 90 days ± 0.2, between 90 and 150 days ± 0.4).

collection unit, which is in contradiction with Mottram *et al.'s* (2008) work, but in accordance with Falk *et al.* (2016). For Falk *et al.* (2016), this was partially due to failing radio equipment. In total, 48 % of the potential total measurements were missing. In the study of Mensching *et al.* (2020), the eCow boluses worked more reliably than in our study. Nevertheless, 3 out of 13 eCow boluses showed an extreme drift after approximately 80 days of pH measurements; 14 % (109 of 786 d) of the daily mean pH values were classified as outliers. In contrast, all Smaxtec boluses recorded pH during the 150 days exactly after the beginning of the experiment. The reading out was performed automatically via a fixed base station installed near the milking parlor.

Including both buffer solutions, the average pH differences between the reference measures and eCow or Smaxtec records amounted to 0.09 (standard deviation (SD) 0.48) or –0.29 (SD 0.22), respectively. For eCow boluses, the 95 % CI of the mean pH difference indicated no systematic error (–0.02 to 0.19). In contrast, the CI of the mean pH difference (–0.33 to –0.25) suggested a systematic negative bias with Smaxtec. Figure 2 shows Bland-Altman plots for the eCow and Smaxtec boluses, respectively, at the challenges of pH 4 and 7. Strongly deviating pH measurements of the eCow boluses led to an enormous range of agreement, one that was larger at the pH 4 challenge than at the pH 7 challenge. The range of agreement is smaller for the Smaxtec boluses, but the CI of the mean pH differences indicates a systematic underestimation of the pH values.

The subsequent evaluations were only carried out for the Smaxtec boluses, as too many measurements were missing for the eCow devices. Figure 3 shows the mean and the SD of the differences between the pH measurements of the Smaxtec boluses and the reference pH-measurement method of the buffer solutions during the fortnightly challenges. This reveals that the measurement accuracy specified by the manufacturer (up to 90 days ±0.2, between 90 and 150 days ±0.4, Smaxtec 2021) was not observed for every bolus over the entire measurement period. During the buffer solution challenges at pH 7, which is closer to the typical range of rumen content than pH 4, the deviations seem smaller. Nevertheless, it has to be mentioned that the manufacturer specifies a measuring range of the pH between 3 and 9 (Smaxtec, 2021). The fixed factors of the linear mixed model evaluation, buffer solution, and date of measurement had a significant effect (both $p < 0.001$) on the pH differences between the reference method and Smaxtec boluses. Even the random factor, individual bolus, showed a significant effect, which means that the results may differ depending on the bolus used. In contrast, Schneider *et al.* (2010) found an extremely high correlation coefficient ($r = 0.998$) between the pH of buffer solutions and sensor measurements before and after using them in rumen-fistulated animals. In contrast to our study, the boluses were recalibrated after each use and serviced if needed. In intact animals, this maintenance of the boluses would not be possible, and the boluses were actually designed for oral application and intact animals. Sato *et al.* (2012 a, b) quantified the drift of their wireless pH measurement system with 0.2 pH units over two to three months. The boluses would not only have to work more reliably and measure more precisely and for longer periods than 150 days, but they would also have to become cheaper to make their widespread use on farms worthwhile.

Conclusion

In conclusion, to be of real use, the eCow boluses used in our study need to function more reliably, and Smaxtec boluses have to measure more precisely. ■

Declaration of conflict of interest

The authors declare that no conflict of interest exist.

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