



Article

Body Shape Analysis in Reticulated Giraffe, Okapi, and Black Rhinoceros Using Three-Dimensional Laser Measurements

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Abstract: Health management in captive animals is difficult for various unknown reasons presumably related to physiological functions, disease, and diet. Generally, abnormal conditions are diagnosed based on body weight; however, zoos lack appropriate scales for megafauna. Body shape evaluation is often used to evaluate the nutritional status of breeding animals; however, this is inaccurate for zoo animals because of inter-observer variability, especially in megafauna. Previously, three-dimensional laser measurements were used to analyse body shape of reticulated giraffe, but further studies are required to examine its effectiveness in more individuals, and other species. Here, we applied this method to seven reticulated giraffe (*Giraffa reticulata*), five okapi (*Okapia johnstoni*), and three black rhinoceros (*Diceros bicornis*) individuals for which cross-sectional area, width, and height in transverse section were determined. Relative change rates of each variable in relation to measurements at the axillary region revealed changes in body shape for each individual. Further, scatter plots and corresponding fitted curves and correlation coefficients showed a correlation between body length and approximate volume. The accuracy of three-dimensional laser measurements was demonstrated in three animal species, whereby we propose its use as an alternative method to evaluate body shape in megafauna without the inter-observer variability. In addition, this handheld device may be applied for various zoos without the scale for megafauna.

Keywords: F6 SMART; handheld device; inter-observer variability; subcutaneous fat; volume



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1. Introduction

Various wildlife species are kept in zoos worldwide. Although captive zoo animals are usually kept in healthy conditions, their health management is difficult owing to reasons as diverse as physiological function, disease, and diet. Generally, an abnormal physical condition is expressed by obesity or emaciation under the condition of captive wildlife. Obesity increases the risk of dystocia, reproductive disorders, arthritis, diabetes, and other chronic conditions, and emaciation to reduced reproductive success, poor recovery from illness, and signs of disease or age [1–6]. Various methods have been developed to obtain the animal's physical condition by invasive or non-invasive methods, and non-invasive ones may be helpful for the live animal. Body weight evaluation is usually a basic healthcare factor. However, many zoos in Japan lack adequate scales especially for megafauna, making it difficult to measure animal body weight. Body condition score (BCS) has been widely adapted [7]. BCS may be evaluated by palpable and visual factors in domestic animal, but it is restricted to visual factors in most wildlife species [8]. In birds and some mammals, the dense hair coat prevents any visual evaluation of BCS, while animals with short or no hair are obviously well suited for an assessment based on visual factors [7]. Therefore, various species-specific protocols have been shown to be useful [9]. Body condition scoring

systems are established for farm animals at first [10,11], then species-specific visual scoring systems have already been developed in zoo animals [7,9,12,13]. To warrant a visual scoring system as a tool, various factors have been developed for wild and zoo animal species [14–21]. To ensure reliable and consistent results, BCS with a validation process have been expected [22–25]. In spite of these effort, BCS can be influenced by various factors such as intestinal tract filling and hydration status [14] and the reproductive stage in females [16,26,27]. In addition, inter-observer variability might be a concern due to this subjective method of this BCS. Because of concerns about inter-observer variability, the reliability of BCS has been ensured by correlating it with a variety of other assessment methods [7]. Thereby, it has been demonstrated that BCS is a simple and inexpensive way to evaluate the animal condition and useful for daily health management. However, due to the subjective method of BCS, it is difficult to eliminate the variation in evaluation among observers [7]. In zoos, where various people are involved in animal care, it is desirable to establish a technique that is simpler and enables people with not enough experience in BCS evaluation to evaluate animal body shape.

Image analysis techniques have improved remarkably over the past few years. Thus, recently, three-dimensional measurement has been applied in various fields, such as industrial installation, city landscape, digital elevation, and archaeology [28,29]. Moreover, this methodology, mainly photogrammetry that is derived from various wavelengths of electromagnetic radiation and constructed by digital image processing, has been applied in medicine, especially in orthopaedics, ophthalmology, dermatology, forensic analysis, and dentistry [30], and in wildlife, in multi-object tracking and size measurement [31–33]. Three-dimensional laser measurement uses laser lights to capture the shape, size, geometries, and textures of physical objects. In dairy cattle, several studies have evaluated BCS using three-dimensional laser measurement analysis [34–38]. Previously, we examined three giraffe somatotypes using three-dimensional laser measurements and showed the effectiveness of the method for this species in zoos [39]. However, further studies are required to evaluate the effectiveness of this method in more individuals and in other species and the volume of animal body. In the present study, seven reticulated giraffe (*Giraffa camelopardalis reticulata*), five okapi (*Okapia johnstoni*), and three black rhinoceros (*Diceros bicornis*) individuals kept in three zoos in Yokohama, Kanagawa Prefecture in Japan, were examined via three-dimensional laser measurements.

2. Materials and Methods

2.1. Animals

The present study involved seven reticulated giraffe, five okapi, and three black rhinoceros individuals (Table 1).

2.2. Instrument

Three-dimensional images were obtained for all individuals using a handheld F6 SMART three-dimensional laser measurement device (Mantis Vision Ltd., Petach Tikva, Israel). The measurement accuracy error is within 0.5 mm when taken from the distance of 0.3 m away [40]. The device was connected to a laptop computer via USB. Images were simultaneously obtained from the left and right sides of the animals by using two measuring devices placed approximately 2 m away from the animal. The measurement was performed without moving from the position where the person measuring the animal was standing, and the hand holding the device was moved left and right to trace the animal's body. The three-dimensional coordinate was obtained by the phase difference between irradiated and reflected laser wave. It took around 1 min to obtain each three-dimensional image. Data obtained were analysed using the Galaxy-Eye software version 3.4 package (Fuji Technical Research Inc., Yokohama, Japan), which converted the set of three-dimensional laser measurements into a computer-aided model.

Table 1. Seven reticulated giraffe, five okapi and three Black rhinoceros were examined in the present study.

Animal	No.	Sex	Age	Place	Note
Reticulated giraffe	1	female	14 years	Kanazawa	Pregnant 6 months before
	2	female	13 years	Kanazawa	
	3	male	3 years	Kanazawa	
	4	male	6 years	Nogeyama	
	5	female	4 years	Nogeyama	
	6	female	6 years	Yokohama	
	7	female	5 years	Yokohama	
Okapi	1	male	22 years	Kanazawa	
	2	male	17 years	Yokohama	
	3	female	18 years	Yokohama	
	4	female	15 years	Yokohama	
	5	female	4 years	Yokohama	
Black rhinoceros	1	male	30 years	Kanazawa	
	2	female	30 years	Kanazawa	
	3	female	6 years	Yokohama	

Kanazawa: Kanazawa Zoological Gardens; Nogeyama: Nogeyama Zoological Gardens; Yokohama: Yokohama Zoological Gardens.

2.3. Measurement

During the measurement by the device, the animals were able to control their body movements by feeding without any special training and sedation. Whole-body and transverse-section body images were obtained once. In transverse sections, cross-sectional area, width, and height were measured at 5 cm intervals over the distance between the axillary and inguinal regions, according to a previously [39] described method (Figure 1). In areas where data were missing (especially the abdominal region, as shown in Figure 1c,f), the data were estimated based on the datasets obtained for the other individuals of the same species. To evaluate the body shape of the animal, each set of values (cross-sectional area, and body width and height) measured at each 5 cm interval was divided by the values of the axillary region. These values were then multiplied by 100 to obtain a change rate relative to the values of the axillary region, which are shown for every 5 cm of body length. The body length was measured from the protrusion of the proximal end of the humerus to the buttock of the animal (Figure 1, black line on the body). The accuracy of three-dimensional laser measurement was evaluated by our previous study, comparing between the direct measurement and the value by the three-dimensional measurement of the body circumference [39].

The approximate volume of each animal was calculated by integrating the cross-sectional area measured at 5 cm intervals. The interval between each cross-sectional area was hypothesized to change linearly. A scatter plot was obtained for body length and approximate volume, and a fitted curve and the corresponding Pearson correlation coefficient were calculated in Microsoft Excel Office 2021 (Microsoft Corporation, Redmond, WA, USA). Scatter plots, the corresponding fitted curve and correlation coefficient might show the appropriate correlation between the body volume and length.

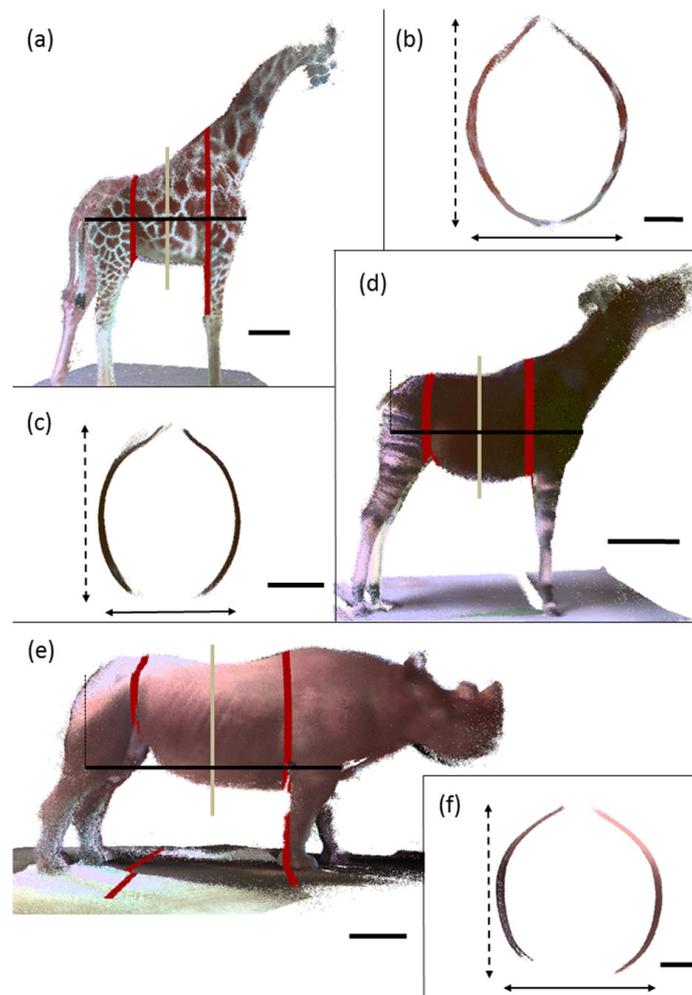


Figure 1. Three-dimensional dot plots for reticulated giraffe (No. 1 (a,b)), okapi (No. 1 (c,d)), and black rhinoceros (No. 1 (e,f)). (a,d,e) Whole body: transverse sections obtained at 5 cm intervals from the axillary to the inguinal region (between red lines). Body length was measured from the protrusion of the proximal end of the humerus to the buttock of the animal (black line). Scale bar represents 40 cm. (b,c,f) Transverse section at the body centre (grey line (a,d,e)). Body width (black line) and height (black dotted line) were measured. Scale bar represents 20 cm.

3. Results

Three-dimensional dot plots were obtained for the seven reticulated giraffe (Figure 1a,b), five okapi (Figure 1c,d), and three black rhinoceros individuals (Figure 1e,f). The relative changes in the cross-sectional area and body width and height of reticulated giraffe individuals are shown in Figure 2a–c. The values in the axillary region were considered as the 100% standard, and the subsequent values were graphed by comparing them with the values in the axillary region. The cross-sectional area measured at the middle of the body increased by 23.7%, 20.7%, and 18.6% compared with the one at the axillary region in individuals No. 7, 4, and 6, respectively, but not in individuals No. 1, 2, 3, or 5. On the other hand, the cross-sectional area measured at the inguinal region decreased by 36.2%, 24.1%, 15.8%, and 14.3% in individuals No. 5, 3, 1, and 4, respectively, and increased only about 10% in individuals No. 2, 6, and 7. Body width measured at the middle of the body increased by 42.6% (No. 6), 36.2% (No. 1), 33.9% (No. 4), 21.8% (No. 7), 20.0% (No. 3), 18.8% (No. 2), and 11.4% (No. 5), whereas body height at the inguinal region declined by 43.3% (No. 1), 31.6% (No. 5), 31.2% (No. 6), 30.8% (No. 4), 29.9% (No. 3), 27.9% (No. 7), and 25.0% (No. 2).

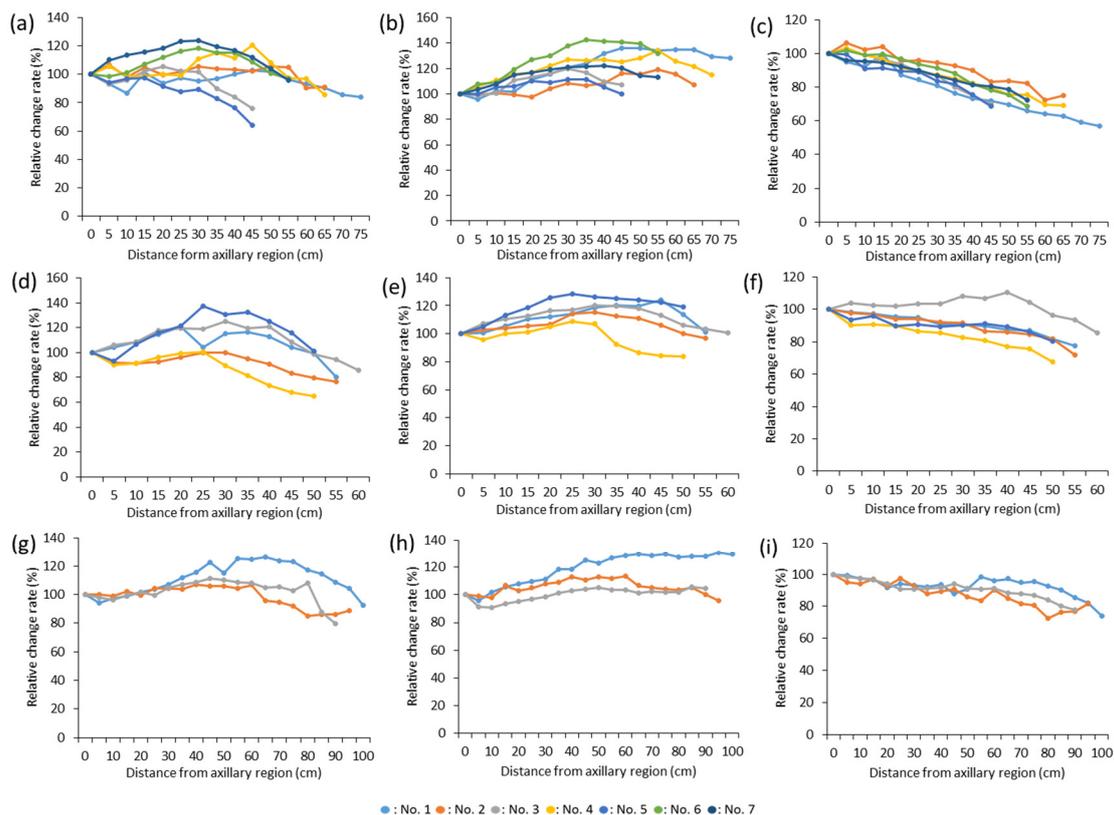


Figure 2. Relative changes (%) with respect to the values at the axillary region of reticulated giraffe, okapi, and black rhinoceros measured at 5 cm intervals from the axillary to the inguinal region in transverse sections. Giraffe: (a) Cross-sectional area; (b) Body width; (c) Body height, Okapi: (d) Cross-sectional area; (e) Body width; (f) Body height and Black rhinoceros: (g) Cross-sectional area; (h) Body width; (i) Body height.

The relative changes in cross-sectional area, body width and height of okapi individuals are shown in Figure 2d–f. The values in the axillary region were considered as the 100% standard, and the subsequent values were graphed by comparing them with the values in the axillary region. The cross-sectional area measured at the middle of the body increased by 37.3%, 25.1%, and 20.7% compared with the value at the axillary region in individuals No. 5, 3, and 1, but not in individuals No. 2 and 4. However, the cross-sectional area measured at the inguinal region decreased by 35.4%, 23.5%, 20.0%, and 14.1% in individuals No. 4, 2, 1, and 3, respectively, and increased by 1.2% in individual No. 5. Body width, measured at the middle of the body, increased by 28.4% (No. 5), 23.8% (No. 1), 20.3% (No. 3), 15.3% (No. 2), and 8.8% (No. 4). Body height at the inguinal region declined by 32.3% (No. 4), 28.1% (No. 2), 22.5% (No. 1), 19.9% (No. 5), and 14.7% (No. 3).

The relative changes in the cross-sectional area, body width, and height of black rhinoceros are shown in Figure 2g–i. The values in the axillary region were considered as the 100% standard, and the subsequent values were graphed by comparing them with the values in the axillary region. The cross-sectional area measured at the middle of the body increased by 26.1% (No. 1), 11.3% (No. 3), and 6.7% (No. 2) compared with the value at the axillary region. The cross-sectional area measured at the inguinal region decreased by 20.5% (No. 3), 11.1% (No. 2), and 7.6% (No. 1). Body width at the inguinal region increased 31.1% (No. 1), 13.7% (No. 2), and 5.0% (No. 3), whereas body height at the inguinal region declined 25.9% (No. 1), 22.4% (No. 3), and 18.4% (No. 2). The body length and approximate volume of each individual are shown in Table 2. The scatter plot, fitted curve, and correlation coefficients between these variables are shown in Figure 3.

Table 2. The body length from the protrusion of the proximal end of the humerus to the buttock and the approximate volume from axillary to inguinal region.

Individual Number	1	2	3	4	5	6	7	Average	S.D.
Reticulated giraffe									
Body length (cm)	176.5	136.4	132.3	164.8	139.4	134.9	156.5	148.7	17.26529
Approximate volume (cm ³)	396,562.2	287,961.2	145,747.4	355,944.6	149,166.2	248,185.5	251,600.9	262,166.9	95001.3
Okapi									
Body length (cm)	121.9	124.6	128.9	121.9	112.2			121.9	6.107367
Approximate volume (cm ³)	125,402.5	130,615.7	141,742.4	136,588.1	116,640.3			130,197.8	9760.724
Black rhinoceros									
Body length (cm)	197.9	195.2	185.1					192.7	6.751363
Approximate volume (cm ³)	604,861.8	621,407.6	470,810.5					565,693.3	82586.31

S.D.: standard deviation.

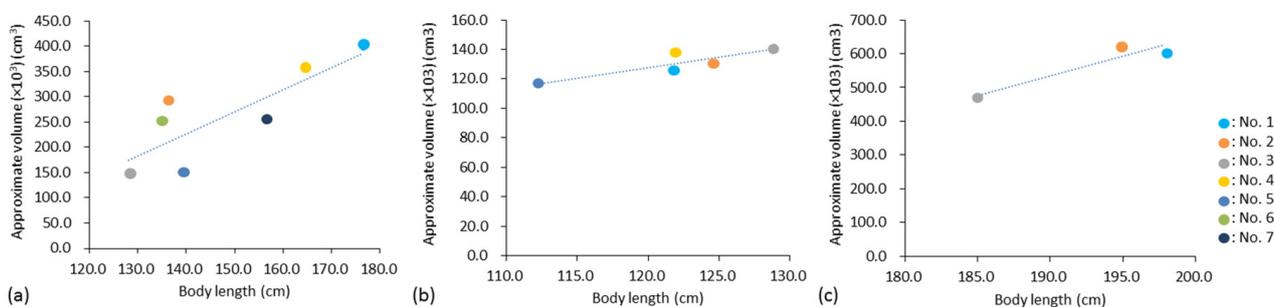


Figure 3. Scatter plot, fitted curve, and correlation coefficient (R^2) between body length and approximate volume. (a) Reticulated giraffe, positive correlation, $R^2 = 0.8128$, $p = 0.026$; (b) Okapi, positive correlation, $R^2 = 0.8933$, $p = 0.018$; (c) Black rhinoceros, positive correlation, $R^2 = 0.9532$, $p = 0.025$.

4. Discussion

The present study revealed that the three-dimensional laser measurement technique facilitated the body shape analysis of reticulated giraffe, okapi, and black rhinoceros individuals and demonstrated that this technique can be applied in a broad range of species. However, the technique presents two disadvantages. First, it cannot be applied in animals that keep actively moving while the measurement is being performed. Although the dataset is obtained within a short time (1–2 min) and the laser instrument can be operated on a moving target, to obtain an accurate dataset, the animal should not move during measurements. Second, as described in our previous study, this technique does not directly evaluate the subcutaneous or visceral adipose tissue; thus, results might only reflect differences in skeletal structure [39]. In addition, in reticulated giraffe and okapi, the rumen volume due to recent feed intake may affect the results. Despite these disadvantages, the technique can be effectively applied to a broad range of species of wildlife and livestock, as well as zoo and field animals.

The present study adopted relative change rates and scatter plots to evaluate body shape and showed that both might become regular evaluation factors. As described in our previous study [39], the dataset obtained by the three-dimensional laser measurement technique varied among individual animals. Therefore, standardized evaluation factors not affected by individual size are required. Relative change rates between the values obtained at the axillary region and at 5 cm intervals from this region could describe changes in the body shape of animals, thus allowing the determination of if the animal is obese or emaciated, regardless of its body size. This is because the relative change rates graph described how the body shape changes relative to the reference point in the axillary region. Moreover, scatter plots between body length and approximate volume, and the corresponding fitted curve and correlation coefficient, enabled the determination of whether the body volume of each individual was small or large in relation to body length.

These methods might also be applied to other species. As we worked with a very small sample in the present study, the number of examined individuals should be increased in future studies to improve the accuracy of the evaluation method.

Relative change rates revealed that the body shape varied among species and individuals. Animals with larger cross-sectional areas, such as reticulated giraffes No. 4, 6, and 7, okapi No. 1, 3, and 5, and black rhinoceros No. 1, tended to present a larger body width compared to the other individuals. Conversely, body height tended to show similar relative change rates. Therefore, changes in cross-sectional area might reflect changes in body width, which is in agreement with our previous observations [39]. This applies similarly, not only to reticulated giraffe, but also to okapi and black rhinoceros.

Scatter plots showed the correlations between body length and volume from the axillary to the inguinal region. Although our sample size was rather limited, animals showing the largest relative cross-sectional areas (reticulated giraffes No. 4, 6, and 7, okapi No. 1, 3, and 5, and black rhinoceros No. 1) did not show the largest volume against body length in scatter plots. Moreover, reticulated giraffe No. 2, which was considered non-obese, based on relative change rates, presented a large volume against body length in the scatter plot. These results might be explained by the following reasons. First, the combination of body length and volume in scatter plots was inadequate; instead, a different combination of factors should be considered in future evaluations. Second, since relative change rates described the body shape by comparing them with the value of the axillary region, there is a possibility that the result will be different from the approximate volume derived from the actual measurement value. Third, the body volume considered here corresponded to total body volume; therefore, it might not reflect obese or emaciated body shapes. Fourth, if the values at the axillary region considered standard values for the calculation of relative change rates were large, the body would be considered approximately cylindrical in shape, as was the case of reticulated giraffe No. 2. On the other hand, reticulated giraffe No. 6, which was pregnant, presented larger relative change rates and body volume than the others, which were approximately of the same size. Therefore, it might be useful to evaluate both relative change rates and body volume. Further studies are required with larger samples in both number and size of animals to clarify these issues and obtain an adequate dataset.

Generally, animal body weight decreases if the animal contracts a disease or is fed an unbalanced diet. Therefore, it is important to examine their body weight frequently. However, in megafauna, body weight measurement is difficult due to the lack of appropriate scales. In addition, it is difficult to evaluate if the measured body weight is within the normal range or not against the individual body size, because size can vary greatly, especially among megafauna. Various reports described not only nutritional but also genetic factors affecting the body size [41–43]. Thus, body shape evaluation is important but difficult due to the associated inter-observer variability. In particular, zoo staff that take care of the animals every day might not readily identify abnormal body shapes due to chronic disease or inappropriate diet, and animal body conditions may gradually decline because humans are not able to identify gradual changes. In particular, when all individuals of the same species kept at an institution are fed the same nutritional unbalanced diet, all individuals present the same body change, and zoo staff will not be able to identify such changes. Several body changes associated with an inappropriate diet have been reported. Several studies on giraffes have described adipose atrophy, wasting syndrome, and sudden death associated with nutritional status [44–47], although the frequency of such conditions has decreased because of improved feeding practices [48]. In okapi, gastrointestinal disorders, chronic interstitial nephritis due to the ingestion of toxic plants, and glycosuria have been reported [49–53]. In black rhinoceros, hyperferræmia was reported [54–56]. In addition, many diseases of unknown aetiology might be related to the inability of replicating feeding habits in the wild while under captivity [57], thus leading to an improper fatty acid balance, lack of antioxidant and polyphenolic components, excess of starch and other glucose supplies, and inadequate fibre intake [58,59].

5. Conclusions

More attention should be paid to nutrition-associated diseases, and zoo staff should identify abnormalities in animal body shape as soon as possible. Moreover, it is important to compare animal body shape between institutions using a standard methodology, such as the three-dimensional laser measurement technique used here.

The present study showed that the dataset obtained by the three-dimensional laser measurement technique facilitated the body shape analysis of reticulated giraffe, okapi, and black rhinoceros individuals. Further studies are required to examine its effectiveness in more individuals, and in other animal species.

6. Ethics

This research adheres to the “Japanese Association of Zoos and Aquariums Ethics and Welfare Guidelines” and “Caring for Wildlife: The World Zoo and Aquarium Animal Welfare Strategy”, and was approved by the Kanazawa Zoological Gardens ethical and welfare assessors, reference number: Kana-1136, 20 March 2018.

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Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Conflicts of Interest: Takanori Munkata declares that the research was conducted in the absence of any commercial or financial relationship from Fuji Technical Research Inc. that could be constructed as a potential conflict of interest.

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