Electronic bolus design impacts on administration

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ABSTRACT: Electronic identification of animals has become increasingly important worldwide to improve and ensure traceability. In warm and hot climates, such as Brazil, boluses can have advantages over ear tags as the internal devices reduce the risks of ear tag losses, tissue damage, and lesions on the ear. Electronic boluses, however, are often perceived as having negative characteristics, including reported difficulties of administration in small ruminants. This paper describes the factors associated with bolus design that affect the swallowing of a bolus in sheep. Other factors that might influence bolus swallowing time have also been considered. In addition, the effect of bolus design on its performance was evaluated. A total of 56 Suffolk ewes were used to assess the ease of administration and retention of 3 types of electronic ruminal boluses (mini, 11.5 × 58.0 mm and 21.7 g; small, 14.8 × 48.5 mm and 29.5 g; standard, 19.3 × 69.8 mm and 74.4 g) during a whole productive year, including pregnancy and lamb suckling. Ewe age (5.6 ± 2.3 yr) and weight (85.07 ± 8.2 kg BW) were recorded, as well as time for bolus swallowing. The deglutition of the bolus and any resulting blockages in the esophagus were monitored by visual observations. Retention and readability of the boluses were regularly monitored for d 1, wk 1, mo 1, and every mo until 1 yr. Time for bolus swallowing differed substantially with bolus type and was greater (P < 0.05) for the standard bolus (32.8 ± 6.9 s) when compared to small and mini boluses, which did not differ (8.5 ± 2.0 vs. 9.2 ± 2.7 s; P > 0.05). The bolus o.d. and length were positively correlated with swallowing time (P < 0.01). The ewe weight was negatively correlated with swallowing time (P < 0.05). At 6 mo all electronic boluses showed 100% retention rate, and at 12 mo, bolus retention was 100%, 94.5%, and 100% for mini, small, and standard boluses, respectively (P > 0.05). At 12 mo, all boluses showed 100% readability, except for small boluses, which had a readability of 94.5%. In conclusion, bolus design affected swallowing time and bolus readability. A reduction in boluses length and o.d. needs to be carried out to provide ease of administration and for boluses to be used as an effective means of electronic identification. Therefore, this study shows that adequately designed boluses are safe and suitable for identifying adult sheep and can therefore be used in hot climates.

Key words: bolus length, bolus outside diameter, electronic identification, sheep, swallowing time

INTRODUCTION

Electronic identification of animals using radio-frequency passive transponders has become important worldwide because of an increased interest in livestock monitoring. Electronic boluses were designed to be retained in the rumen, and their retention is largely associated with proper adjustment of the physical characteristics of the capsule that encloses the transponder (Hasker and Bassingthwaighte, 1996).

As indicated, a bolus can be safely administered if the reflex of deglutition is stimulated (Caja et al., 1999; Ghirardi et al., 2006). However, boluses are often perceived as having negative characteristics, including reported difficulties of administration in small ruminants. Difficulties of bolus administration in goats were indicated by the measurement of a number of administration attempts until deglutition was possible


1 This study is part of a research project evaluating electronic devices for use in small ruminants in Brazil. The authors are grateful to Luis Henrique Amadeu (Saint Gobain, now CoorsTek do Brasil, Vinhedo São Paulo, Brazil) for providing the boluses and radio-frequency readers, to Carlos Henrique Kulik and Eneida Bezerra Soares Ribeiro for assistance in the evaluation with animals, to Raphael Fernandes for statistical support, and to John Holland and Tony Waterhouse (SRUC, Edinburgh, UK) for the English revision of the manuscript.

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(Carné et al., 2009b). As a result, large boluses were reported to have a higher administration attempt rate compared to smaller ones. However, little information is available on the factors that may influence this response. It seems that bolus dimensions can affect the swallowing reflex and make the administration process more difficult. Additionally, evidence of factors that affect bolus swallowing times in sheep can help us to design devices that contribute to an easier administration process.

Boluses are a better tamper-proof system compared to ear tags. Additionally, in hot climates, boluses can have advantages over ear tags as the internal devices prevent the risks of tissue damage and lesions on the ear, which can occur when injuries related to the ear tagging process are not adequately treated (Edwards et al., 2001).

The objective of this study was to assess the difficulties of administration as well as performance of 3 types of common boluses in adult sheep in terms of design. Therefore, the effects of the bolus and the animal characteristics on swallowing time were investigated.

**MATERIALS AND METHODS**

The experimental procedures and animal care conditions were approved by the Ethics Committee for Animal Use at Federal University of Paraná, Brazil (protocol 032/2010).

**Animals and Management**

A total of 56 Suffolk ewes belonging to the Experimental Farm of the Federal University of Paraná located in Pinhais, Brazil, were used for the study. The animals had an average age of 5.6 ± 2.3 yr and were monitored for 12 mo.

The sheep rotationally grazed on perennial tropical pastures of Tifton-85 (*Cynodon spp.*) and Aruana (*Panicum maximum* cv. Aruana), overseeded in the fall with pasture mix (60% ryegrass, 40% wheat) at a seeding rate of 120 kg/ha. During the last third of pregnancy and during lactation, ewes were supplemented in the shed twice a day (0730 and 1630 h) with a total amount of 2.0 kg of corn silage (DM, 29.0%; CP, 9.0%; TDN, 65.0%) and 0.65 kg of concentrate (DM, 87.59%; CP, 16.0%; TDN, 74.0%; Ca, 1.16%; and P, 0.69%). The ewes had free access to mineral salt (Tortuga, São Vicente, Brazil) and fresh water in the paddocks and shed.

Ewes were dewormed with a combination of Dovenix (Supra, Merial, Lyon, France) and Cydectin (Pfizer, Campinas, Brazil) according to the ocular anemia degree indicated by the Fafa Malan Chart (FAMACHA) method (Molento et al., 2004). The FAMACHA method was developed to evaluate the degree of animal anemia as a result of *Haemonchus contortus* infection. In hot climates where this internal parasite presents with high prevalence, using the method as a selective treatment tool is recommended. Animals were dewormed if they showed a FAMACHA degree ≥ 3 (range 1 to 5). Sheep were also given a booster vaccination for tetanus, enterotoxaemia, and gangrene prophylaxis (Sintoxan Polivalent, Merial, Lyon, France) in June.

After lambing in July, boluses were applied. Animals were sheared in the middle of spring (late October) and were subjected to a hormonal induction protocol and inseminated in March using a transcervical technique.

Ewes were identified with commercial plastic ear tags (Fockink, Panambi, Brazil) used as a farm management number. Even when ear tags were lost, the electronic bolus number was read, and the animal was re-identified with an ear tag.

**Boluses**

Three types of cylindrical ruminal boluses produced by Saint Gobain Ceramics and Plastics, now CoorsTek of Brazil (Vinhedo, Brazil), were evaluated (Table 1). The boluses (*n* = 56) were made of alumina (*Al₂O₃*) according to the patent (European Community et al., 1998). The standard bolus was approved in a full conformance test in 2006 by the International Committee on Animal Recording (ICAR), and therefore, other prototypes of boluses were produced for testing.

A random sample of 10 boluses of each type were collected to measure their features under laboratory conditions using a digital weighing scale with a precision of 0.1 g (Bel Engineering, Piracicaba, Brazil) and a digital caliper (Starrett, 727, Itu, Brazil), which were used to measure bolus weight, length, and o.d. (Table 1). The specific gravity (g/cm³) was determined in the Laboratory of Physics of Universidade Federal do Paraná, according to the principle of Archimedes, as indicated by Ghirardi et al. (2006). The devices were classified according to their o.d. as a mini bolus (smallest o.d.), small bolus (intermediate o.d.), and standard bolus (largest o.d.).

Each bolus contained a half-duplex, read-only, glass-encapsulated transponder of 32 × 3.8 mm (Texas

### Table 1. Characteristics of the 3 different electronic bolus types

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Mini</th>
<th>Small</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>o.d., mm</td>
<td>11.50 ± 0.07</td>
<td>14.76 ± 0.06</td>
<td>19.30 ± 0.05</td>
</tr>
<tr>
<td>Weight, g</td>
<td>21.65 ± 0.48</td>
<td>29.52 ± 0.08</td>
<td>74.44 ± 0.78</td>
</tr>
<tr>
<td>Volume, mL</td>
<td>6.84 ± 0.01</td>
<td>8.28 ± 0.01</td>
<td>22.00 ± 0.07</td>
</tr>
<tr>
<td>Specific gravity, g/cm³</td>
<td>3.01 ± 0.02</td>
<td>3.02 ± 0.01</td>
<td>3.37 ± 0.08</td>
</tr>
</tbody>
</table>
The device performance was determined by the retention rate and readability, both expressed as a percentage as follows: retention rate (%) = (number of retained devices/number of monitored devices) × 100; readability (%) = (number of devices able to be read/number of monitored devices) × 100. Unreadable devices included losses and electronic failures. The retention rate was affected when a device applied to the animal was not retained. This needed to be confirmed by a reading control and radiographic examination at the laboratory. Readability was affected when a device applied to and retained in the animal was unable to be read but was identified by a radiographic examination at the laboratory.

**Statistical Analysis**

The data were analyzed using the statistical package SAS 9.0 (SAS Inst. Inc., Cary, NC) and Genstat (14th ed., Lawes Agricultural Trust, VSN International Ltd., Oxford, UK).

We have used a generalized linear mixed model (GLMM) with a normal distribution and identity as the link function. The response variable was swallowing time, the fixed effects were bolus type, ewe weight, and ewe age, and the random effect was animal. We also ran the same test with a smaller data set, consisting of the data from only the small and mini boluses. In addition, we looked at the t test and F test for 2 samples in a 2-sided test with a confidence interval of 95%. We compared the standard bolus vs. the mini bolus, the mini bolus vs. the small bolus, and the small bolus vs. the mini bolus.

Retention rates were analyzed with the CATMOD procedure on the basis of the categorical nature of these variables. A logit model with an estimation method of maximum likelihood (Cox, 1970) was used to evaluate the effects of bolus weight and volume as well as ewe age and weight at administration on bolus retention rate. Significance was declared at P < 0.05, and factors that were not significant (P > 0.20) were removed from the final model.

Bolus survival curves were analyzed using a log-rank test (R Software, R Core Development Team, Vienna), as previously done by Fosgate et al. (2006) and Carné et al. (2009b). This analysis allows the retention rate to be compared throughout the entire period of the study without excluding animals that left the study before a device was lost. Survival monitoring started at device administration and was subsequently monitored at defined control points in time.

**RESULTS AND DISCUSSION**

At the end of the first year, 55 (98.2%) of the initially identified animals continued to be monitored. Only 1 ewe identified with a standard bolus died during the...
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Death occurred 3 mo after bolusing, when lambs were weaned, and was associated with high *Haemonchus contortus* worm infection.

**Bolus Administration**

Time for bolus swallowing varied by bolus type (Table 2), but no differences were found between mini and small boluses. On average, swallowing time for mini and small boluses was 25% of that needed for standard boluses.

Administration attempt rate varied by bolus type (Table 2). Bolus expulsion before swallowing was successfully completed was only observed for standard boluses. Standard bolus administration attempt rate was 1.22 ± 0.03, and overall attempt rate was 1.07 ± 0.02. Carné et al. (2009b), using different goat breeds, observed that mini boluses showed a lower administration attempt rate (1.06 ± 0.03) compared to the other two standard-sized boluses (75.0 and 82.1 g; 1.20 ± 0.05 and 1.21 ± 0.06). The authors also reported interaction between bolus type and goat breed. Results also indicate a similar tendency for bolus administration time and attempt rate.

There were no cases of bolus blockage in the esophagus or other incidences linked to bolus type (Table 3). Absences of problems during administration were also reported by Caja et al. (1999) and Stanford et al. (2001). Problems with bolus blockage in the esophagus were mainly reported in studies conducted to determine minimum BW for bolus administration in lambs (Garin et al., 2003, 2005; Ghirardi et al., 2006, 2007) and kids (Carné et al., 2009a). Ghirardi et al. (2007) suggested that the bolus o.d. is critical in terms of whether a lamb is able to swallow a bolus, thus determining the minimum weight at which an animal can be identified. Carné et al. (2009a) suggest that safe bolus administration at early ages mainly depends on the development of the pharynx and esophagus and on the length and o.d. of boluses used.

Additionally, no apparent health problems for the sheep were observed as a result of administration of the 3 bolus types at bolusing or at the subsequent reading control points. This agrees with the fact that boluses with an average o.d. of 19 mm can be safely administered by trained operators to sheep and goats with BW greater than 25 and 20 kg, respectively (Caja et al., 1999).

**Factors Affecting Bolus Swallowing Time**

Bolus type and therefore dimensions affected swallowing time (*P* < 0.001). Additionally, ewe weight at administration also affected (*P* < 0.03) swallowing time. However, swallowing time was not affected by ewe age (*P* = 0.88). When looking just at the data of the small and the mini boluses, a different picture can be observed. In that case, the bolus type does not have a significant effect on swallowing time (*P* = 0.134), and neither does the ewe age or weight.

Although the standard bolus o.d. was, on average, 1.4 and 1.25 times greater than the diameters of mini and small boluses, the administration time was, on average, 3.5 and 4 times higher, respectively. Figure 1 demonstrates clearly that there is a significant difference between bolus type and swallowing time. Length and o.d. are both visualized in the same graph to be able to compare both parameters and their effect on swallowing time. Interestingly, the small bolus was shorter than the mini bolus, and the swallowing time reflected this with a decrease of 1.3 s (Fig. 1). The results indicate that the length has a greater effect on swallowing time than the o.d. for these specific dimensions, but further research is needed to separate the two parameters, length and o.d., to evaluate the effect on swallowing time. This is in line with the observations that showed that during

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**Table 2.** Administration time of electronic boluses in Suffolk ewes according to bolus type

<table>
<thead>
<tr>
<th>Item</th>
<th>Mini</th>
<th>Small</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Administration time, s</td>
<td>9.5 ± 2.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>8.3 ± 2.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>32.9 ± 6.9&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Attempt rate&lt;sup&gt;1&lt;/sup&gt;</td>
<td>1.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.22 ± 0.03&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a,b</sup>Values with different superscripts differ significantly (*P* < 0.05).

<sup>1</sup>Three animals identified with standard bolus expelled bolus once before swallowing, and 1 ewe also identified with a standard bolus expelled it twice before swallowing.

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**Table 3.** Boluses lost, electronic failure, readability, and retention rate for 3 different bolus types administered to Suffolk ewes and monitored over 12 mo

<table>
<thead>
<tr>
<th>Item</th>
<th>Overall</th>
<th>Mini</th>
<th>Small</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boluses administered, <em>n</em></td>
<td>20</td>
<td>18</td>
<td>18</td>
<td>56</td>
</tr>
<tr>
<td>Electronic failure, <em>n</em></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Readability, %</td>
<td>100</td>
<td>94.5</td>
<td>100</td>
<td>98.1</td>
</tr>
<tr>
<td>Boluses lost, <em>n</em></td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Retention rate, %</td>
<td>100</td>
<td>94.5</td>
<td>100</td>
<td>98.1</td>
</tr>
</tbody>
</table>

<sup>1</sup>One standard bolus was removed from the study as the sheep died after 3 mo because of high worm burden.

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**Figure 1.** Effects of bolus o.d. and length (mm) on bolus swallowing times (s) in Suffolk ewes.
the administration of standard boluses the ewes manipulated the bolus in the oral cavity before the bolus entered the esophagus tube. An animal can have more difficulty swallowing boluses of greater dimensions from the natural angle formed between the oral cavity and the upper esophageal sphincter. Moreover, in boluses with greater dimensions, the device body could not be released entirely in the oropharyngeal region, which is needed to induce an involuntary reflex of deglutition.

As discussed by Goyal and Cobb (1981), animals show voluntary control of the first swallowing phase, also known as the preparatory phase, during which the alimentary bolus is formed and can be interrupted at any time, whereas the pharyngeal and esophageal phases are involuntary. Therefore, it is possible that boluses with greater dimensions may induce the activation of a preparatory phase mediated by the central nervous system. As a result, a bolus remains and is manipulated in the oral cavity for a longer time before the pharyngeal phase starts. These results are supported by evidence that the duration of the whole oropharyngeal sequence is remarkably constant in all mammals, in the range of 0.6 to 1 s (Doty, 1968; Goyal and Cobb, 1981).

As a result of the observed swallowing times, it can be concluded that mini and small boluses have dimensions that ensure that the involuntary swallowing reflex is activated as a primary response after they are released in the animal’s mouth. The increase in swallowing times for standard boluses indicates that the device is too large to induce an involuntary deglutition reflex as the primary response. Therefore, the time response with the bolus being manipulated in an animal’s oral cavity seems to be the first indication that it was not possible to release the device in the correct place. Bolus expulsion or bolus manipulation in the oral cavity therefore makes the administration process more difficult. To our knowledge, there are no other studies showing the effect of bolus length and o.d. on bolus swallowing time; however, it can be seen from our results that a reduction in device length and o.d. is desirable to allow for an easy administration.

The ewe BW also affects the bolus swallowing time for standard boluses. Figure 2 shows the correlation between swallowing time and ewe BW for the 3 different bolus types. A distinct difference can be found between the mini and the small boluses compared to the standard bolus, which has a greater negative correlation ($r = -0.46$, $P = 0.053$ for the standard bolus; $r = -0.36$, $P = 0.124$ for the mini bolus; $r = 0.15$, $P = 0.555$ for the small bolus). This result gives an indication that with increasing ewe weight, the swallowing time decreases. The effect was significant, as can be seen in Tables 4 and 5.

This was an unexpected outcome as all the ewes’ BWs were much higher than the minimum recommendation for safe administration of a bolus. Lower bolus administration times were observed for ewes with higher BW. It is likely that animals with higher BW have a longer oral cavity, which leads to a greater chance of the bolus being released in the correct place. This evidence is important and indicates that there may be differences in anatomical development that can influence the ease of administering boluses in adult animals, and therefore, this evidence should be considered. This could also be an important effect in young animals whose body development is not complete. Otherwise, ewe age at bolus administration did not affect bolus swallowing time, although the animal ages varied from 3 to 7 yr.

**Bolus Performances**

Data associated with bolus performance through the study period can be seen in Table 3. Bolus retention rate and readability did not differ with bolus type ($P > 0.05$). There were no electronic failures that compromised the readability of the transponders over the 12 mo. The absence of failures observed in the present study is in accordance with the values (<0.01%) reported by Caja

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### Table 4. Effects of bolus type and ewe characteristics on bolus administration time (GLMM)

<table>
<thead>
<tr>
<th>Fixed term</th>
<th>Wald statistic</th>
<th>$F$ statistic</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolus type</td>
<td>386.05</td>
<td>193.02</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Ewe weight</td>
<td>5.13</td>
<td>5.13</td>
<td>0.029</td>
</tr>
<tr>
<td>Ewe age</td>
<td>0.12</td>
<td>0.12</td>
<td>0.726</td>
</tr>
</tbody>
</table>

### Table 5. Effects of bolus type and ewe characteristics on bolus administration time calculated with data on mini and small boluses only (GLMM)

<table>
<thead>
<tr>
<th>Fixed term</th>
<th>Wald statistic</th>
<th>$F$ statistic</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolus type</td>
<td>2.37</td>
<td>2.37</td>
<td>0.134</td>
</tr>
<tr>
<td>Ewe weight</td>
<td>1.35</td>
<td>1.35</td>
<td>0.255</td>
</tr>
<tr>
<td>Ewe age</td>
<td>0.00</td>
<td>0.00</td>
<td>0.964</td>
</tr>
</tbody>
</table>

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Figure 2. Correlation between ewe weight at administration and swallowing time for the 3 bolus types.
et al. (1999) and indicates many fewer difficulties than reported by the Identification électronique des animaux (IDEA) project (Ribó et al., 2003), with failures ranging from 0.004% to 0.28% (sheep) and 0.1% to 4% (goats).

At 6 mo, no losses were observed, and all devices met the ICAR requirements (a device should provide a retention rate over 99% at 6 mo of evaluation; ICAR, 2012). However, at mo 10, 1 small bolus administered to a 7-yr-old ewe was found on the floor of the shed where the animals were kept overnight. Although not confirmed, the loss of the device may have occurred by regurgitation. At that time ewes were being supplemented.

Effective retention until 1 mo after administration may be indicative of appropriate device design, and retention over the life span can be maintained as suggested by Ghirardi et al. (2006). Losses by regurgitation after administration were reported when device characteristics were inadequate (Garin et al., 2003, 2005; Ghirardi et al., 2007). Because the bolus remains in the rumen, losses associated with the rumination process are possible if the specific gravity of the bolus is less than that of food present in this compartment. Otherwise, even if the specific gravity is appropriate, the bolus can be lost if its volume is low.

Breakages could change the specific gravity and result in the loss of a bolus, but that was not the case for the bolus found. There were no signs of breakage, and the transponder was still working. Additionally, adherence of food particles to the bolus body could effectively change its specific gravity and volume and therefore result in loss, but there were no food particles adhered to the lost bolus either. The loss of boluses after being retained for some months was also reported in sheep by Ghirardi et al. (2006, 2007) and goats by Carné et al. (2009a,b).

The loss of a small bolus in our study suggests that the increase in bolus volume may not be compensated by the small increase of specific gravity. Therefore, we made sure that all 3 bolus types used had a higher specific gravity than the minimum specific gravity calculated by Ghirardi’s model. For example, the small bolus had a specific gravity of 3.02 g/cm³ and a suggested minimum specific gravity for effective retention of 2.79 g/cm³. As indicated by Ghirardi et al. (2006), the increase in bolus volume must be accompanied by an increase in its specific gravity so that retention is preserved.

There were no differences between mini and small bolus survival retention curves (P = 0.29). Also, small and large boluses (P = 0.33) did not differ as only one small bolus was lost. Thus, mini and standard boluses could not be compared as they did not show losses. At 12 mo, the retention rate of 100% for mini and standard boluses indicates that characteristics are adequate to provide effective retention in sheep. The retention rate of small boluses was 94.5% and did not differ from other devices. The sample size for the parameter retention rate was too small in this study to conclude if there were any underlying design problems for small boluses that could lead to lower retention rates compared to mini or standard boluses.

In conclusion, a well-dimensioned device allows us to induce the involuntary deglutition reflex. In this respect a reduction in boluses length and o.d. needs to be performed to provide ease of administration and for these devices to be used as an effective means of electronic identification. Standard boluses are too large for ease of administration and are not suitable for many of the smaller adult sheep. However, the mini bolus has greater ease of administration and exhibits good results in terms retention rate. Therefore, if countries are interested in the electronic bolus as a means for sheep identification, they should consider the difficulties related to administration of standard boluses. Also, policy makers should effectively develop policies that ensure that the dimensions of boluses are adequate for livestock.

LITERATURE CITED


