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DETERMINATION OF RELATIVE LENGTHS OF BONE SEGMENTS OF THE DOMESTIC CAT'S LIMBS BASED ON THE DIGITAL IMAGE ANALYSIS

Abstract

This paper is an introduction to the issues related to obtaining information on the metric dimensions of selected bone segments of a domestic cat based on the analysis of digital images. The main objective is to acquire this data using only image processing methods. Particular emphasis was placed on obtaining data on the proportions between specific bones within the limbs. This data will be used in the process of creating a project of a four-legged walking robot whose structure will be inspired by solutions characteristic of the analyzed species.

1. INTRODUCTION

Obtaining information on the dimensions of individual bones, e. g. those belonging to the limbs of a specific animal species is a very time-consuming process. In most cases, access to appropriate X-rays or prepared bones is required. This issue becomes even more complex for species whose skeletons are less frequently analyzed, as exemplified by cats. In the case of the felids (Felis catus) family, it is extremely difficult to obtain accurate information on the dimensions of individual bone segments. The bone examination is usually associated with key segments such as femur or tibia, and it is difficult to find data for other segments (Schmidt, 2005; Udrescu & Van Neer, 2004). There is also a lack of data concerning the proportions, e. g. between individual limb bones. The majority of researchers who

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analyze the anatomy of cats focus their analysis on the measurement of angles obtained in the joints, both mechanical and anatomic, and on the extraction of natural tilt angles of selected bone segments (Brown, Bertocci & Cheffer, 2018; Day & Jayne, 2007; Fonseca, Lobo-Jr & Santana, 2017; Pike & Alexander 2002).

Measurements relating to the determination of the ratio between individual bones within a cat's limbs are often omitted. Although they may provide a lot of useful information, among others on the subject of changes in the anatomical structure of the species. This may be caused by a limited number of available research materials. In the case of domestic cats, the appropriately reconstructed skeletons are extremely rare. On the other hand, their X-rays are most often taken for the purpose of bone tissue traumatology. This causes that they only cover the area of an injury. In most cases, it is a single bone or joint (Coulson & Lewis, 2002; Zwierucho & Strokowska, 2018).

There are small databases that can provide information about the metric dimensions of individual bones, but there is no information about their interrelationships within the entire skeleton. There are few papers on this subject matter. However, they highlight the problem related to the large variation in metric dimensions in the group of domestic cats. An example can be the work (O'Connor, 2007), in which a part of individuals belonging to this group was characterized by dimensions of limb bones similar to wild animals like wildcats (Felis silvestris), which are characterized by significant elongation.

The use of image processing and analysis methods in order to obtain approximate dimensions of individual bone segments for a specific species allows using materials from generally available databases in research. In this case, the dimensions can be determined on the basis of a variety of video materials or digital photos. This allows obtaining approximate data on the anatomical structure of animals, without the need for direct physical contact with the animal or its skeleton. The use of image processing in the discussed process has a significant influence on the acceleration of its course.

2. MATERIALS AND METHODS

The aim of the study was to determine the total length of limbs and the anatomical, relative mean lengths of selected bone segments of a domestic cat based on the analysis of digital images. The first database of analyzed images contained 20 digital photos representing skeletons of a selected species. Most of them were photographs of real skeletons which are exhibits in a museum or scientific centers (Fig. 1) and illustrations from anatomical atlases (Fig. 2).

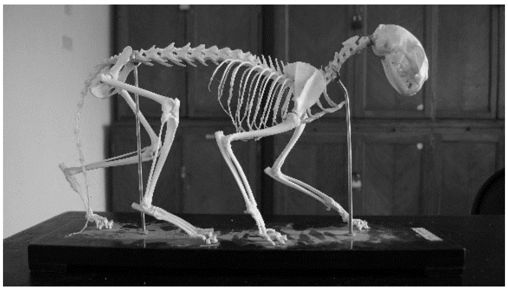

Fig. 1. Cat (Felis catus) skeleton from the collection of Moscow State University Department of Biology [source: https://meta.wikimedia.org]

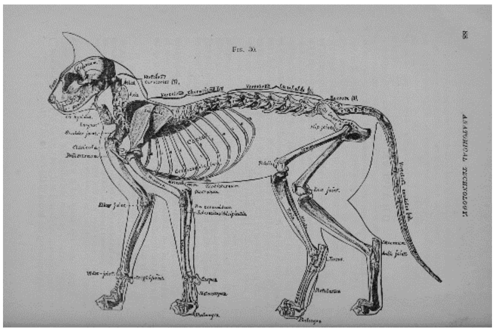

Fig. 2. Felis catus – image from the book [source: https://meta.wikimedia.org]

Each of the images under analysis was published under licenses enabling their use during the research, including CC0 type licenses – the so-called public domain transfer. The second base consisted of 20 frames isolated from various video materials containing the registered cat's gait in the sagittal plane (Fig. 3).

During the research, approximate dimensions of selected bone segments were obtained for each of the tested individuals. The following bones were analyzed: humerus, ulna/radius, metacarpals, femur, tibia/fibula, metatarsal, carpals, and phalanges (Fig.4). The total limb lengths have been calculated as the sum of the length of the respective segments, separately for the fore and hind limbs. Relative distances were calculated by dividing the specified anatomical length by the total length of the relevant limb and expressed as a percentage. During the tests, anatomically characteristic distances were also determined, for example, a two-dimensional distance between the shoulder and the hip joint

The anatomical lengths of individual bones were determined on the basis of the two-dimensional analysis of appropriately selected digital images. The measurements were carried out using Kinovea software. It is a free, powerful tool for analyzing digital images and video materials using a wide variety of measurement functions. It is mainly used for sports analyses, but due to its characteristics, it could also be used to carry out the aforementioned anatomical measurements.

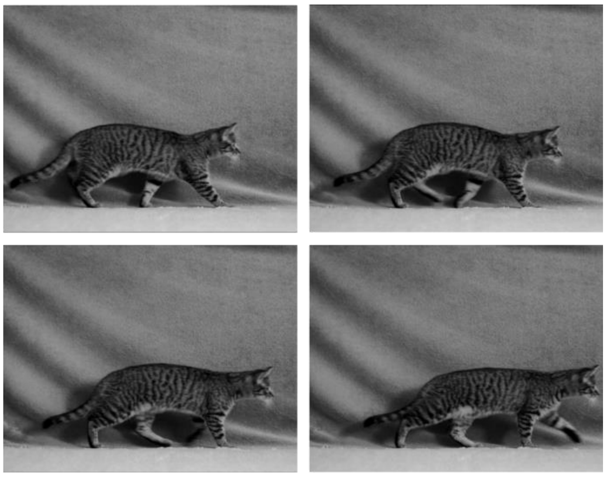

Fig. 3. Selected frames of the video sequence illustrating the cat's walk recorded in the sagittal plane

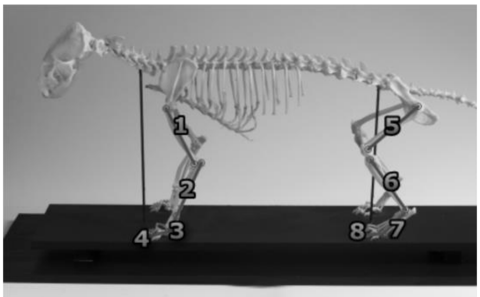

Fig. 4. Specimen of eyra cat skeleton on display at the Museum of Veterinary Anatomy, FMVZ USP (1 – humerus, 2 – ulna, 3 – metacarpals, 4 – carpals, 5 – femur, 6 – tibia, 7 – metatarsal, 8 – phalanges)

3. DESCRIPTION OF THE RESEARCH PROCESS

The research was carried out separately for two specially prepared test bases. As the first, the images containing representations of the skeleton of a domestic cat were analyzed. The second group that was analyzed were images containing representations of real individuals.

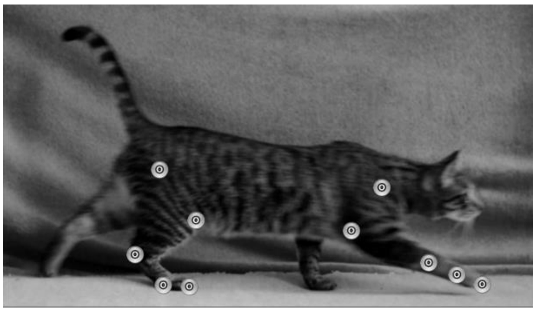

Fig. 5. Frame with marked characteristic key points

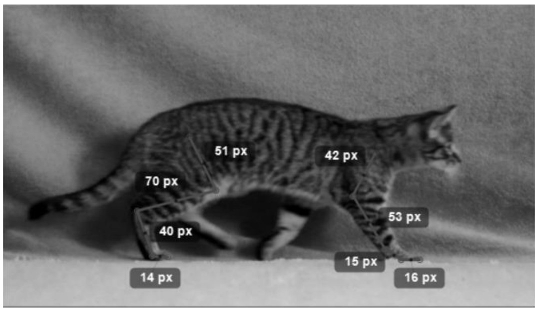

Fig. 6. Frame with absolute lengths of segments expressed in pixels

The analysis of each database consisted of several stages. Initially, for each individual, and more precisely for his representation in the form of a digital image, characteristic key points were marked. They symbolize selected anatomical points such as joints or bony process (Fig. 5). Then the absolute lengths of individual segments expressed in pixels were determined (Fig. 6). The next step was to determine the total length of the limbs, divided into hind and fore. These data were then used as reference values in calculating the relative lengths of the analyzed bones and selected anatomical distances. These data were then used as reference values in calculating the relative lengths of the analyzed bones and selected anatomical distances. In order to obtain the most reliable results, each of the analyzed images was measured five times and the output results were based on the arithmetic mean.

The final stage of the study was to determine the mean relative lengths of each bone segments of the limbs for each of the bases separately. The sample means were determined on the basis of the formula:

$$\mu_x = \frac{\sum_{i=1}^{n} x_i}{n}, \tag{1}$$

where: μ_x – mean,
x_i – observed values,
n – number of sample.

For each determined length, the value of the standard deviation and the standard mean error (s. e. m.) were calculated:

$$s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \mu_x)^2}{n-1}}, \tag{2}$$

where: s – standard deviation,
x_i – observed values,
n – number of sample,
μ_x – sample mean.

$$SE_{\mu_x} = \frac{s}{\sqrt{n}}, \tag{3}$$

where: $SE_{\mu x}$ – standard error of the mean,
s – standard deviation,
n – number of samples.

4. RESULTS

The data obtained during the tests allowed to determine approximate lengths of specific bone segments in relation to the total length of the limbs. The results are presented in the tables below. The first (Tab. 1) contains the results obtained for a group of images containing skeleton representations. The second one contains the results obtained for a group of images containing representations of real individuals. The proportions are in accordance with the available literature data of the domestic cat's anatomy. Which allows that these results may be considered as a characteristic reference point for the analysis of the anatomical structure of the species concerned. The species characteristics obtained in the study, e. g. that the tibia is usually slightly longer than the femur, were confirmed in the analysis of research carried out in a given subject area. The same conclusions appear in the works of researchers analyzing animal skeletons directly (Fonseca et al., 2017; Petrov, 1992) and in the works related to the analysis of materials containing their recorded gait (Day & Jayne, 2007). In both cases, the differences in relative bone lengths obtained did not exceed 5%, while in terms of determining the proportion between individual bones, compliance at level 86. 33% was obtained. In only one case, discrepancies were found in the analyses. It was a relation between humerus and ulna bones.

Tab. 1. Proportional lengths of individual limb segments – results obtained for a group of images containing skeleton representations (values are means ± s. e. m.)

Hind-limb Segment	**Relative Length (% Hind-limb Length)**
Femur	32,90 ± 0,41
Tibia	36,43 ± 0,43
Metatarsals	20,09 ± 0,52
Phalanges	10,59 ± 0,42
Fore-limb Segment	**Relative Length (% Fore-limb Length)**
Humerus	35,75 ± 0,41
Ulna	40,84 ± 0,71
Metacarpals	12,66 ± 0,40
Carpals	10,75 ± 0,40

Tab. 2. Proportional lengths of individual limb segments – results obtained for a group of images containing representations of real individuals (values are means ± s. e. m.)

Hind-limb Segment	**Relative Length (% Hind-limb Length)**
Femur	30,03 ± 0,55
Tibia	36,03 ± 0,65
Metatarsals	22,68 ± 1,03
Phalanges	11,27 ± 0,44
Fore-limb Segment	**Relative Length (% Fore-limb Length)**
Humerus	34,46 ± 0,73
Ulna	42,10 ± 0,70
Metacarpals	11,59 ± 0,51
Carpals	11,85 ± 0,59

The proportions between individual limb bones determined during the analysis of digital images are consistent with the characteristics of the examined species. In all cases, the total length of the hind-limb was longer than that of the fore-limb. The tibia was usually slightly longer than the femur. The same applies to the ulna and humerus bones.

When comparing the results for both test bases, it can be seen that they are quite consistent. Differences generally do not exceed three percentage points. Although the measurements carried out for images containing pictures of living individuals were burdened with difficulties related to the necessity of partial prediction of the position of key joints. The highest correlation between the measurements for two bases was obtained in the case of tibia and humerus bone. However, the lowest correlation of measurements was obtained in the case of the femur bone.

3. CONCLUSIONS

The results obtained as part of the research were fully obtained using non-invasive measurement techniques. Determined relative lengths of individual limb bones of the analyzed species mostly coincide with the available literature data. The differences appearing in the results are mostly derived from the high intra-species diversity in cats

In order to obtain higher accuracy of results, it would be necessary to conduct the research process separately for many subgroups of individuals, with the division of gender or origin. However, it should be taken into account that even the work of researchers dealing with the subject of one subgroup of felids, characterized by a significant similarity (e.g. wildcats) show high variability of the obtained results even in the case of direct measurements (Day & Jayne, 2007; Petrov, 1992). This means that most bone length measurements in a particular species group usually give results in the form of averaged, approximate values.

The results of the study show that it is possible to measure the approximate lengths of selected bone segments in animals using procedures exclusively related to image processing and analysis. The proposed method is one of the non-invasive measurement techniques. It allows obtaining a large amount of data on species characteristics without the necessity of direct contact with the analyzed individual. This information can be extracted from the materials that are available in public databases.

The proposed methodology of collecting data on the relative length of limbs of a given species broadens the possibilities related to the analysis of skeletal anatomy. It constitutes a significant contribution to this research area, due to a very limited number of observations and related works (Day & Jayne, 2007; Fonseca et al., 2017; Petrov, 1992). The approach presented in the paper can be used in particular for the design of robots designed on the anatomical structure of specific animals. This is a promising solution because the metric features are already successfully used in the construction of humanoid robots.

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