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Body measurement of riding horses with a versatile tablet-type 3D scanning device

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The measurement of various body dimensions of horses plays a significant role in quality improvement, genetic breeding, health, and soundness. There has been significant advancement in the technology for acquiring stereoscopic images with a three-dimensional (3D) scanner. This study aimed to validate the accuracy of body measurements obtained from stereoscopic images taken with a 3D scanner. We manually took the following body measurements for 8 riding horses: height at the withers, height at the back, height at the croup, chest depth, width of the chest, width of the croup, width of the waist, girth circumference, cannon circumference, and body length. Using a versatile tablet-type 3D scanning device, we captured a 3D image of each horse. Relative errors varied from −1.37% to 6.25%. The correlation coefficient between manual and 3D measurements was significant for all body measurements ($P<0.01$) except for width of the waist and cannon circumference. The low accuracy of cannon circumference ($r=0.248$) was due to effect of hair. A simple regression analysis of all body measurements revealed a strong correlation ($P<0.001$, $R^2=0.9994$, root-mean-square error [RMSE]=1.522). Notable advantages of this methodology include high accuracy, good operability, non-contact, high versatility, and low cost. Further studies are required for the establishment of an accurate measurement methodology that can scan the whole body in a shorter time.

Key words: *conformation, horse, light detection and ranging (LiDAR), non-contact, 3D images*

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In the management techniques for race and riding horses, understanding the body conformation of horses is a major factor. However, it is generally difficult and time-consuming to accurately take manual measurements for many parts of the body. Although there have been reports of indirect measurement using photography [2, 8], deviations in camera–horse angle, geometrical errors when a three-dimensional (3-D) object is reduced to 2-D image, and limited accuracy when measuring conformational parameters manually from photographs can also be expected when using photography [20]. Therefore, for better management of horses, there remains a need to develop new technologies that can take measurements accurately and easily to replace conventional methods.

In recent years, there has been advancement in the technology for acquiring stereoscopic images with a 3D scanner, even for large animals such as cattle [4, 5, 9, 10] and horses [16]. The key feature of these studies is that the experimenter can take measurements without touching the animal. It is possible to obtain more detailed

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body information than that obtainable with conventional body measurements given that body conformation can be measured from all angles and cross sections in a 3D image. Measurements using completely non-contact conditions are of great significance in carrying out research, particularly that carried out on delicate and expensive racehorses. However, advanced data processing technologies, such as filtering and deep learning, were required to analyze the rear shape of cows [5], the conformation of Qinchuan cattle [9, 10] and Andalusian horses [16]. It is currently difficult to say that a horse's conformation can be easily measured in their normal environment. Quick and easy measurement of body conformation, which can change daily, is necessary, particularly on breeding and rearing farms. Moreover, even if researchers or specialists in the field of information engineering were to assemble a special device to measure a horse each time, it would not be practical. On the other hand, it would actually be more meaningful if measurements could be accomplished with off-the-shelf products that are easy to handle by the keepers who usually take care of the horses. Therefore, the development of measurement techniques that are as easy as possible using a highly versatile device is important.

In the present study, we performed 3D scanning to determine the conformation of riding horses using a highly versatile device. The study aimed to compare body measurements obtained using a 3D image constructed by a 3D scanner with conventional manual measurements.

Materials and Methods

The Ethics Committee of Kitasato University, School of Veterinary Medicine, Japan, approved this study.

Horses

We studied 8 riding horses (two mares and six geldings) that were 4–18 years of age (mean ± standard deviation [SD], 14.4 ± 4.6 years): 6 Thoroughbreds and 2 crossbreds (mix × Haflinger and Haflinger × Japanese native horse). The body weight (BW, mean ± SD) of the horses was 517.9 ± 37.8 kg. The horses were routinely used as riding horses for the equestrian team of Kitasato University or as scientific research animals. They were in good condition and well trained.

Conventional manual measurements

To reduce possible variations, conventional manual measurements were always carried out by the same animal scientist, similar to the study by Pérez-Ruiz *et al.* [16]. We measured equine conformation according to the modified method of Kristjansson *et al*. [12]. The horses were hitched to the posts at a wash rack without a handler, and they stood in a standard position without a rider. As shown in Fig. 1, we took the following manual measurements:

M1 − height at the withers (HWi), measured from the ground to the withers

M2 − height at the back (HBa), measured from the ground to the lowest point of the back

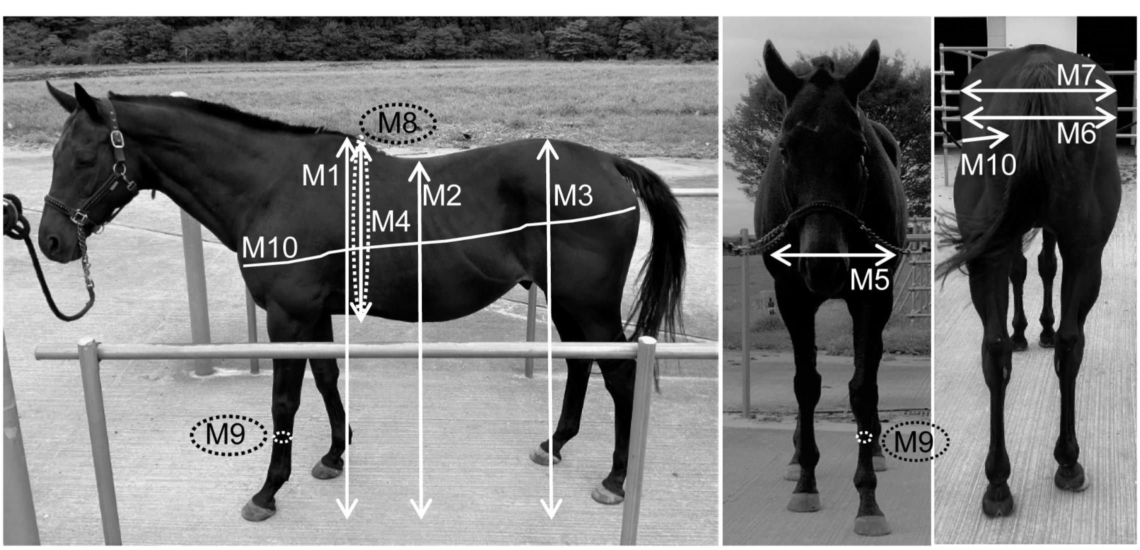

Fig. 1. The following body measurements were taken manually: M1, height at the withers (HWi); M2, height at the back (HBa); M3, height at the croup (HCr); M4, chest depth (ChD); M5, width of the chest (WCh); M6, width of the croup (WCr); M7, width of the waist (WWa); M8, girth circumference (GiC); M9, cannon circumference (CaC); M10, body length (BoL).

M3 − height at the croup (HCr), measured from the ground to the highest point of the tuber sacrale
M4 − chest depth (ChD), measured from the highest point of the withers to the lower edge of the sternum (the point behind the posterior edge of the elbow joint) [11]
M5 − width of the chest (WCh), measured distance in the front side between the outer sides of the right and left humeri [14]
M6 − width of the croup (WCr), measured between the hip joints
M7 − width of the waist (WWa), measured between the tuber coxae
M8 − girth circumference (GiC), measured circumference of the trunk through the withers and the sternal area
M9 − cannon circumference (CaC), measured circumference of the front cannon at the middle
M10 − body length (BoL), measured from the point of the shoulder to the midpoint of the distance between the widest part of the stifle and the tail when viewed from the rear, making the measuring tape fit the curve line of the horse's body surface according to Wagner and Tyler [21]

The measuring tools included measuring stick (M1−4), caliper (M5−7), and measuring tape (M8−10). During stick measurements, an assistant standing behind the horse made sure that the stick was standing vertically. Each measurement was made twice, and the average value was used in the statistical analysis.

3D image constructed using a 3D scanner

In this study, an iPad Pro (Apple Inc., Cupertino, CA, U.S.A.) was used as a tablet-type 3D scanning device (3D scanner), and 3D images were taken of each horse using a 3D image capture app (Scandy Pro 1.7.5, Scandy LLC, New Orleans, LA, U.S.A.). It is equipped with wide and ultra-wide cameras and a light detection and ranging (LiDAR) scanner. LiDAR is used to determine distance by measuring how long it takes light to reach an object and reflect back, and conveniently, the LiDAR scanner could measure reflected light from up to 5 m away, either indoors or outdoors [1].

Each horse stood without a rider in a standard position at an outdoor wash rack. We separately took 3D images of i) the whole body and ii) the left front limb of each horse using a 3D scanner. We performed scanning without any contact with the horse. i) For the whole-body image, one experimenter scanned the horse over the course of 1 min while walking slowly around the horse, starting from front left of the horse and then moving to the right lateral view, caudal view, and left lateral view before returning to the front, moving the device up and down smoothly. We started from the front left side of the horse because the horses frequently moved their heads. ii) The left front limb of each horse was also scanned for 20 sec because the horses moved their limbs more often than other parts of their bodies. We completed all scans within 5 min per animal. We performed the scanning between 2 and 5 more times, just in case we had not scanned the horses properly. In total, it took about 15 min per animal. We cropped unnecessary parts out of the captured 3D images, such as the ground and background, using 3D image analysis software (CloudCompare 2.10.2 Stereo, GNU General Public Licence). We used different 3D image analysis software (Fusion 360, Autodesk, San Rafael, CA, U.S.A.) to manually take the same body measurements as on the 3D image. Each body measurement was taken from the whole-body image using cross-sectional analysis, except for the cannon circumference. The cannon circumference was measured from the image of the left forelimb. For measurement sites M1 to M7, we measured the lengths of line segments drawn on cross sections of the 3D image. For measurement sites M8 to M10, we drew curves on the cross sections at the measurement sites so as to trace the measurement sites using spline control points, and we measured the loop lengths of the curves. We also took each body measurement on the 3D image twice, and we used the average value for statistical analysis.

BW

We measured the BW of each horse with a weight scale. We calculated estimated body weights from both manual and 3D measurements using the following formula derived by Wagner and Tyler [21]:
Estimated BW (kg)=(girth circumference [cm])^2 × (body length [cm])/11,880.

Statistical analysis

Data are presented as the mean ± standard error (SE). We conducted statistical analyses using statistical analysis software (IBM SPSS Statistics, version 21, IBM Corp, Armonk, NY, U.S.A.). We used the paired *t*-test and Pearson product-moment correlation coefficient to compare the 3D measurements with the manual measurements. We also calculated the coefficient of determination (R^2) and the root-mean-square error (RMSE) between manual measurements and 3D measurements using all of the data obtained. In addition, we expressed variation in all of the data obtained between manual measurements and 3D measurements using Bland–Altman plots [3]. We plotted the differences between data from both measurements against their means. We used the one-sample *t*-test to determine if the mean differences were significantly different. We considered differences to be significant at $P<0.05$. We used the relative error formula to compare manual measurements with 3D measurements to discern errors made with this latter method, using the method of Pérez-Ruiz *et al*. [16]:

Relative error (%)=(3D Measurement–Manual Measurement)/(Manual Measurement)

We also estimated the accuracy of this method (v^2) by calculating the error of the 3D method with respect to the variance [17]:

v^2=Variance $_{(3D\ Measurement–Manual\ Measurement)}$/Variance $_{Manual\ Measurement}$

Results

A typical example of a whole-body 3D image obtained in the present study is shown in Fig. 2a. An image of the head was often not obtained because of frequent, slight movements of the head. Similarly, we could not obtain limb measurements from whole body 3D images. Therefore, the cannon circumference could only be measured by taking another image of the left forelimb (Fig. 2b).

The lengths, widths, and circumferences of each body part determined by the two methods are shown in Table 1. There were no significant differences between the two methods for HWi, ChD, WCh, WCr, WWa, GiC, and BoL. The correlation coefficient between manual and 3D measurements (r) was significant for all parts except for WWa and CaC. The 3D measurements were significantly

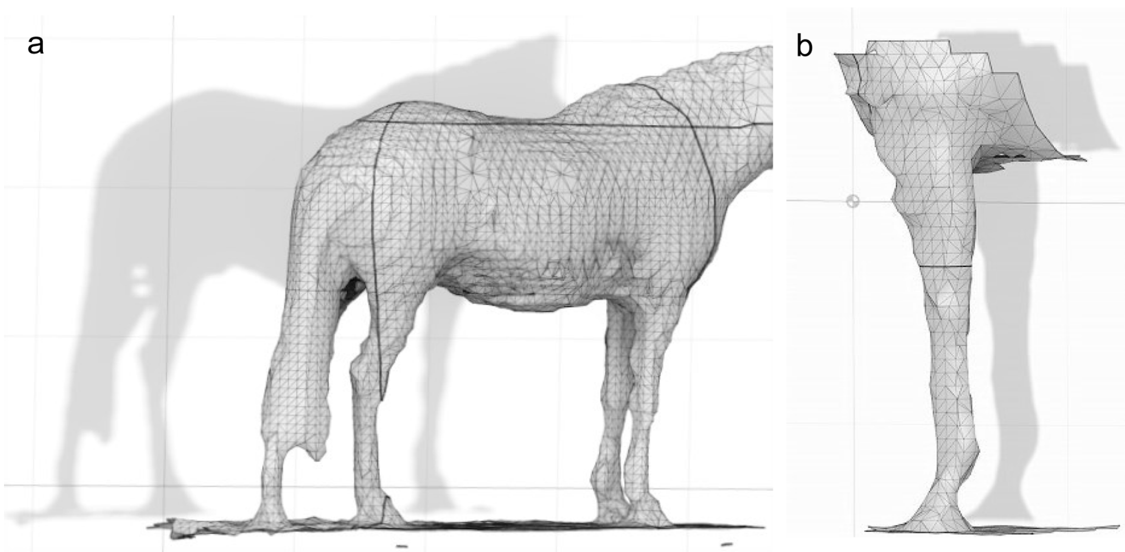

Fig. 2. Three-dimensional images of the entire body, excluding the head (a) and left limb (b).

Table 1. Comparison of each body measurement between manual and 3D measurements

Body measurement	Manual (cm) Mean ± SE	3D (cm) Mean ± SE	Paired *t* *P*		Relative error Mean (%)	v^2	Correlation r	Correlation *P*	
HWi	158.3 ± 2.6	157.5 ± 2.5	0.073		−0.48	0.013	0.992	0.000	**
HBa	150.8 ± 2.9	149.4 ± 2.7	0.021	*	−0.92	0.025	0.990	0.000	**
HCr	160.4 ± 2.9	158.7 ± 2.6	0.010	*	−1.03	0.028	0.993	0.000	**
ChD	74.4 ± 1.0	74.7 ± 1.0	0.376		0.42	0.034	0.950	0.000	**
WCh	38.1 ± 0.6	38.4 ± 0.7	0.236		0.66	0.043	0.958	0.000	**
WCr	52.8 ± 0.5	52.5 ± 0.5	0.369		−0.42	0.102	0.893	0.003	**
WWa	55.0 ± 0.5	54.3 ± 0.3	0.208		−1.37	0.881	0.153	0.718	
GiC	187.1 ± 1.5	188.0 ± 0.8	0.345		0.50	0.278	0.856	0.007	**
CaC	19.1 ± 0.3	20.2 ± 0.3	0.019	*	6.25	1.293	0.248	0.554	
BoL	170.8 ± 3.3	170.8 ± 3.2	1.000		0.01	0.001	0.998	0.000	**

HWi, height at the withers; HBa, height at the back; HCr, height at the croup; ChD, chest depth; WCh, width of the chest; WCr, width of the croup; WWa, width of the waist; GiC, girth circumference; CaC, cannon circumference; BoL, body length. Relative error (%)=(3D Measurement–Manual Measurement)/(Manual Measurement). v^2=Variance $_{(3D\ Measurement–Manual\ Measurement)}$/Variance $_{Manual\ Measurement}$. Pearson correlation coefficient (r). *P<0.05; **P<0.01. SE, standard error.

smaller than the manual measurements for HBa ($P<0.05$) and HCr ($P<0.05$), while the 3D measurements were larger than the manual measurements for CaC ($P<0.05$). However, even CaC, which had the highest relative error, had a relative error of less than 7%.

Figure 3 shows the results of the regression analysis between the manual and 3D measurements. Simple regression analysis revealed a strong correlation (r=0.9997, $P<0.001$). The R^2 and RMSE were 0.9994 and 1.522, respectively.

Figure 4 shows Bland–Altman plots demonstrating the degree of agreement between the manual and 3D measurements. The mean differences (3D-manual) was −0.23 cm, and it was not significantly different from 0 according to the one-sample *t*-test ($P=0.176$).

The BWs and estimated BWs calculated by the two methods are shown in Table 2. The values estimated by the two methods were generally consistent with the actual measured values.

Discussion

Conformation has been regarded as an important indicator of performance and soundness for as long as horses have been used by humans [6]. There have been several studies on race and riding horses. According to Janczarek *et al.* [11], the most important traits to potentially help with an initial assessment of racing predisposition of young

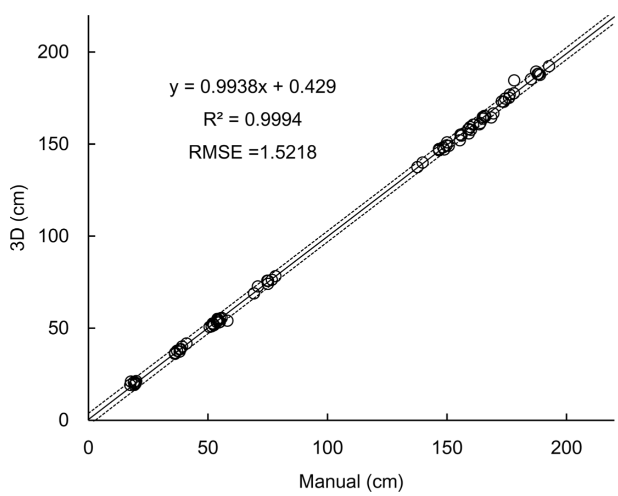

Fig. 3. Regression analysis comparing manual and 3D measurements. The dashed line shows the 95% confidence interval. R^2, coefficient of determination; RMSE, root-mean-square error.

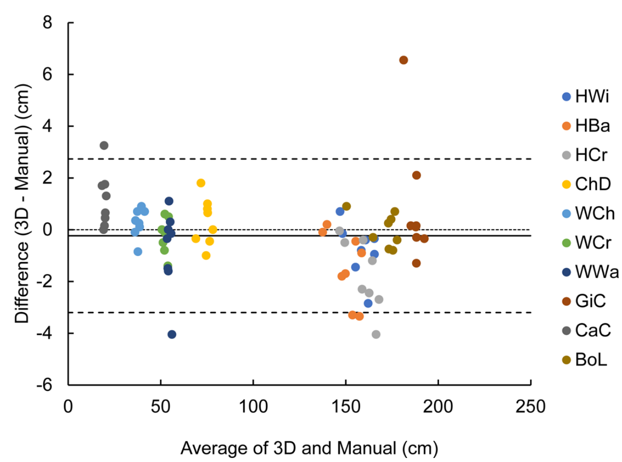

Fig. 4. Bland–Altman plots demonstrating the degree of agreement between the two methods—manual measurements and 3D measurements. The solid line shows the mean difference, whereas the upper dashed line represents the upper limit of agreement (difference +1.96 × standard deviation (SD)); the lower dashed line represents the lower limit of agreement (difference −1.96 × SD).

Table 2. Sex, age, breed, body weight, and estimated body weight of each horse

Horse No.	Sex	Age (years)	Breed	BW (kg)	Estimated BW	
					Manual (kg)	3D (kg)
#1	M	4	Crossbred [a]	499	476.1	476.0
#2	G	18	Thoroughbred	524	516.4	514.7
#3	G	12	Crossbred [b]	436	400.6	433.2
#4	G	16	Thoroughbred	518	526.0	521.9
#5	G	16	Thoroughbred	536	523.7	517.7
#6	M	16	Thoroughbred	542	525.6	536.3
#7	G	15	Thoroughbred	526	514.8	516.4
#8	G	18	Thoroughbred	562	550.9	551.1
Mean ± SE	-	14.4 ± 1.6	-	517.9 ± 13.4	504.3 ± 16.5	508.4 ± 13.1

G, gelding; M, mare; BW, body weight. [a] Mix × Haflinger, [b] Haflinger × Japanese native horse. Estimated BW (kg)=(girth circumference [cm]) ^{2} × (body length [cm])/11,880 (Wagner and Tyler, 2011 [21]).

Danish trotters include ischium length, height at the croup, shoulder length, and thigh length. In Thoroughbred racehorses, yearling measurements for height at the croup, body length, and girth circumference were found to be correlated with winning percentage in both females and males [19]. However, Paksoy and Ünal [14] found no relationship between the results of morphological measurements and race performance. There have been many fewer studies of the relationship between conformation and performance in racehorses than in riding horses [2, 6, 7, 13, 18]. Three-dimensional scanning of racehorses should greatly increase the understanding of the morphological characteristics and growth of individual horses. The demand for 3D scanning is likely to increase due to the need for repeated measurements, especially for foals and young horses.

According to a study of Andalusian horses, which evaluated the correlation between manual and 3D measurements at the same sites as the present study, the correlation coefficients for HWi, HCr, BoL, and GiC were −0.32, 0.77, 0.39, and 0.90, respectively [16]. On the other hand, they were 0.992, 0.993, 0.998 and 0.856, respectively, in the present study. When compared to the Andalusian study [16], the results for HWi, HCr, and BoL were much better in the present study, although the results of the two studies were similar for GiC. An overview of the correlation coefficients for all the body measurements in the present study showed that they varied from 0.856 to 0.998, except for WWa (0.153) and CaC (0.248), and the correlation coefficients were significant for all the body measurements (P<0.01) except for WWa (P=0.718) and CaC (P=0.554). The low accuracy of CaC was due to the effect of the horses' hair. In other words, the 3D measurements of CaC were considered to be larger than the manual measurements because of the large effect of hair thickness. Bland–Altman plots also demonstrated this bias in CaC. The low accuracy of WWa is likely due to the difficulty of performing manual measurement for one specific horse with the second highest HCr and the highest HWi and HBa. In general, it is difficult to measure the WWa of tall horses with a caliper. When the data of this horse was excluded, the correlation coefficient increased to 0.456, but it was not significant (P=0.304). The relative error when the data of this horse was excluded also improved to −0.57%, which was the same level as for other body measurements. Similarly, Bland–Altman plots also demonstrated that the WWa of this horse was below the lower limit of agreement; however, the measurement error of one specific horse could not entirely explain on its own the reason for the low accuracy of WWa.

There were no significant differences between the two measurements for seven of the 10 body measurements. As already mentioned above, the low accuracy for CaC was due to the effect of the horses' hair. For HBa and HCr, the differences were statistically significant, but the differences between the two types of measurement were less than 2 cm. The reason for these differences could also be clarified based on the Bland–Altman plots. The Bland–Altman plots demonstrated that the HBa and HCr in one or two horses were below the lower limit of agreement. In the case of horses that do not like to be touched on the back or the croup, it is necessary to measure quickly during manual measurement. For HBa and HCr, manual measurement values will be larger than the actual body scale unless the stick scale is oriented completely vertically. In the present study, the manual measurement values for HBa and HCr were likely larger than the 3D values in certain horses because the manual values could not be measured accurately. Based on these results, 3D measurement, which could be done without making contact with the horses, was superior to manual measurement.

Bland–Altman plots also demonstrated that GiC was beyond the upper limit of agreement in one horse. The CaC of the same horse also exceeded the upper limit of the Bland–Altman plots. Similar to CaC, GiG was larger in 3D measurements than in manual measurements in the thick-haired individual. Based on this, 3D measurements should be taken during the season when the effects of hair are small.

In a morphometric study of Lipizzan horses using a dual web camera system, the relative errors varied from 0.54% to 2.09% [15]. Furthermore, the relative errors for HWi and ChD varied from −2.56% to 7.98% and from 10.81% to 25.00%, respectively, in a study of Andalusian horses using LiDAR [16]. In the present study, the relative errors varied from −1.37% to 6.25%. The v^2 values for HWi and ChD were 1.14 and 3.58 in the study of Andalusian horses [16], while they were 0.013 and 0.034 in the present study. This indicates that the accuracy of the present study was equivalent or higher than the results of other studies on horses.

The values for ChD, WCh, and GiC were obtained by averaging the values measured at the time of exhalation and inhalation only during manual measurements; the same operation was not possible during 3D measurement. Conversely, an intermediate image between exhalation and inhalation should have been consequently obtained given that it took about 1 min to scan a whole-body image.

In a study measuring 30 Holstein dairy cows using a 5-camera system, the correlation coefficients between manual and 3D measurements were 0.89 for ChD, 0.82 for HWi, 0.78 for GiC, 0.76 for backside width, 0.63 for ischial width, and 0.62 for WCr [4]. Huang *et al.* [9, 10] used a non-contact body dimension measurement approach for Qinchuan cattle using a LiDAR system and found that the final deviations were close to 2 mm and within approximately 2%. Measuring horses is more difficult than measuring cows because the more an object moves, the more difficult it is to measure. The accuracy of the present study was almost equivalent to that of a study by Cozler *et al.* [4] and slightly lower than those of studies by Huang *et al.* [9, 10]. Even a horse that moves frequently can be made to stay still for a short time. Therefore, it is necessary to develop a method of scanning the whole body in a shorter time.

The difference between the average estimated BW calculated from the 3D measurements and the actual measured BW was 9.5 kg. In two particular individuals, the estimated BW from 3D measurement differed from the actual BW by about 20 kg. Since the present study was not designed to estimate BW, a different approach is needed for more accurate BW estimation. However, for better husbandry and management of horses, it would be more important to understand the changes of many body dimensions of the horse easily and accurately rather than BW only.

In conclusion, the correlation coefficients between manual and 3D measurements ranged from 0.856 to 0.998, except for WWa and CaC. There were no significant differences between the two types of measurement for seven of the 10 body measurements. The relative errors varied from −1.37% to 6.25%. Although measurement of CaC was inaccurate due to effect of hair, all parts of the trunk could be measured without significant problems. The advantage of the methodology used in the present study was non-contact measurement with a highly versatile tablet-type device. The application of this methodology allowed for easier on-site body measurement of the horses.

Acknowledgments

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