Evaluation of the retention of electronic identification boluses in the forestomachs of cattle

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ABSTRACT: A total of 1,203 beef calves were used to evaluate 2 series of electronic identification boluses. Calves were intensively fattened and slaughtered at approximately 1 yr of age. Series 1 (n = 576 calves) consisted of 10 types of boluses with the same external dimensions (o.d. × length: 21 × 68 mm) but varying in weight (11 to 75 g) and specific gravity (0.63 to 3.36). Six boluses were made of ceramic (5 prototypes and 1 commercial bolus) and 4 were tubes made of plastic filled with concrete. Series 2 (n = 627 calves) consisted of 3 prototypes and 5 commercial boluses of different ceramic materials varying in external dimensions (o.d.: 15 to 21 mm; length: 39 to 78 mm), weight (20 to 73 g), and specific gravity (3.00 to 3.87). Boluses were administered to milk-fed calves (2 to 5 wk of age) by using adaptedballing guns. To determine the anatomical limit for a bolus passing through the gastrointestinal tract, the size of the reticulo-omasal orifice was measured in 90 male and 62 female fattened calves at slaughter. Three calves in series 1 (0.3%) could not swallow the 21-mm (o.d.) bolus at the first attempt and received the bolus 1 wk later. No problems for early administration were found with thinner boluses (o.d. <20 mm) in series 2, and no signs of disease or growth alteration were detected in any bolused calves. Retention rate until slaughter varied according to bolus features and ranged from 0 to 100% (series 1), and from 69.7 to 100% (series 2). Inadequately dimensioned boluses were regurgitated or passed through the gastrointestinal tract and were excreted with the feces. The diameter of the reticulo-omasal orifice differed between male and female yearling calves (32.5 and 29.9 mm, respectively; P < 0.01) and was greater than the o.d. of the retained boluses. Retention rate was predicted from bolus weight and volume by a logistic regression (R² = 0.99, P < 0.001), in which the minimum bolus weight estimated to reach a 99.5% retention rate was 61 g when volume and specific gravity were 22.4 mL and 2.72, respectively. To achieve an effective retention rate of electronic identification boluses in the forestomachs of fattening calves, bolus volume and specific gravity, in addition to weight, should be optimized. No boluses of specific gravity lower than 3.0 and thicker than 20 mm o.d. are recommended for identification of cattle from early rearing (<20 d of age) to slaughtering.

INTRODUCTION

The idea of using a bolus as a carrier of active electronic devices dates from the 1970s (Hanton and Leach, 1974; Hanton, 1976), but has only received attention for the electronic identification (e-ID) of livestock after incorporation of passive transponders (Caja et al., 1996, 1997, 1999). The electronic bolus has proved to be a reliable and tamper-proof identification system for ruminants from birth to slaughter (Caja et al., 1999; Fallon, 2001; Garin et al., 2005) and the most...
used and the most retainable device in the European IDEA Project on e-ID (Ribó et al., 2003). Boluses are easily applied and can be safely retrieved at slaughter (Caja et al., 1999; Lambooij et al., 1999; Fallon, 2001), when it is important to avoid leaving residues in the carcass that could cause meat contamination.

Bolus dimensions are a critical factor (Caja et al., 1996; Hasker and Bassingthwaithe, 1996; Fallon, 2001) for retention rate. Therefore, one of the first aims in bolus design is to increase their retention rate in the forestomachs (Hasker and Bassingthwaithe, 1996; Caja et al., 1999; Garín et al., 2005) and reduce size to facilitate an early application (Garin et al., 2005). Specific gravity (SG) greater than 2.0 was originally thought to be necessary to obtain a high retention rate of boluses in ruminants (Hanton, 1976; Ribó et al., 1994; Hasker and Bassingthwaithe, 1996), but Caja et al. (1999) and Fallon (2001) indicated that the SG needed for permanent retention in the cattle forestomachs is at least 3.0. Moreover, abrupt changes in feeding and suckling may induce bolus losses in cattle (AMLC, 1995) and goats (Carné et al., 2005).

The aim of this work was to evaluate retention and readability of e-ID boluses differing in physical characteristics (length, weight, volume, SG, and volume), and to establish a model to predict bolus retention rate in the forestomachs of cattle.

MATERIALS AND METHODS

The experimental procedures and animal care conditions were approved by the Ethical Committee of Animal and Human Experimentation of the Universitat Autonoma de Barcelona (Ref. 01/343 m).

Animals and Management

Beef calves (n = 1,203; 2 to 6 wk of age) enrolled in labeled ‘Fabricarn Vitalca’, Cargill Europe-España, Barcelona, Spain) and meat-certification (‘Marca Q’ in Catalonia, Spain) programs were used. Calves were obtained from livestock markets in the Autonomous Communities of the Northern Spain (Asturias, Cantabria, and Galicia) and transported to a commercial farm (Ganados Font, Santpedor) in Barcelona, Spain. Calves were representative of Spanish autochthonous (Asturiana and Bruna dels Pirineus) and composite (Belgian Blanc Bleu, Holstein-Friesian, and Limousin) breeds. All calves wore 2 officially approved, plastic ear tags of 2 flaps (weight, 10.1 g; Senior tag, Azasafelex, Madrid, Spain) inserted in the ears before leaving the farm of birth according to the European Union Regulation CE 1760/2000 for cattle identification.

After arrival, calves were maintained in groups of approximately 100 according to date of entrance, and subjected to an adaptation period of 2 to 3 d, during which they were rehydrated (Lactolyte, Virbac, Barcelona, Spain), and vaccinated against enterotoxemia (Clostriguard, Schering-Plough, Madrid, Spain) and against infectious bovine rhinotracheitis, bovine viral diarrhea, parainfluenza 3, and bovine respiratory syncytial virus with a tetravalent vaccine (Cattlemaster-4, Pfizer, Madrid, Spain). Calves were also treated with an endectocide (Bayverm, Bayer Hispania, Barcelona, Spain) for control of gastrointestinal and pulmonary parasites.

After adaptation, calves were introduced to artificial rearing with a milk replacer (Celtilait Croissance, Celtilait, Ploudaniel, France) fed from buckets for 6 wk. While restrained in a head gate, calves were fed milk replacer (1.5 L/d) twice daily for the first 4 wk and then once daily for the remaining 2 wk. Starter concentrate feed [as-fed basis: 23.0% corn, 17.5% corn germ, 15.0% wheat, 7.0% barley, 18.7% soybean meal (44% CP), 6.9% soybean hulls, 5.0% alfalfa pellets, 2.5% gluten feed, 1.3% cane molasses, 2.0% calcium carbonate, 0.45% dicalcium phosphate, 0.45% magnesium oxide, 0.2% salt, and 0.2% microminerals and vitamins mix], barley straw, and clean water were offered ad libitum. At weaning (6 wk after arrival), a third plastic ear tag (weight, 8.3 g; no manufacturer indicated), corresponding to the Catalanian meat label ‘Marca Q’, was applied to the calves.

After weaning, calves were maintained in straw-bedded pens in groups of 25 to 30, according to sex and date of arrival to the farm, and intensively fattened with ad libitum concentrate feed [as-fed basis: 24.5% corn, 20.0% barley, 13.0% wheat bran, 12.0% sunflower meal, 12.0% soybean hulls, 5.0% soybean meal (44% CP), 5.0% corn germ, 3.0% gluten feed, 1.9% calcium soap, 0.9% palm oil, 0.8% sodium bicarbonate, 0.7% calcium carbonate, 0.1% dicalcium phosphate, 0.4% magnesium oxide, 0.5% salt, and 0.2% microminerals and vitamins mix] and barley straw.

Calves were slaughtered at approximately 1 yr of age (female BW = 380 to 400 kg; male BW = 480 to 500 kg). For slaughter, calves were transported to the Escorxador Gremial de Catalunya (Castellbisbal, Barcelona) or Mercabarna (Barcelona, Spain) abattoirs (distance = 55 or 75 km, respectively) according to European Commission regulations for animal transport (Directive 95/29/EC). Calves were processed at approximately 70 calves/h.

Electronic Boluses and Transponders

Eighteen types of cylindrical boluses (n = 1,203) were used to study the retention rate in the forestomachs of the calves. Fourteen boluses were made of different ceramic materials based on patents of the European Community et al. (1998) and Caja et al. (2001, 2005), and 4 were made of plastic tubes filled with high-density concrete and pieces of lead ballast to obtain the desired weight. Boluses were grouped in 2 series according to their features.

Series 1 (n = 576) consisted of 10 types of boluses designed to maintain the external dimensions and volume, but to vary in weight. Six boluses were made of
ceramic and included the bolus (Rumitag 0001, Rumitag, Barcelona, Spain) used in the European Union’s IDEA research project (Ribó et al., 2003; San Miguel et al., 2005). Series 2 (n = 627) consisted of 3 prototypes and 5 commercial types of boluses of different ceramic materials varying in weight, o.d., length, and SG.

Features of each bolus type were measured in random samples of 10 under laboratory conditions by using a precision weighing scale (BP 3100 P, Sartorius, Goettingen, Germany; accuracy: 0.01/600 g) and a stainless steel precision caliper (Medid Precision, Barcelona, Spain; accuracy: 1/20). Specific gravity was measured according to the Archimedes principle by weighing the bolus in air and then weighing it again when totally submerged in distilled water at 20°C (density = 1); its value was obtained by the formula: 

\[
SG = \frac{\text{air weight}}{\text{water weight} - \text{liquid density}}
\]

Its value was obtained by the formula: 

\[
SG = \frac{\text{air weight}}{\text{water weight} - \text{liquid density}}
\]

with the air weight being equivalent to the volume.

All boluses contained 1 passive read-only, glass-encapsulated transponder from 1 of the 2 radio frequency technologies (full duplex-B and half duplex) recognized by the current International Organization for Standardization 11784 and 11785 standards (ISO, 1996a,b). Transponder identification codes were recorded by the manufacturer according to the ISO 11784 standard and included the official manufacturer code (4 digits) granted by the International Committee for Animal Recording (ICAR, 2005b) and a serial code (12 digits). The manufacturer code for full duplex-B transponders was 0981 (Datamars, Vedano-Lugano, Switzerland); the manufacturer codes for half-duplex transponders were 0964 (Rumitag, Barcelona, Spain), 0982 (Allflex, Vitre´, France), and 0983 (Texas Instruments, Almelo, the Netherlands). The transponders operated at a frequency of 134.2 kHz, with a reading range of at least 23 cm with handheld transceivers and at least 80 cm with stationary transceivers, in accordance with the IDEA project list of certificates (Korn, 2004).

**Transceivers**

Gesreader 2S ISO (Rumitag) handheld transceivers connected to a 40-cm external stick antenna (Rumitag) were used for control readings. Handheld transceivers and external stick antennas were certified by the Tempest laboratory (Korn, 2004). To ensure the proper reading of the bolus, the stick antenna was aimed at the left side of the animal as near as possible to the reticulum, and perpendicular scanings were done until the transponder was read. A bolus was considered lost (not retained) when the handheld transceiver was unable to read its transponder in successive scanings. Retention rate was calculated as readability (Caja et al., 1999; Conill et al., 2000), excluding the dead calves: retention rate = ([administered – dead – lost]/[administered – dead]) × 100. Lost boluses were confirmed at slaughter to avoid nonfunctioning transponders.

Dynamic readings were also done to evaluate retention rate. Animals were passed in front of a stationary transceiver (Model F-210, Rumitag), certified by the Tempest laboratory (Korn, 2004), working at a field strength of 140 dBuV/m at 3 m. The stationary transceiver was connected to a 94- × 52-cm frame antenna (Rumitag), placed on the left side of a raceway (width, 0.8 m), and interfaced to a portable computer via an RS-232 serial port. A software program (Manga, version 5.3, Rumitag) was used to collect electronic data and to obtain a final reading report of the dynamic reading. Dynamic reading efficiency was estimated as: (bolus read/bolus readable) × 100, according to Caja et al. (1999) and Conill et al. (2000).

**Bolus Administration, Reading, and Recovery Procedures**

After being fed the milk replacer, calves were bolused by one trained operator with the animals restrained in head gates built into the manger side of the calf-holding pen. Bolus administration time was recorded by using the handheld transceiver (Gesreader 2S), and difficulties at application were evaluated according to subjective scoring (Table 1). Boluses were released onto the posterior part of the tongue (torus linguae) at the back of the oral cavity to induce the involuntary swallowing reflex, as indicated by Caja et al. (1999). For this operation, 2 types of balling guns (Ref-0012, Rumitag) were used with different dimensions of the bolus-holding piece according to bolus sizes. Groups of calves were randomly assigned to experimental treatments according to bolus type and farm availability. All boluses were manually read before and after application, and after 24 h and 1 wk to record early losses. Thereafter, the boluses were checked after 1, 5, and 7 mo, by means of dynamic reading; a final reading of the transponders was made by using a handheld transceiver at the beginning of the slaughter line.

Boluses were recovered in the offal plant of the abattoir by a trained operator. Location of boluses in the forestomachs was determined by palpation with the help of a handheld transceiver. Located boluses were removed manually from the reticulorumen by cutting the wall next to the location site. The diameter of the reticulo-omasal orifice was measured after slaughter in a sample of 152 forestomachs from male (n = 90) and female (n = 62) calves of different breeds. A conical caliper calibrated between 5 and 40 mm (with marks every 2.5 mm), was used for measuring the diameter of the reticulo-omasal orifice.

**Statistical Analysis**

Bolus retention rate was analyzed by means of a nonlinear, least squares regression model, assuming a logistic distribution. Calculations were made using the NLIN regression procedure of SAS (version 8.2,
Table 1. Scoring system for bolus administration incidences

<table>
<thead>
<tr>
<th>Bolus administration incidences</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy administration and fast swallow</td>
<td>0</td>
</tr>
<tr>
<td>Fell out once during administration</td>
<td>1</td>
</tr>
<tr>
<td>Fell out twice during administration</td>
<td>2</td>
</tr>
<tr>
<td>Fell out thrice or more during administration</td>
<td>3</td>
</tr>
<tr>
<td>Slow swallow</td>
<td>4</td>
</tr>
<tr>
<td>Downwards massage on the esophagus necessary for bolus to pass</td>
<td>5</td>
</tr>
<tr>
<td>Upward massage on the esophagus necessary to recover bolus</td>
<td>6</td>
</tr>
<tr>
<td>Blocked inside the esophagus but animal apparently fine</td>
<td>7</td>
</tr>
<tr>
<td>Blocked inside the esophagus and animal showing pain symptoms or sick</td>
<td>8</td>
</tr>
<tr>
<td>Bolus considered unable to pass and administration suspended</td>
<td>9</td>
</tr>
</tbody>
</table>

SAS Inst., Inc., Cary, NC). Provided that the number of calves bolused was different for each bolus type, the WEIGHT statement was used to assign the relative weight, according to the number of animals, to each value of bolus retention rate, allowing for a weighted regression. The model included the weight (W) and volume (V) of the boluses as independent covariates. The model was

\[
y = \frac{A}{1 + b_0 \cdot e^{-(b_1 \cdot W + b_2 \cdot V)}},
\]

where \(y\) represented the bolus retention rate; \(b_0, b_1,\) and \(b_2\) represented the regression coefficients; and \(A\) was the maximum value of bolus retention rate. The \(A\) value was set to 100 to express retention rate as a percentage. Significance was declared at \(P < 0.05\).

RESULTS AND DISCUSSION

Bolus Dimensions

Boluses of series 1 had the same external dimensions (o.d. \(\times\) length: 21 \(\times\) 68 mm) and volume (22.42 \(\pm\) 0.03 mL), but varied markedly in weight (from 11 to 75 g) according to the materials used for their fabrication, as shown in Table 2. The SG of these boluses ranged from 0.63 to 3.36 (Table 2). Boluses of series 2 varied in weight (20 to 73 g), o.d. (15 to 21 mm), length (39 to 78 mm), and SG (3.00 to 3.87) as indicated in Table 2. Volumes ranged from 6.5 to 22.2 mL (average 14.6 \(\pm\) 6.1 mL).

Bolus Administration and Effects on the Calves

Almost all boluses (\(n = 1,121; 93.1\%\)) were administered during wk 1 of the milk-fed period with few administration difficulties and without injuries to the calves (administration score = 0), as previously reported by Caja et al. (1999) with boluses of 20.5 \(\times\) 66 mm (SG = 3.1) and Hasker and Bassingthwaighte (1996) with boluses of 20 \(\times\) 68 mm (SG = 2.0). In 19 calves, the bolus fell out once (1.7%, administration score = 1), and in 5 more calves, the bolus fell out twice (0.4%, score = 2) during administration. These values were in the range of McAllister et al. (1998) who reported that 0.7% of boluses fell out during administration in replacement dairy heifers. However, 1 Asturiana and 2 Limousin crossbred calves (0.3%) in series 1 using 21 \(\times\) 68 mm boluses, could not be administered due to difficulties in swallowing (administration score = 9) related to their underdevelopment with regard to the bolus diameter (o.d. of 21 mm). These calves had boluses administered again 1 wk later, in a second attempt at the planned control readings. Age of the calves at administration agreed with the recommendation (1 to 3 wk, or heavier than 30 kg of BW) made by Caja et al. (1999). The difficulties found in the administration of regular boluses (21 \(\times\) 68 mm) in young calves, disappeared when thinner but longer boluses were administered in series 2 (i.e., 17 \(\times\) 77.5 mm) confirming the need to develop boluses of smaller dimensions to ensure a safe identification at the first week of age, regardless of breed or calf development differences. This would fulfill the Article 4.2 of the EC 1760/2000 European Union Regulation requirement for cattle identification: “...be applied within a period to be determined by the Member State as from the birth of the animal and in any case before the animal leaves the holding on which it was born. The period may not be longer than 30 d up to and including 31 December 1999, and not longer than 20 d thereafter.”

The average time required by a single operator to administer the boluses, with the calf restrained in a head-locker, was 44.6 \(\pm\) 0.4 s. Bolusing time obtained in this experiment was greater than the time recorded in calves of 1 to 20 wk of age by Caja et al. (1999) and Baldo and Goitia (2000), who reported values of 19 and 25 s, respectively. Nevertheless, the time required was lower than the 60 s necessary for dairy cows and fattening bulls (Hasker and Bassingthwaighte, 1996; Caja et al., 1999), and the 240 s in beef cows under rangeland conditions (Caja et al., 1999). Average bolusing time in the IDEA project in Europe ranged between 3 and 10 min, for all types of cattle farms under practical conditions (Ribó et al., 2003).

No injuries or casualties were related to bolus administration and average calf mortality was 1.9% for the entire fattening period, which is similar to the 2.1% mortality rate reported in Bruna dels Pirineus.
### Table 2. Features and performances of boluses used for the electronic identification of fattening calves

<table>
<thead>
<tr>
<th>Series</th>
<th>Type</th>
<th>o.d. × length, mm</th>
<th>Weight, g</th>
<th>Specific gravity</th>
<th>Volume, mL</th>
<th>Calves, No.</th>
<th>Retention rate, %</th>
<th>Dynamic reading, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Applied</td>
<td>Dead</td>
<td>Lost</td>
</tr>
<tr>
<td>1</td>
<td>Plastic tube</td>
<td>21.0 × 68.0</td>
<td>10.85 ± 0.44</td>
<td>0.63 ± 0.02</td>
<td>22.42 ± 0.03</td>
<td>22</td>
<td>1</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Plastic tube</td>
<td>21.0 × 68.0</td>
<td>15.59 ± 0.89</td>
<td>0.85 ± 0.07</td>
<td>22.42 ± 0.03</td>
<td>20</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Plastic tube</td>
<td>21.0 × 68.0</td>
<td>20.15 ± 0.14</td>
<td>1.04 ± 0.02</td>
<td>22.42 ± 0.03</td>
<td>19</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Plastic tube</td>
<td>21.0 × 68.0</td>
<td>31.67 ± 0.73</td>
<td>1.63 ± 0.04</td>
<td>22.42 ± 0.03</td>
<td>27</td>
<td>0</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Ceramic</td>
<td>21.0 × 68.0</td>
<td>53.44 ± 0.34</td>
<td>2.39 ± 0.01</td>
<td>22.42 ± 0.03</td>
<td>29</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Ceramic</td>
<td>21.0 × 68.0</td>
<td>57.95 ± 0.18</td>
<td>2.59 ± 0.01</td>
<td>22.42 ± 0.03</td>
<td>42</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Ceramic</td>
<td>21.0 × 68.0</td>
<td>62.61 ± 0.15</td>
<td>2.79 ± 0.01</td>
<td>22.42 ± 0.03</td>
<td>34</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Ceramic</td>
<td>21.0 × 68.0</td>
<td>66.18 ± 0.41</td>
<td>2.95 ± 0.02</td>
<td>22.42 ± 0.03</td>
<td>40</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Ceramic</td>
<td>21.0 × 68.0</td>
<td>70.21 ± 0.22</td>
<td>3.12 ± 0.01</td>
<td>22.42 ± 0.03</td>
<td>40</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Ceramic</td>
<td>21.0 × 68.0</td>
<td>75.10 ± 0.23</td>
<td>3.36 ± 0.01</td>
<td>22.42 ± 0.03</td>
<td>303</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Ceramic</td>
<td>15.0 × 39.1</td>
<td>20.28 ± 0.11</td>
<td>3.08 ± 0.01</td>
<td>6.52 ± 0.07</td>
<td>33</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Ceramic</td>
<td>15.0 × 50.5</td>
<td>25.76 ± 0.04</td>
<td>3.03 ± 0.01</td>
<td>8.49 ± 0.02</td>
<td>29</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Ceramic</td>
<td>16.1 × 64.2</td>
<td>42.00 ± 0.10</td>
<td>3.63 ± 0.01</td>
<td>11.58 ± 0.09</td>
<td>44</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Innoeramics</td>
<td>17.2 × 67.8</td>
<td>51.43 ± 0.11</td>
<td>3.60 ± 0.02</td>
<td>14.29 ± 0.09</td>
<td>41</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Allflex</td>
<td>19.5 × 62.0</td>
<td>64.72 ± 0.19</td>
<td>3.59 ± 0.01</td>
<td>18.04 ± 0.07</td>
<td>100</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Rumitag A-65</td>
<td>20.5 × 66.0</td>
<td>65.17 ± 0.31</td>
<td>3.11 ± 0.02</td>
<td>20.97 ± 0.09</td>
<td>100</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Datamars</td>
<td>20.0 × 76.0</td>
<td>71.92 ± 0.32</td>
<td>3.24 ± 0.01</td>
<td>22.17 ± 0.09</td>
<td>100</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Rumitag Z-73</td>
<td>18.0 × 77.5</td>
<td>72.49 ± 0.23</td>
<td>3.87 ± 0.01</td>
<td>18.90 ± 0.09</td>
<td>180</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1,203</td>
<td>22</td>
<td>109</td>
</tr>
</tbody>
</table>

1. Retention rate = (applied – dead – lost)/slaughtered] × 100.
2. Dynamic reading = (read /readable) × 100.
3. Specially made prototype containing a 32-mm, half duplex, glass-encapsulated transponder (Texas Instruments, Almelo, the Netherlands).
4. Manufactured by Rumitag (Barcelona, Spain) and containing a 32-mm, half duplex, glass-encapsulated transponder (Rumitag).
5. Manufactured by Innoeramics (Teramo, Italy) and containing a 32-mm, half duplex, glass-encapsulated transponder (Allflex, Vitré, France).
6. Manufactured by Allflex (Vitré, France) and containing a 32-mm, half duplex, glass-encapsulated transponder (Allflex).
7. Manufactured by Datamars (Bedano-Lugano, Switzerland) containing a 32 mm full duplex-B glass-encapsulated transponder (Datamars).
8. One bolus was found located in the abomasum at slaughter.
Figure 1. Bolus retention rates (%) according to their weight (W, g) and volume (V, mL) in intensively fattened calves (●, bolus series 1, n = 576; and ○, bolus series 2; n = 627). Lines are the predicted retention rate according to the logistic model:

\[
\text{Retention rate} = \frac{100}{1 + 1.427 \cdot e^{0.267 \cdot V - 0.160 \cdot W}}
\]

suckling calves until weaning (Tarrés et al., 2005). Mortality was low with regard to the 6% mentioned by Buxadé (1997) for similar intensive beef fattening conditions in Spain.

**Bolus Retention, Reading Procedures, and Forestomachs Location**

Retention rate of the different bolus types ranged from 0 to 100% according to their features (Table 2). Although retention rate values for series 1 and 2 converged to 100% for the larger bolus dimensions, a significant difference was observed with regard to bolus weight (Figure 1). Values of retention rate for series 2 were greater than for series 1 for similar bolus weight (e.g., for 20 g: series 1, 5.3%; and series 2, 69.7%), showing the negative impact of the bolus volume on its retention in cattle forestomachs.

Obtained retention rate values fit a logistic regression \( R^2 = 0.99 \) when bolus weight and bolus volume were used as covariates \( (P < 0.001) \). Other combinations of independent variables in the logistic model gave lower \( R^2 \) values for the estimation of retention rate, and were not considered. The equation predicting the percentage of retention rate, by using bolus weight and bolus volume, was

\[
\text{Retention rate} = \frac{100}{1 + 1.427 \cdot e^{0.267 \cdot V - 0.160 \cdot W}},
\]

where \( W \) was the bolus weight (g), and \( V \) was the bolus volume (mL).

As shown in Figure 1, retention rate increased with bolus weight but decreased with bolus volume, showing the importance of miniaturized heavy boluses in cattle, as previously reported in sheep (Garín et al., 2005). Figure 1 also includes the predicted values for the parameterization of equation [1] at 8, 15, and 22 mL bolus volumes compared with observed values. On average, error of the predicted retention rate was 1.5 percentage points (Figure 2).

Two more equations were calculated from equation [1] to estimate the values of bolus weight, volume, and SG that reach a retention rate = 99.5%, greater than the ICAR recommendation (98%). Equations were:

\[
W = 27.14 + 1.513 \cdot V, \quad \text{and} \quad \text{[2a]}
\]

\[
SG = 27.14/V + 1.513. \quad \text{[2b]}
\]

According to equations [2a] and [2b], bolus weight to obtain the 99.5% retention for series 1 \( (V = 22.4 \) mL) was 61 g (SG = 2.72). Given that series 2 boluses varied in volume, the corresponding values for the parameterized 8, 15, and 22 mL of bolus volume were 39 g (SG = 4.91), 50 g (SG = 3.32), and 60 g (SG = 2.75), respectively. No glass or plastic polymers are able to reach the required SG for bolus retention in cattle.
foremostomachs, and nonmagnetic materials transparent to the radiofrequency radiation (e.g., ceramic) should be used for producing electronic boluses. These values are greater than the SG range (1.8 to 2.5) considered necessary for the retention of therapeutic boluses in cattle (Riner et al., 1982; Allen et al., 1985).

Retention rates of series 2 boluses (69.7 to 100%) with SG ranging between 3.1 and 3.6 also indicated that SG is not the only factor necessary for obtaining high retention rate values. Moreover, SG > 3 does not warrant that bolus losses will be avoided in all cases as concluded by Caja et al. (1999) and Fallon (2001); bolus dimensions seem to play an important role in forestomachs retention rate, as shown in our results. Figure 3 shows the bolus weight and volume combina-

tions, according to SG, that allow retention rates > 99.5%.

With regard to the readability of the electronic bolus, handheld transceivers used in our experiment were able to read all the present boluses (Table 2) at any age of the fattening calves, despite the reading difficulties indicated by Klindtworth et al. (1999) in similar conditions. Moreover, dynamic reading efficiency for the different types of ruminal boluses used was 100% at each reading control done. These values agreed with the 99% efficiency reported by Caja et al. (1996) and Baldo and Goitía (2000) in beef cattle. The high values of reading efficiency obtained may be a consequence of the fixed body position (left armpit region) where the bolus is normally located, as previously indicated by Conill et al. (2000) by comparing transponders injected in different body sites in cattle. This allows the installation of the antenna in a fixed optimal position in the raceway, which should increase the effectiveness of dynamic readings.

All the boluses read at the beginning of the slaughtering line were retrieved in the offal plant of the slaughterhouse (bolus recovery, 100%). Location of boluses in the reticulum of the slaughtered calves (82.4%) was in the range of values (80 to 96.5%) reported by Caja et al. (1999) and Lambooij et al. (1999), and close to the values (84 to 100%) reported by Hasker and Bassingthwaighte (1996), Caja et al. (1999), and Fallon (2001).

Nevertheless, 1 Allflex bolus (64.7 g; 19.5 × 62.0 mm) read normally in the live animal was retrieved in the abomasum, indicating that the bolus left the reticulorumen and passed through the reticulo-omasal orifice. No signs of discomfort or impaired growth were observed in this animal. Similar results were reported by Garín et al. (2005) when boluses of small dimensions were tested in lambs. The bolus retrieved in the abomasum appeared dark-brown tainted as a result of the abomasum acid secretions, which may be used as a sign to detect the passage through the reticulo- omasal orifice in retrieved boluses. No more dark-brown tainted boluses were detected in our study.

The measured diameter of the reticulo-omasal orifice in our results indicated greater ($P < 0.01$) values in the male (32.5 ± 1.4 mm) than in the female (29.9 ± 1.3 mm) calves, although both were in the range of the values (28 to 45 mm) previously reported in cows (Buéno, 1975; Mc Bride et al., 1983). These values are greater than the diameter of the retained boluses (15 to 21 mm), and therefore the open reticulo-omasal orifice was able to allow the passage of the bolus. In conclusion, for effective bolus retention in the reticulo-rumen of cattle, other criteria (e.g., bolus length), in addition to minimum weight and volume discussed above, should be considered. Moreover, bolus dimensions allowing a predicted retention rate >99.5% are recommended as a safety margin to ensure the greatest identification performances in practice.
Conventional Ear-Tag Losses

Official ear-tag losses during the entire feeding period for a single ear averaged 3.5%. No cases of both ear tags being lost were reported. Losses of the ‘Marca Q’ ear tags (4.1%) were numerically greater than the official ear tags probably as a result of a more external insertion of the ear tag in the ear and the lower quality of the ear tag, although no significant differences were found between these 2 ear-tag types.

In conclusion, bolus weight and volume are key dimensions for the electronic identification of cattle to achieve their maximum retention rate in the reticulum and to avoid losses by regurgitation or by passage through the reticulo-omasal orifice. According to the prediction model obtained, the minimum bolus weight estimated to reach an effective retention rate >99.5% was 61 g, if specific gravity was 2.7. No boluses with specific gravity <3.0 and thicker than 2.0 mm o.d. are recommended in practice. With the recommended bolus design, it should be possible to obtain the permanent identification of cattle from early rearing (20 d of age) to slaughtering.

LITERATURE CITED


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