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3D Modeling of Abdominal Surface Area in Cats

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Abstract

Background

In humans and rats the peritoneal surface area is described, but not the abdominal cavity surface area (ACSA). On the literature review undertaken, no discriminatory values of surface area of the abdominal cavity in cats were found. The objective of the study is to determine the ACSA in cats, through three-dimensional (3D) modeling. For this purpose it was performed a retrospective study of a series of cases of tomographic exams of cats, without changes in the abdominal cavity. Processing the digital images and through segmentation techniques was constructed the 3D model of the abdominal cavity of 26 cats, making it possible to determine its volume and surface area.

Results

The volume (mean ± standard deviation) of the abdominal cavity of cats was $6.59 \times 10^{-4} \pm 2.22 \times 10^{-4}$ m^3, and the area of abdominal surface $5.11 \times 10^{-2} \pm 9.86 \times 10^{-3}$ m^2.

Conclusions

The values determined provide not-existent anatomical information and contribute to the study of diseases affecting this area. The determination of this area allows its application in calculating and determining intra-abdominal pressures and understanding them better. The same methodology can be used in other species for the determination and calculation of the abdominal surface area.

Keywords: Abdominal surface area; 3D Modeling; Mathematical determination; Intra-abdominal pressure

List of abbreviations

ACSA:Abdominal Cavity Surface Area; PSA: Peritoneal Surface Area; IAP: Intra-Abdominal Pressure; CT: Computed Axial Tomography; DICOM: Digital Imaging And Communications In Media; ROI: Region Of Interest; CAD: Computer-Aided Design; 3D: Three Dimensional; STL: Stereolithography; BSA: Body Surface Area; TM: Transurethral Method

Introduction

The abdominal cavity it presents an ovoid shape and is compressed laterally and is considered the largest body cavity. It is delimited, cranially, by the diaphragm and, caudally, connected with the pelvic cavity. Dorsally, it is bounded by the lumbar vertebrae, muscles and lumbar part of the diaphragm. The side walls are formed by abdominal muscles, peritoneum, caudal ribs, iliac wings and its muscles. The ventral portion is bordered mainly by abdominal muscles and peritoneum [1,2]. The dividing line between the abdominal and retroperitoneal cavities is called terminal line; it is formed dorsally by the base of the sacrum, laterally by the iliopectineal lines, ventrally by the cranial edges of the pubic bones. The retroperitoneal cavity contains the rectum and part of the internal and urinary genital organs [1,2].

In the literature review carried out by the authors, no morphometric study was found that would determine the abdominal cavity surface area (ACSA) in cats. In humans and rats, the peritoneal surface area (PSA) is indeed described by various methods, due to its importance as direct barrier of exchanges in intraperitoneal therapy [3,4].

The determination of ACSA is important as a morphometric parameter of quantification of the body surface; it provides non-existent basic anatomical information and enables better understanding of physiological or pathological concepts, affecting the abdominal cavity.

The use of this parameter may acquire particular relevance in the determination of the intra-abdominal pressure (IAP) and in understanding the abdominal compartmentalization syndrome. The IAP is defined as a state of pressure in the abdominal cavity, which is determined by body mass index, posture, muscle activity of the wall and respiration [5-7]. The IAP is directly influenced by a number of factors such as: volume of the organs; bones; contents of the abdominal

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area; degree of elasticity of the abdominal wall. These structures, by directly varying the volume or the accumulated fluid or gas, are likely to change the IAP in acute, sub-acute and chronic forms [5]. The measurement of IAP is usually performed using the transurethral method (TM) and this is considered the gold standard for its evaluation [8,9]. Normal values for the feline species have already been described between 2.15-6.15 mmHg (2.90 to 8.80 cm H_2O) [10,11]. However, the measurements made by the TM are still subject to some controversy and it is discussed whether the IAP should be measured using more sensitive, reproducible and reliable methods [8,12]. Although no cases of compartmentalization syndrome have ever been found in cats, it has recently been demonstrated that the values rise after elective abdominal surgery, despite causing no symptoms [13].

The ACSA is a variable that directly influences the IAP, because pressure (P) is a scalar quantity that represents the action of one or more forces (F) on a given area (A), in this case the ACSA [14-16]. The determination of ACSA can bring new data for understanding the IAP and attempt to replicate more reproducible methods, since it is one of the variables that directly affect this parameter. The determination of ACSA will allow their use in the physical definition of pressure (P=F/A) allowing the emergence of new methods and concepts for determining the IAP [15,16].

The determination of ACSA is difficult to obtain, since it is a parameter that can only be obtained with the help of imaging or post-mortem exams. The physical determination of viscera and organic cavities dimension, like volume and surface area, sometimes is a challenge in the several fields of medicine [4,17-22]. The last two decades have led to great advances in medical systems of image acquisition and its manipulation, allowing its use in quantifying anatomic structures [23].

Since 1970, the computed axial tomography (CT) has revolutionized the radiological diagnosis; it was also the first tomographic technique to be combined with computational calculation [24]. Since then, there has been great technological development, allowing the use of these techniques to determine and calculate anatomical parameters of various organs with precision, when compared with real models [23,25-28]. The three-dimensional (3D) construction of anatomical models is possible through the segmentation, with demarcation of each region of interest (ROI), and construction of the mesh representative of the structure. Using computer-aided design (CAD) software, such as Solid Works (Dassault Systemes, US, enables the modelling of the structure and the calculation of mass properties such as volume, density, surface area and centre of mass of the ACSA [23,29].

Using computational calculation, through the identification of systems, allows creating mathematical models of dynamic systems, facilitating the interface between real-world applications and the mathematical world [30]. Through these techniques it is possible to find simple mathematical solutions for the determination of ACSA, based on morphometric parameters.

Materials and Methods

Retrospective study of cat cases, from a database of tomographic exams. The exams were performed using a General Electric CT HiSpeed LX/I scanner, and they show constant thickness of cut, between 1 and 3 millimetres. From the population studied (132 exams), a sample of 26 exams was selected. From the 26 CT exams selected, there were 17 females and 9 males, with an average age of 9.19 ± 4.76 years and average live weight of 3.88 ± 1.01 kg (Adam CPW plus 150, USA). The study population is mostly domestic short hair cats.

As inclusion criteria, we selected all exams of cats that showed the entire abdominal cavity regarding the presence of all anatomical limits. The exams were also assessed regarding the non-existence of anatomical changes or abdominal disease.

Manual Segmentation

Each exam was worked in digital imaging and communications in media (DICOM) format, using a software database of medical imaging, Osirix® (Pixmeo Sarl, Swiss), which allows the visualization of CT. This type of software allows the user to view simultaneous images in three distinct anatomical plans (axial, sagittal and coronal), making it easier to view and delimit anatomical structures (Figure 1). Using the delimitation tool, Closed Polygon, the user may define, in each axial cut, the anatomic structure of interest. With this tool it is also possible to determine the abdominal perimeter around the fourth lumbar vertebra [31]. The purpose of manual segmentation is to define the ROI, needing to be carried out in all the cuts as to decrease the error (Figure 2). The next step is to erasing all information outside the ROI; all data outside the limits must be considered background noise. The function Set Pixel Values it will work as segmentation tool. In this function, we change the values of Outside ROI to -1500 and the values Inside ROI to 300. The latter value is a crucial detail, since the volume of the abdomen created should be a compacted solid (Figure 3). No amendments to these components will result in a 3D model with organs presented in its interior, making it difficult to model the anatomical structure of interest in CAD software. The final model of the abdominal cavity is completed with the function 3D Surface rendering (Figure 3), which allows to export the data of the structure created, in a stereolithography file extension (.stl), enabling the modelling on CAD software (Figure 4) [32].

3D Modelling

The 3D modelling of the abdominal cavity was performed using the SolidWorks software (Dassault Systemes, US). This type of program is easy to work with and allows determining the volume and the surface area in just a few steps. The file, which was exported from Osirix using the extension .stl, has now been imported/opened as a Mesh File (Figure 5). Using the Mesh Prep Wizard function, the mesh is prepared and errors eliminated to create a solid model. The mesh is then prepared for the creation of the 3D model, using the Solid/Surface Creation function, the automatic utility is advised. The final model is prepared and allows obtaining the morphometric values of the model through the Mass Properties tool (Figure 6).

Calculating morphometric parameters

The calculation of morphometric parameters, and mathematical determination of the correlation between these and the ACSA, was performed with the program Matlab (Mathaworks, USA) [33]. The determination of the body surface area (BSA) was calculated using the formula: BSA (m^2)=K x body weight (grams) 2/3 × 10^{-4}, with the constant (K) for cats being 10.0 [34,35].

We hence used the weight, abdominal perimeter and body surface area to try to establish, through interpolation and curve fitting, a formula that would determine the ACSA. Through the processes of linear interpolation, by using the method of least squares and applying the polyfit function, it is possible to approximate the set of points by a polynomial of any kind [33]. Finally, ACSA values gathered by various polynomial functions, obtained through morphometric parameters, were compared with the measured ACSA values obtained by CT.

Statistical analysis was performed on all the data. After checking the normal distribution of data, it was subject to an analysis of variance (ANOVA, general linear model) through IBM, SPSS software (Statistical Package for the Social Sciences, 2010), to ascertain whether there were statistically significant differences between them. The values are shown as mean ± standard deviation and, on the statistical tests of mean comparisons, the differences are considered statistically significant when P<0.05. The Pearson's correlation coefficient was used to verify the strength of the association of variables.

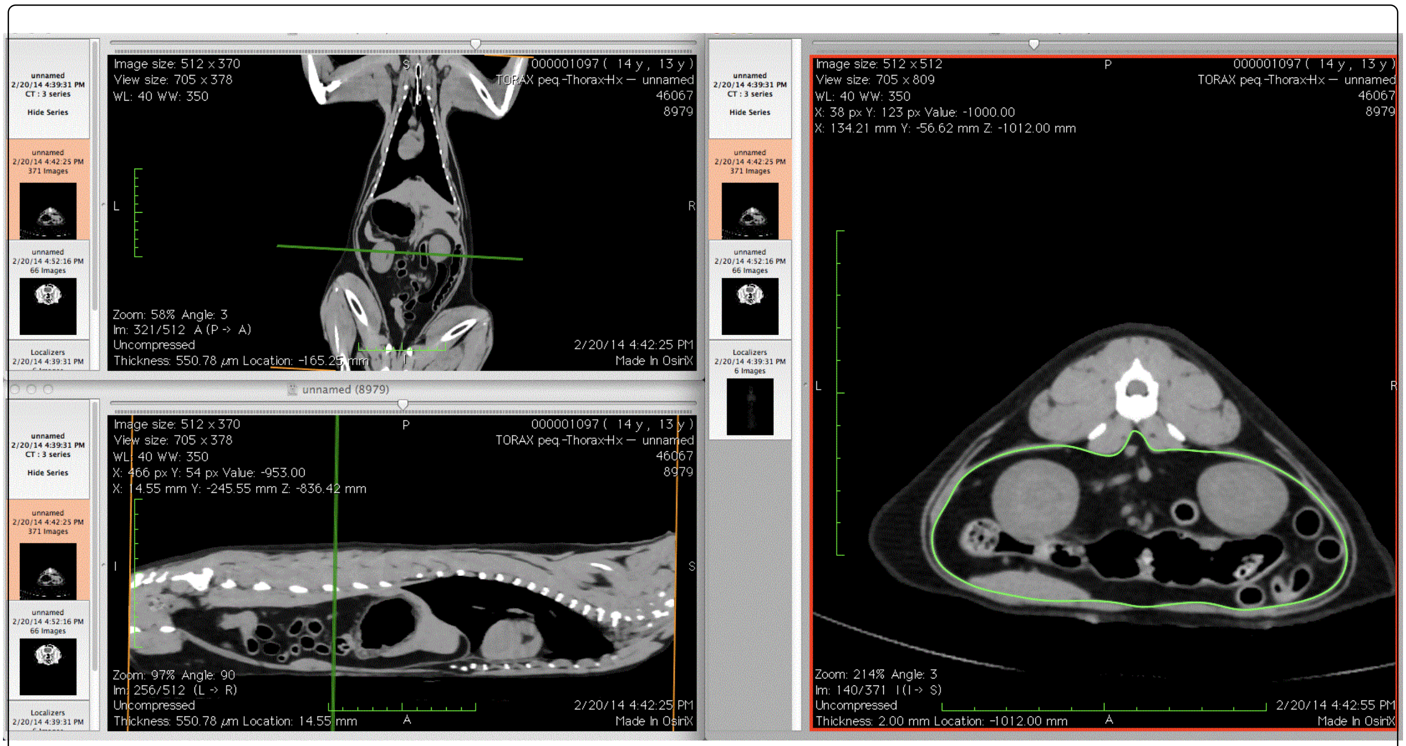

Figure 1: Simultaneous images of the abdominal cavity of a cat, in the three distinct anatomical plans (axial, sagittal and coronal), allowing a better visualization of the structure to limit.

Results

All values of cat subject characteristics measured, such as weight, abdominal perimeter and body surface area are presented in Table 1.

The 3D models created for the abdominal cavity made allowed determining the average volume of the abdominal cavity of cats, 6.59 × 10-4 ± 2.22 x 10-4 m3, with the minimum limit being 3.75 × 10^{-4} m^3 and the maximum 1.39 × 10^{-3} m^3. These models also allowed calculating the ACSA, the average value being 5.11x10-2 ± 9.86 × 10^{-3} m^2, with minimum limit of 3.64 × 10^{-2} m^2 and maximum of 7.91 × 10^{-2} m^2 (Table 2).

Parameter	Lower Limits	Upper limits	Mean	Standard Deviation
Body weight (Kg)	2.30	7.30	3.88	1.01
Abdominal Perimeter (m)	2.70 x 10^{-1}	5.30 x 10^{-1}	3.53 x 10^{-1}	6.29 x 10^{-2}
Body surface area (m^2)	1.7 x 10^{-1}	3.8 x 10^{-1}	2.45 x 10^{-1}	4.12 x 10^{-2}

Table 1: Values of morphometric determinations: body weigth, abdominal perimeter, body surface area.

Parameter	Lower Limits	Upper limits	Mean	Standard Deviation
Abdominal cavity surface area, ACSA (m^2)	3.64 × 10^{-2}	7.91 × 10^{-2}	5.11 × 10^{-2}	9.86 × 10^{-3}
Abdominal cavity volume (m^3)	3.75 × 10^{-4}	1,39 × 10^{-3}	6.59 × 10^{-4}	2.22 × 10^{-4}

Table 2: Values determined from the abdominal cavity, ACSA and abdominal cavity volume.

Mathematic correlation

Using the processes of linear interpolation, we created mathematical functions that correlated weight, abdominal perimeter or BSA with the ACSA, as to determine it without performing imaging exams. Using the entire data group, various formulas for correlations with the ACSA were created, however all of them presented statistically significant differences (P<0.05) when compared with the determinations made by CT.

From all formulas created, the one allowing the calculation of ACSA with best result was based on live weight, excluding 6 individuals by presenting values outside of the normal distribution. The formula obtained was ACSA=0.0093 Live Weight (Kg)+0.0141, with value shown in m^2. This formula does not have statistically significant differences (P=0.981), when compared with actual areas determined by CT (Figure 7). The calculation of Pearson's correlation coefficient was also completed, as to determine the force between the high associations of variables; the coefficient found was 0.914.

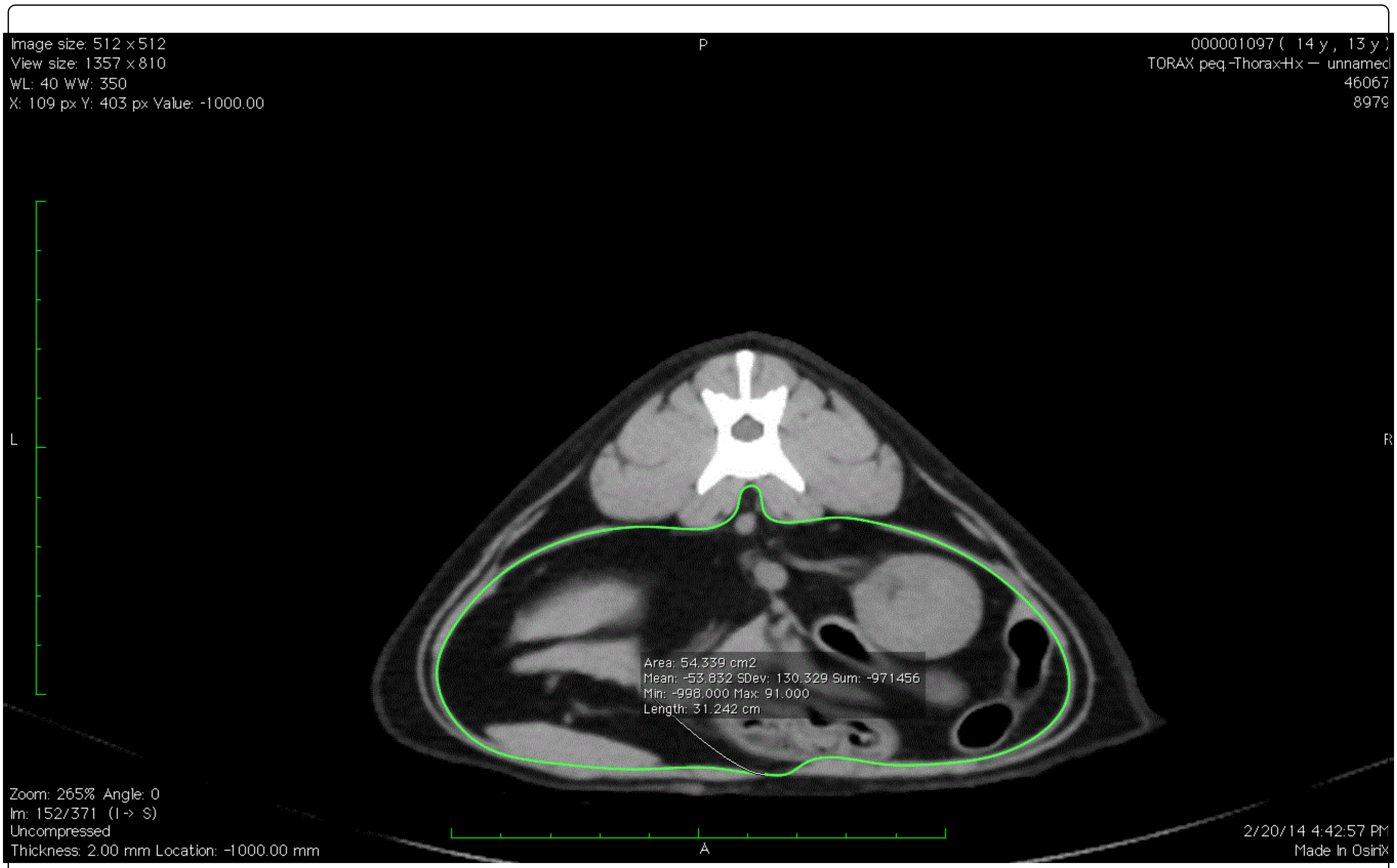

Figure 2: Segmentation of the ROI in each axial cut.

Discussion

The pathological increase of IAP is a phenomenon now well documented, directly associated with serious pathophysiological changes. When found, these changes lead to increased morbidity and mortality of patients, causing the compartmentalization syndrome [36,37]. Following the literature review carried out, no prior determination of ACSA was found. Besides the contribution of providing non-existent basic anatomic information, this determination is also particularly important because the IAP is the result of forces exerted in this area [15].

The physical determination of organic cavities dimensions sometimes is a challenge [3].

The technological developments in the last two decade allowed the application of CT in this problem. Using techniques of organ segmentation, or in this case of the abdominal cavity, allow the determination of the volume and surface area of the abdominal cavity. This method have the disadvantage of being very time-consuming, since it is necessary to carry out in each axial cut the boundary of the ROI in order to decrease the error. Today's medical software have tools which allow to avoid the delimitation in each cut, automatically completing the ROI, although associated with an increase of the error [38,39]. In addition to the fact that the division being time-consuming, shaping the .stl file of the ROI in CAD software also presents some difficulties. One of the problems is the fact that these systems require a large storage space, making the modelling difficult when the files are large [23]. Nevertheless, these techniques allow a great step forward since it is very difficult to measure internal cavities with exact methods [4,17-19]. The described technique of 3D modelling of anatomical structures are associated with some error, when compared with the actual structures; the literature describes errors between 2.9 % and 4.95 %, an error considered quite low [23,24,27].

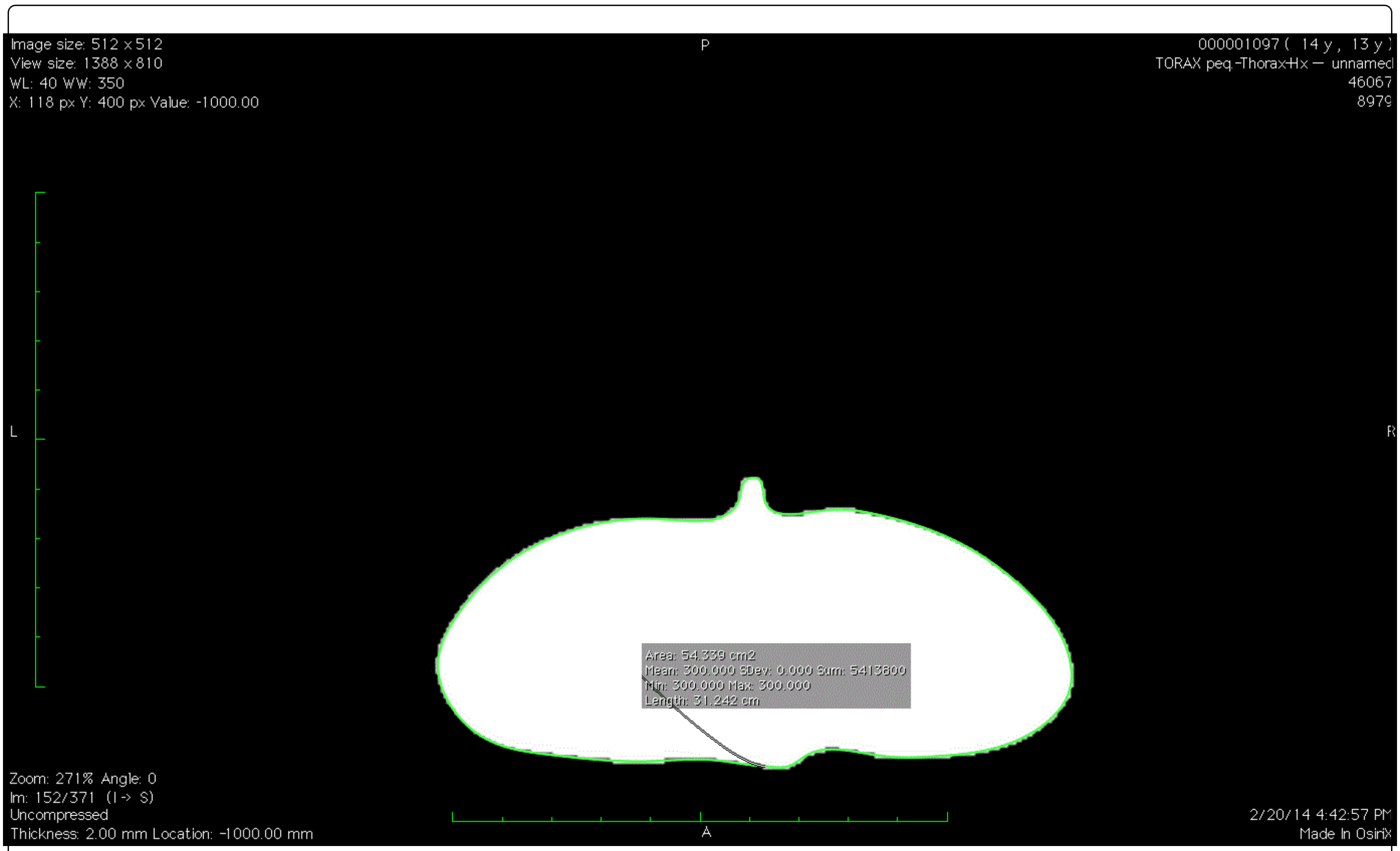

Figure 3: Image of axial cut of the ROI, after changes to pixel values.

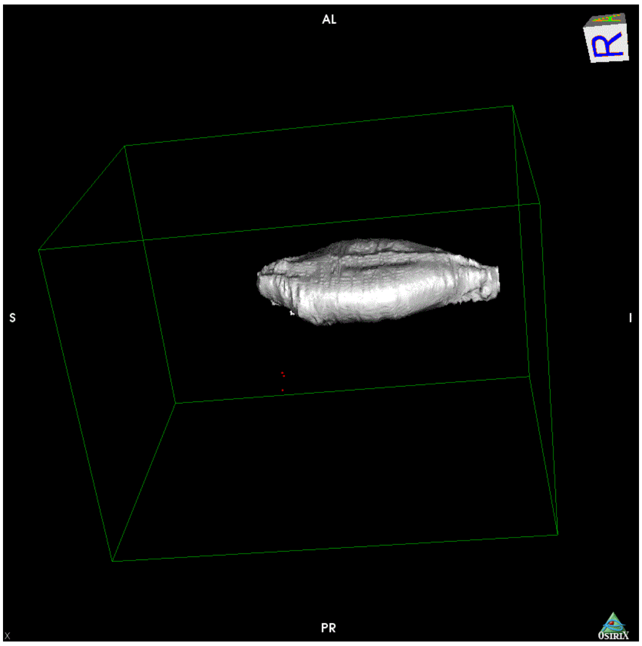

Figure 4: Abdominal model in 3D Surface rendering function in Osirix.

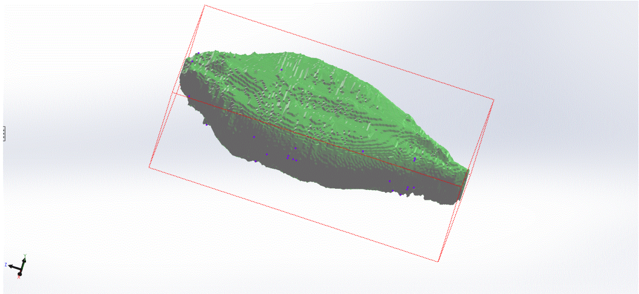

Figure 5: Abdominal model imported into Solid Works in .stl extension.

The 3D anatomical model of the abdominal cavity of cats is in accordance with what is described in the anatomic literature: a structure without major changes in terms of shape between individuals, and without major changes in terms of volume and area [1,2]. The result obtained for the area and volume of the abdominal cavity, respectively $5.11 \times 10^{-2} \pm 9.86 \times 10^{-3}$ m^2 and 6.59×10-4 $\pm 2.22 \times 10^{-4}$ m^3 allow checking this fact with no major surface changes between individuals. We believe that this is directly related to the anatomical structure of cats. Cats do not have a sharp anatomical dimorphism between breeds maintaining a relatively constant weight [40]. In dogs this dimorphism between breeds is more pronounced

[41]. The comparison between the weight of cats, BSA and the ACSA determination showed that they are directly proportional. Is seems logical if body density is maintained substantially constant the weight gain leads to an increase of volume and surface area. This fact occurs because density is equal to the quotient between the weight and volume [15,16]. One of the factors that we think can influence ACSA is obesity because leads to fat accumulation in the abdominal cavity. Should be realized futures studies determining the body fat index and the body mass index to evaluate the influence of fat in ACSA.

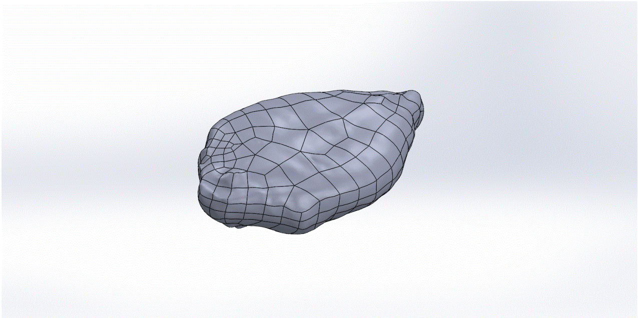

Figure 6: Final abdominal model in Solid Works, allowing obtaining mass values.

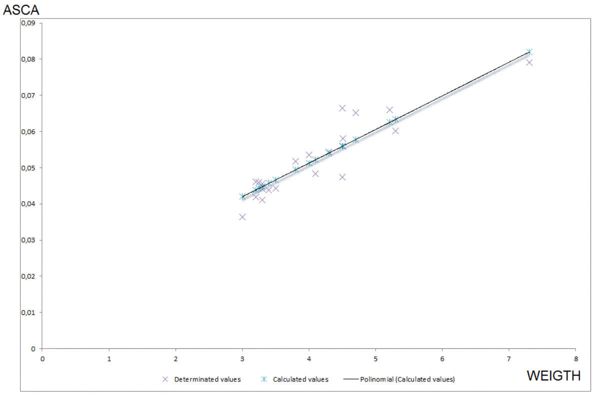

Figure 7: Graphical dispersion of points of mathematical formulation, ACSA=0.0093 Live Weight (Kg)+0.0141 with statistical significance (P=0.981).

The techniques for identification of systems also enable optimizing mathematical solutions and thus allowing determining a solution for calculating the ACSA based on morphometric parameters. Through these systems we create some solutions that allow the calculation of ACSA from weight, abdominal perimeter or BSA in order to facilitate its determination. In the various formulas created, from data of the whole sample of population, it was not possible to create a formula that would determine the ACSA with statistical significance. In this first approximation they all showed differences when compared with the real determinations of CT ($P<0.05$). We believe this may be due to errors in modelling the structures, associated with the technique, or errors on the medical register of weight of the animals that affects directly the solutions created. Using the same techniques of mathematical formulation, but eliminating the data of 6 cats outside the normal distribution, we were able to formulate an equation that already predicts the ACSA based on live weight. The data in the formula ACSA=0.0093 Live Weight (Kg)+0.0141, when compared with the determinations made by CT, no longer present statistically significant differences (P=0.981) and show a high correlation index (cc 0.914). The graphical representation of the dispersion of points calculated can be seen in Figure 7. We believe this may be due to the size of the sample, decreasing the error if the sampling was wider. This type of technique has been increasingly used, enabling the creation of algorithms for various anatomical structures [42].

The type of methodology used, segmentation and 3D modelling of the abdominal cavity in a feline model, has been successfully used to determine non-existent anatomical information of the abdominal cavity, surface area and volume. The mathematical correlation found to calculate the ACSA may contribute to estimate the parameter without needing to resort to imaging methods. The determination of ACSA may assist in determining and understanding the IAP, since the pressure is the quotient between the forces applied per unit area.

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Competing interests

The author(s) declare(s) that there is no conflict of interest.

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