Zoometry of obese pigs undergoing experimental bariatric surgery hourglass with gastro-jejunal bypass

Mastoby M. Martínez M1*; Diana M. Pérez B1; Valery Lancheros S2.

1Universidad de Córdoba, Facultad de Medicina Veterinaria y Zootecnia. Departamento de Ciencias Pecuarias, Grupo de Investigación en Medicina y Cirugía Veterinaria (MECIVET). Montería, Colombia.
2Universidad de Córdoba, Facultad de ingeniería. Departamento de Ingeniería Mecánica, Grupo de investigación ingeniería ciencia y tecnología (ICT). Montería, Colombia.
*Correspondencia: mmiquelmartinez@correo.unicordoba.edu.co

Received: January 2023; Accepted: June 2024; Published: July 2024.

ABSTRACT

Objective. To evaluate zoometric variables in obese Landrace pigs undergoing experimental hourglass bariatric surgery with gastro-jejunal bypass (CBERADG-Y). Materials and methods. The evaluation was performed in three phases with 12 purebred animals divided into an experimental group and two control groups. Phase 1: induction of obesity reached in 120 days. Phase 2: practice of experimental surgery. Phase 3: evaluation of zoometric variables [body mass (BM), occipital-coccygeal length (L Occ-Co), abdominal diameter (AD), and body mass index (BMI)] in the experimental pigs; comparing measurements at day zero, day 15, and day 30 between groups and intra-group. Results. At the end of the study, the experimental group reduced MC, DA, and BMI without affecting L Occ-Co, while the two control groups maintained these variables stable. Conclusions. Although there were no significant differences between groups, it was possible to standardize a bariatric surgery that had a quantitative influence on the zoometric variables of the experimental group.

Keywords: Pigs; metabolic surgery; obesity; overweight; zoometry (Source: DeCS, MeSH).

RESUMEN

Objetivo. Evaluar variables zoométricas en cerdos Landrace obesos intervenidos con la cirugía bariátrica experimental reloj de arena con derivación gastro-eyunal (CBERADG-Y). Materiales y métodos. La evaluación se realizó en tres fases con 12 animales puros divididos en un grupo experimental y dos grupos control. Fase 1: inducción de obesidad alcanzada en 120 días. Fase 2: práctica de la cirugía experimental. Fase 3: evaluación de variables zoométricas [masa corporal (MC), longitud occipito-coccígea (L Occ-Co), diámetro abdominal (DA) e índice de masa corporal (IMC)] en los cerdos del experimento; comparando medidas al día cero, día 15 y día 30 entre grupos e intra-grupo. Resultados. Al final del estudio, el grupo experimental redujo la MC, el DA y el IMC sin afectar la L Occ-Co, mientras que los dos grupos control mantuvieron estables estas variables. Conclusiones. Pese a no existir diferencias significativas entre grupos, se logró estandarizar una cirugía bariátrica que influyó cuantitativamente sobre las variables zoométricas del grupo experimental.

Palabras clave: Cerdos; cirugía metabólica; obesidad; sobrepeso; zoometría (Fuente: DeCS, MeSH).
INTRODUCTION

Obesity is a chronic state of pathological increase in the mass of white adipose cells and represents one of the global epidemics of the 21st century. (1). In 2022, according to WHO data, 2.5 billion adults aged 18 years or older were overweight, equivalent to 43%, of which 43% were men and 44% women, and about 16% of adults aged 18 years or older worldwide were obese with a prevalence that is increasing if we take as a reference the data from 1990 (increased by more than 100% compared to 2022). (2). Obesity predisposes to diabetes and worldwide, there are approximately 500 million people with the pathology, and an approximate growth of 25% and 51% is expected by 2030 and 2045, respectively (3).

In veterinary medicine and especially in companion animals, obesity has also reached high figures: approximately 40% of dogs, and around 35-50% of cats, are overweight or obese, where animal sedentary lifestyle and little exercise are factors that are related to the condition. In addition, there are other predisposing factors such as breed, age, gender, and reproductive status. (4).

Overweight and obesity are 90-95% associated with the risk of type 2 diabetes mellitus (DM2) in humans (5) as well as in cats, with the aggravating factor of renal disease. As for obese dogs, about 23% may present hypercholesterolemia, hypertriglyceridemia, arterial hypertension, and functional limitation in walking due to the tendency to develop osteoarthritis. (4). In humans, in addition to the above pathologies, they can develop pancreatic diseases, non-alcoholic fatty liver disease (NAFLD), and several specific cancers (6). In humans, overweight and morbid obesity are associated with a high mortality rate and an increased risk of cardiovascular disease or death from associated causes (7). In addition to the comorbidities associated with obesity, there is an important psychosocial and occupational impact, which reduces the quality of life of obese individuals (5).

Bariatric surgery provides the most robust option for treating obesity compared to other currently available strategies that include lifestyle modification, pharmacotherapy, and endoscopic therapy (6,7,8,9). Sleeve gastrectomy (SG) is the most widely used surgery and since 2013 has become the preferred weight loss procedure and even above Roux-en-Y gastric bypass (RYGB) with influence on the digestive microbiota and the entero-endocrine-immune system (10).

Changes in satiety are profound from the early postoperative period after BGYR and SG and, in some cases, there are also alterations in food preferences after these procedures. These bariatric techniques can be effective in inducing weight loss, however; the vast majority of people fail to maintain it in the long term and even with postoperative complications such as nutritional deficiencies (6).

From the above, it can be inferred that any intervention made to the digestive system induces changes ranging from the native microbiota to morpho-physiological changes with an impact on metabolism and weight. That is why the research group on companion animal medicine and surgery (MECIVET) of the University of Cordoba, Colombia in search of answers to hypotheses and in order to minimize post-surgical complications; evaluated the influence of a new bariatric technique on zoometric parameters in obese Landrace pigs (Sus scrofa domesticus) as a biological model. The new technique combines the compartmentalization of the stomach (two sacks) with the rapid arrival of nutrients to the last quarter of the small intestine.

MATERIALS AND METHODS

Study animals. Male Landrace pigs, six to seven months old, castrated at the second week of life according to the management of the swine program and coming from two different litters, were included. The animals were housed in individual pens, each with an area of 2 m2, with bars that allowed contact between animals from adjacent pens. They were kept under controlled conditions for five months and the temperature was maintained at around 23±2°C, with relative humidity between 45-65%, and living on a 12-hour/12-hour light-dark cycle.

The animals entered the study with an average weight of 20 kg and 2.5 months of age until reaching an average weight of 115 kg and signs of overweight or obesity at 6.5 months. During this period of time, they were fed a commercial finishing diet; and to induce obesity in all animals, the daily ration was enriched with 18% commercial vegetable oil and 15% molasses (Table 1), based on the information reported (11,12). The animals were fed twice a day (07:00...
and 15:00 hours) and the amount depended on body weight and productive stage following the manufacturer’s instructions. All pigs that entered the research were clinically evaluated and blood tests were performed to confirm a good health status.

| Table 1. Composition of the commercial diet and energy supplement fed for four months to Landrace pigs in the growing stage to induce obesity. |
|--------------------|---------------------------------|-----------------|
| **Type of diet**   | **Composition**                 | **Quantity (%)** |
| Commercial         | Minimal protein                 | 17              |
|                    | Minimal grease                  | 5               |
|                    | Maximum humidity                | 13              |
|                    | Maximum fiber                   | 7               |
|                    | Maximum ash                     | 8               |
| Energy supplement  | Commercial vegetable oil\(^1\) | 18              |
|                    | Molasses\(^2\)                  | 15              |

\(^1\)The commercial oil provided 80 calories of fat with a per serving amount of total fat of 9 g (14%).

\(^2\)Molasses provided 2100 Kcal/kg, which for the amount added to the commercial fattening ration corresponds to 787.5 Kcal.

**Ethical aspects.** The study was conducted in accordance with the Declaration of Helsinki and was approved and supervised by the Ethics Committee of the FMVZ of the University of Córdoba - Colombia (Law No.009 of November 30, 2021) for animal studies.

**Study design.** The pigs had four months of animal management starting at 2.5 months of age and an experimental phase lasting 30 days starting at 6.5 months of age where weighing and measurements were performed at day 0, day 15, and day 30 post-surgical intervention.

Initially, 15 animals were selected, but the sample size was reduced to 12 pigs as this was the number approved by the ethics committee. For the experiment, the initial group was divided into three subgroups by purposive sampling, where the first control group (GC1) consisted of three animals without surgery and that continued with energy supplementation until the end of the study; a second control group (GC2) consisted of four animals with celiotomy and energy supplementation was withdrawn, and the experimental group (EG) consisted of the five heaviest animals that underwent experimental surgery without energy supplementation (Figure 1).

**Location.** The study was conducted at the Berástegui campus from Faculty of Veterinary Medicine and Animal Husbandry at University of Córdoba, located in the Berástegui district, rural area of the municipality of Ciénaga de Oro, department of Córdoba, with an average temperature of 29ºC, relative humidity of 85%, altitude of 22 m.a.s.l. and an average annual rainfall of 1200 mm.

**Collection of information.** Among the zoometric variables, weight in kilograms (kg) was obtained with a precision analytical balance (J.W. Baumann Waagenfbrik Thierseim/Bayern balance). The occipito-coccygeal length (L Occ-Co) in centimeters (cm) was measured with a tape measure from the occipital protuberance to the base of the tail. For the abdominal perimeter (AP) in cm; the costal arch was considered, which coincided with the umbilical area of the Landraces pigs. To estimate the body mass index (BMI), the weight in kg divided by the square of the occipital-coccygeal length in cm (weight/L Occ-Co2) was taken into account, which was adapted from a previous study (13). The forms and techniques of restraint and physical immobilization were made taking into account the minimum physical injury to the patients.

**Pre-operative, anesthesia, surgery, and postoperative care.** Prior to surgery, the pigs underwent a water and solid fasting of six and 12 hours, respectively. All surgeries were performed under general anesthesia, and an
Analgesic (flunixin meglumine at 1.1 mg/kg/via IM) and an antiemetic (metoclopramide at 0.5 mg/kg/via IM) were applied beforehand. For tranquilization, azaperone (4 mg/kg/via IM) was applied and anesthesia was induced with intramuscular injection of the mixture of 2% xylazine (0.5 mg/kg) and 5% ketamine (2 mg/kg) and maintained with isoflurane. Oro-tracheal intubation was performed and oxygen was supplied throughout the procedure, heart rate, respiratory rate, temperature, mucosal color, capillary filling time, eyeball position, and pupil size were also monitored.

The experimental technique denominated by the author as hourglass bariatric surgery with gastro-jejunal bypass, identified with the acronym "CBERADG-Y"; is classified as restrictive-malabsorptive, because the stomach was divided into two communicating sacs, where the first receptor sac has approximately 20% of the total capacity and the second sac, approximately 80% of the total capacity; and then the pyloric outlet was closed. The second sac was anastomosed with the last quarter of the small intestine. The technique seeks to reduce the gastric capacity so that the pig has a sensation of early and prolonged satiety with a much smaller amount of food than that usually ingested, and that the chyme reaches the last quarter of the small intestine (distal jejunum and ileum) more quickly, with the consequent loss of excess weight. All surgeries were performed by the author, who is a veterinary surgeon and junior researcher according to Colciencias categorization.

After surgery, pain control was managed with intramuscular injection of flunixin meglumine (1.1 mg/kg b.w.), every 12 hours for 3 days. Antibiotic prophylaxis was performed by intramuscular injection of oxytetracycline (5 mg/kg b.w.) every 24 hours for three days, complemented with a single intravenous dose of metronidazole (10 mg/kg b.w.) during the operation. It should be noted that the pigs in the two control groups also received this treatment.

Statistical analysis. As the data correspond to a small sample size (less than 50), the Shapiro-Wilks normality test was performed, with statistical significance (value of P≤0.05), which resulted in a non-normal distribution, so the Kruskal-Wallis nonparametric test was used to compare the differences in the zoometric measurements of the study groups. The STATA17 software® of the company Innovaseg Colombia SAS was used for the statistical analyses.

RESULTS

Zoometric measurements. The results showed that the occipito-coccygeal length was similar between the groups analyzed (12 cm for the CG and 10 cm for the SG). As for the abdominal perimeter, an average of 13 cm was observed for the CG, while in the SG there was a decrease of 4.4 cm at the end of the study. The same trend was observed in weight, with less increase in this variable in the pigs that underwent experimental surgery (an increase of 5.4 kg), compared to the control groups (28 kg for GC1 and 22 kg for GC2). The BMI behavior in both GC1 and GC2 increased by 17.0% and 9.7%, respectively, while for the SG it presented a reduction of 6% (Table 2).

The results showed that the animals in the experimental group at the end of the study had lower body mass (weight), a significant reduction in BP (p=0.0434) and BMI (p=0.0440) when compared to the control groups (Table 2 and Figure 2,3 and 4).

Finally, when a comparison was made between the groups concerning BMI, the results showed a gain in BMI for groups GC1 and GC2 compared to the experimental group (p= 0.0079).
### Table 2. Medians and interquartile ranges of zoometric measurements of Landrace pigs according to follow-up and group during the study period.

<table>
<thead>
<tr>
<th></th>
<th>Control group 1</th>
<th>Control group 2</th>
<th>GE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median</td>
<td>ICR (25-75)</td>
<td>Median</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>103</td>
<td>95-107</td>
<td>106</td>
</tr>
<tr>
<td>Occ-Co (cm)</td>
<td>122</td>
<td>112-124</td>
<td>121</td>
</tr>
<tr>
<td>AC (cm)</td>
<td>120</td>
<td>118-120</td>
<td>122</td>
</tr>
<tr>
<td>BMI</td>
<td>0.84</td>
<td>0.83-0.87</td>
<td>0.91</td>
</tr>
<tr>
<td><strong>P-Value</strong></td>
<td><strong>0.0206</strong></td>
<td><strong>0.9026</strong></td>
<td><strong>0.0676</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Control group 1</th>
<th>Control group 2</th>
<th>GE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (kg)</td>
<td>119</td>
<td>110-127</td>
<td>119</td>
</tr>
<tr>
<td>Occ-Co (cm)</td>
<td>125</td>
<td>124-127</td>
<td>126</td>
</tr>
<tr>
<td>AC (cm)</td>
<td>124</td>
<td>124-127</td>
<td>127</td>
</tr>
<tr>
<td>BMI</td>
<td>0.95</td>
<td>0.87-0.98</td>
<td>0.96</td>
</tr>
<tr>
<td><strong>P-Value</strong></td>
<td><strong>0.8780</strong></td>
<td><strong>0.8431</strong></td>
<td><strong>0.5156</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Control group 1</th>
<th>Control group 2</th>
<th>GE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (kg)</td>
<td>131</td>
<td>124-134</td>
<td>130</td>
</tr>
<tr>
<td>Occ-Co (cm)</td>
<td>132</td>
<td>127-134</td>
<td>132</td>
</tr>
<tr>
<td>AC (cm)</td>
<td>133</td>
<td>132-133</td>
<td>135.5</td>
</tr>
<tr>
<td>BMI</td>
<td>0.98</td>
<td>0.98-1.01</td>
<td>0.99</td>
</tr>
<tr>
<td><strong>P-Value</strong></td>
<td><strong>0.2288</strong></td>
<td><strong>0.9041</strong></td>
<td><strong>0.0434</strong></td>
</tr>
</tbody>
</table>

### Figure 2. GC1 at 30 days of evaluation shows its overweight condition (=5) according to the zootechnical classification scale and according to the different fat distribution points. A. Buttocks and hams, B. Abdomen, C. Abdomen and flank, D. Jowls and E. Coxal, buttocks and hams.
Figure 3. GC2 at 30 days of evaluation shows its overweight condition (=5) according to the zootechnical classification scale and according to the different fat distribution points. A. Coxa and hams, B. Flank, C. Coxa and back, D. Dewlap, and F. Abdomen.

Figure 4. GE at 30 days of evaluation shows its lean condition (=3) according to the zootechnical classification scale and according to the different fat distribution points. A. Back and coxa, B. Buttocks and hams, C. Dewlap, and D. Dewlap, abdomen, and flank.
DISCUSSION

Zoometric variables: general approach.
Zoometric variables together with animal mass and BMI had a similar behavior to previous studies of bariatric surgery in adolescents (14). Therefore, it is presumed that fat mass had the greatest influence on weight reduction in pigs operated with hourglass bariatric surgery with gastro-jejunal bypass.

In addition; according to the visual scale of zootechnical classification for breeding sows (15) it could be observed that the controls maintained their overweight or obese condition (value=5) while those of the GE involuted their condition to leanness (value=3); therefore, it is inferred that the proposed surgery does not alter the body development of the pigs but it can influence the body mass; where perhaps there was consumption in adequate or sufficient proportions for the maintenance of the vital functions without reaching the energy saving under the fat mass modality.

The tendency of the GE pigs to lose fat mass according to the subjective evaluation and according to the weight during the month of study, allows us to presume that the experimental bariatric surgery influenced this variable and that the results can be similar to those reported by Parmar and Mahawar (16) who managed to reduce overweight with maintenance of the loss in time when they practiced the gastric bypass of an anastomosis or mini-gastric bypass in adult humans, where the weight losses at six, 12, 24 and 60 months were in the order of 60, 72, 78 and 76.6% respectively. Also, similar to the research of Hernandez Hurtado et al. (11) who report that the duodenal-ileal bypass of an anastomosis with sleeve gastrectomy, achieves a percentage of overweight loss of more than 90% two years after surgery and that it was maintained until the fifth year.

From the zoometric parameters obtained, it could also be inferred that: CBERADG-Y possibly influenced fat mass and less on lean mass, which would explain why the animals had weight gain and grew during the study time. In other words, the rest of the systems among which are the musculoskeletal, skin, and viscera that integrate the digestive system; continued their development, agreeing with those who speak of Matiegka’s method that divides the body weight into four parts: skeleton, skeletal muscle, skin plus subcutaneous adipose tissue and the rest with continuous growth up to a certain stage of life (17).

Body mass (weight) - BMI - PA. Lifestyle changes and pharmacotherapy have not been effective in long-term weight loss and mortality reduction. Currently, bariatric surgery is the most effective treatment modality to achieve both of the above goals and even remission of comorbidities in obese individuals. (5). Although bariatric surgery is now accepted as the first option for treating recalcitrant morbid obesity in adults, in adolescents they represent approximately 0.73% of the cases performed in the United States, and this rate is estimated to increase (18).

Investigations in obese minipig pigs (11) confirm that significant weight reduction leads to a decrease in free fatty acids and that caloric restriction alone can positively affect insulin sensitivity, attenuating β-cell lipo-toxicity and glucotoxicity, a statement that encourages us to believe that the proposed experimental surgery (CBERADG-Y) can favor the metabolism of patients with obesity, taking into account that a reduction in BMI of 6% of the pre-surgical baseline weight and lower BP were achieved when compared with the control groups.

It could be thought that the loss of fat mass in the finishing pigs is a reflection of the energy balance reached and that in a certain way and together with the lack of high energy density, it could exert feedback on hormones that regulate appetite, manifesting itself with lower feed intake and loss of overweight due to fat mass. Another hypothesis for the thinning of the GE pigs could be based on the fact that the percentage of energy that is usually produced by the small intestine has to be supported by other sources such as body fat (subcutaneous and abdominal). The above approach is based on the results obtained by Jang et al (19) who state that the small intestine contributes 25% of systemic gluconeogenesis both in prolonged fasting and in diabetes.

In obese animals, especially in those of GC1; the excess fructose provided by molasses, possibly escaped the hepatic control mechanisms generating sources of fatty acids that ended up accumulating in the subcutaneous tissue and as abdominal fat, which are the clinically observable points. The above approach is based on previous findings (19) which state that the excess of fructose in the small intestine affects
the intestinal microbiome and the hepatic function reflected in the activation of genes that improve the absorption and metabolism of this sugar as a source of gluconeogenesis. Based on the above statement, it is hypothesized that these genes were sensitized in GC2 pigs that maintained their obese state despite the removal of the oral energy source (molasses and soybean mineral oil).

According to the data from CG2, the suspension of the supplement was not sufficient to reduce body condition and BMI. From the above, it can be inferred that CBERADG-Y had a greater influence on body condition than the type of feed-supplement because the CG maintained their obese behavior and body condition until the end of the study (Figure 2 and 3). According to the literature (20), the higher intake of energy derived from fat and carbohydrates leads to higher energy intake which clinically is expressed by higher food intake and subsequent weight gain.

There is research (11) that interrelates zoometric variables such as intra-abdominal fat tissue (TGIA) with glucose metabolism and affirms that this parameter seems to play a fundamental role in insulin sensitivity and glucose homeostasis, because in their animal model when they performed laparoscopic Roux-en-Y bariatric surgery it led to glucose control, as well as to a significant reduction in TGIA values in comparison with the evaluations of the model. The lower increase in BP and lower weight of the GE pigs; demonstrate that the experimental bariatric surgery influenced these variables. These results are similar to one of the variables of Hernández Hurtado et al (11), encouraging us to think that CBERADG-Y could have a positive influence on overweight control and glycemic control.

In another sense, bariatric surgeries seek to reduce weight at the expense of adipose tissue, the abdomen being one of the sites of greatest accumulation and among these the visceral adipose tissue (VAT), which is a source of the high rate of lipolysis, with the consequent release of fatty acids and pro-inflammatory cytokines to the liver and circulation at high levels. Free fatty acids cause insulin resistance in recipient tissues by activating apoptosis of pancreatic beta cells, known as lipotoxicity. Insulin resistance is associated with arterial hypertension, hypertriglyceridemia, and decreased HDL cholesterol levels, which together are risk factors for the cardiovascular system. On the other hand, the mobilization of free fatty acids from visceral adipose tissue to the liver and compensatory hyperinsulinemia at the portal circulation level promote the condition of hepatic steatosis (21). The last two paragraphs encourage us to believe that the proposed experimental surgery (CBERADG-Y) can lower the cardiovascular, hepatic, and pancreatic risks associated with morbid obesity; because of the achievements on BMI and abdominal perimeter that were lower than those of the control groups.

In conclusion, according to the anatomical structures intervened, the weight reduction, and the follow-up or phase of development in time respectively; the experimental bariatric hourglass surgery with gastro-jejunal bypass (CBRADG-Y) can be classified as a gastro-intestinal technique, restrictive - malabsorptive and in development; which during the evaluation and based on quantitative data, proved to be effective and efficient in inducing weight loss in a short time, did not affect growth, reduced abdominal perimeter and reduced body mass index. This bariatric/metabolic surgery opens the door for future research oriented to the genesis of weight loss derived from fat mass.

**Conflicts of interest**

We declare that we have no conflicts of interest.

**Acknowledgments**

To the swine program from FMVZ at University of Córdoba-Colombia for providing the pigs, their feed, and management.

**Financing**

The research was conducted with the author’s resources and resources from the University of Córdoba-Colombia.

**Author’s contribution**
REFERENCES


