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REGULAR ARTICLES

Accuracy of image analysis for linear zoometric measurements in dromedary camels

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Abstract

The present study was designed to verify the effectiveness of the image analysis method for body measurement in dromedary camel compared to manual measurements as a reference method. To achieve this aim, twenty-one linear body measurements were estimated on 59 adult Sahraoui dromedary camels (22 males and 37 females) with a normal clinical condition by using a measuring stick or vernier caliper (standard method). On the other hand, image analysis on profile, front, or behind photographs was processed using Axiovision Software. Overall mean comparison, relative error, variance, Pearson's correlation coefficient, and coefficient of variance showed that the image analysis method was accurate in relation to the manual measurement. Furthermore, image analysis results indicated relevant accuracy (bias correction factor, $C_b \approx 1$) and precision (Pearson $\rho \approx 1$) which were significantly correlated with the results of the reference method (Lin's concordance correlation coefficients $r_{ccc} \approx 1$). According to Bland–Altman upper and lower limits of agreement, the concordance was estimated between 93.22 and 98.3%. Passing-Bablok regression showed a good relationship between the results of the two methods displaying no significant systematic and proportional bias. The image analysis method for linear body measurements in dromedary camel showed results that are in agreement with the manual measuring method. Therefore, the image analysis could be considered a valid tool for camel conformation trait studies.

Keywords Dromedary camel · Image analysis · Body measurements · Distance-based measurements

Introduction

At the outset of genetic studies at the beginning of the last century, researchers started with morphological characters, but with time and technological development, these markers gradually lost their importance and biochemical markers and then molecular markers raised as methods for further reliable characterization. However, with the advent of molecular biology techniques of next-generation sequencing and the possibility of identifying genomic regions related to phenotypes of interest by genome-wide association study, morphological markers have regained the forefront of the scientific scene. In addition, they are increasingly being implemented for animal research and health diagnosis, and production management. A previous study indicated that, collecting such information is challenging and requires heavy investigation, especially for wild animals (e.g., feral camels) or those that live in pastoral systems with permanently accessible grazing, like camels which lead to more challenges for standardizing classic measurement collection protocol (Alhajeri et al., 2021).

The use of new technologies has given rise to a new type of farming, precision farming. This concept is defined as the coordinated use of behavioral, physiological, and/or production parameters and information and communication technologies to exchange, store, transform, and return this information to help with decision-making (Allain et al., 2014). Among the emerging technologies is image analysis,

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which is obtained by photography, video processing, thermography or thermal image processing, 3D body scanners, mobile body scanning, etc. Imaging (2D) with the use of devices allows the capture and analysis of shapes which enable mainly to carry out body measurements and access new indicators by geometric morphometrics. Therefore, many functional morphological indexes, body condition evolution, and shape variation of footpads were more easily assessed with minimal direct contact with different animal categories (Al-Atiyat et al., 2016; Alhajeri et al., 2021).

Access to morphological evaluation using image analysis in camel species is of particular interest because of difficulties in handling and restraining, large size, and mobility or even aggressive behavior (Iglesias et al., 2020; Alhajeri et al., 2021). Some challenges arise when taking measurements related to skull bones, the urogenital region, or when taking measurements in a crouch position close to the ground, which might frighten the animal, and that could lead to the animal becoming restless and kicking or stepping on the worker. Moreover, measurements close to the face, especially from males during rutting season, can expose them to bites (Yahaya et al., 2012; Ayadi et al., 2016; Gherissi et al., 2018; Alhajeri et al., 2021). Body measurements in these species require one to two people to immobilize the animal and two other people to take body measurements (Gherissi et al., 2014; Meghelli et al., 2020). Using the manual method is very time-consuming and is not without risk for the handlers and the animal. Image analysis was also used for behavior monitoring, lameness, and posture defectuosity diagnosis in other species (Viazzi et al., 2013; Kashiha et al., 2014; Zhao et al., 2015; Sénèque et al., 2019; Kang et al., 2020).

The main objective of the present study was to verify the effectiveness of distance-based linear body measurements in dromedary camel using an image analysis approach compared to manual measurement, considered the reference method. Accordingly, we look for the possibility to give researchers and camel-breeding practitioners an important tool to lighten camel handling while taking body measurements.

Material and methods

Animals

The study was conducted between February 2019 and August 2020 on randomly selected 59 Sahraoui dromedary camels (22 males and 37 females) with normal clinical conditions (mean age $= 9 \pm 3.56$ years, mean body weight $= 452.10 \pm 98$ kg measured by Kamili et al. (2006) formula, $\text{Live weight (kg)} = 4.06 \times \text{Age (year)} + 3.05 \times \text{CN (cm)} + 3.38 \times \text{TC (cm)} + 1.38 \times \text{HL (cm)} - 191$, with 94% of the explained variance, where CN is the circumference of the neck at the middle of the neck, TC is the thigh circumference at the middle of the thigh, and HL is the hump length).

Manual body measurement

The animals belong to sedentary camel herds in the region of El Oued in the southeast of Algeria. Twenty-one linear body measurements to the nearest centimeter were performed for each animal from the left side of the camel and in a standardized position, according to descriptions given by Alhajeri et al. (2021) (Fig. 1). These measurements were taken manually using a measuring stick or vernier caliper and were considered reference measurements. Long linear measurements, such as body length, were taken with assistance from a second evaluator.

Animal photography and image processing

The setting, the camel's position, and the camera's distance are all important considerations. The place for image collection was chosen since it was open and flat. The camera was positioned at a standardized height of 1.2 m on a camera stand 3 m away from the camel center of balance. This distance and height allowed the animal's body to be properly framed. We draw standard lines on the ground before starting photo taking for each animal to locate the animal in the right place and keep him the same distance from the camera.

The images used for the present study were obtained using a digital camera (Sony DSCW830 Compact) in standard mode (resolution of $4912 \times 1080/3424 \times 1920$ and a focal length of 4.5 to 36 mm). The location of the photos should be well lit and the camel's coat color contrasted well with the animal's background to better target the different anatomical points used in the measurements. A 1-m ruler is placed near the animal on the same midline of the body to be used for calibration of distances on the computer measurement software. Obtaining Portable Graphics Format (PNG) images from the photos taken will compress the image background into a very small size because the content of the pixel is identical. Anatomical reference points for calibration were placed on the animal's body in the following places (Fig. 2): nose tip, head base, neck base, shoulder point, buttock point, withers point, hump point, ilium point, ischium point, trochanter, elbow, knee, hock, and front and rear fetlocks. The photos are taken when the animal is in a static position, in an upright position, head raised in a natural position, in three planes perpendicular to the camera: profile left, front and behind (Fig. 1a, b, c). The obtained images were processed manually using Axiovision Software Rel 4.6 (Carl Zeiss, Thornwood, NY). The measurements of the various linear parameters by drawing a straight line between two points

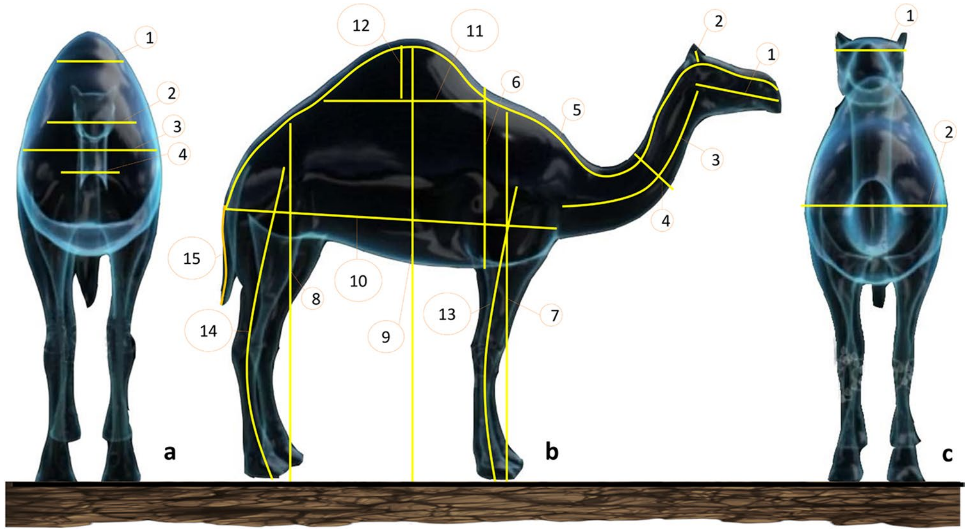

Fig. 1 Linear variables used to validate an image analysis method for determination of camel body measurements. Definitions of the measured body dimensions. **a** Behind position: (1) Hump width (HuW), (2) bi-iliac width (IW), (3) width at trochanter (WT), (4) bi-ischial width (IsW). **b** Profile position: (1) Length of the head (LH), (2) ear length (EL), (3) neck length (NL), (4) neck width (NW), (5) total body length (TL), (6) chest depth (CD), (7) height at withers (HW), (8) height at rump (HR), (9) height at the hump (HH), (10) scapular ischial length (SIL), (11) hump length (HuL), (12) hump height (HuH), (13) length of the anterior limb (LAL), (14) length of the posterior limb (LPL), (15) tail length (TaL). **c** Front position: (1) head width at occipital level (HeW), (2) width of the shoulders (SW)

Fig. 2 Diagram showing profile standard position of the camel ready to be photographed and calibration markers

are obtained in pixels and are automatically converted by the previously calibrated software (Gherissi et al., 2020).

Statistical analysis

MedCalc Statistical Software Ltd., version 20.019 Ostend, Belgium, was used for descriptive statistics, concordance correlation analysis, Passing-Bablok regression analysis, and the Bland–Altman method to determine the agreement between the image analysis method and the reference body measurement method.

The descriptive statistic was used to determine the mean of each parameter according to the measurement method employed, as well as the mean of the two methods, the variance, the relative error of variance, and the Pearson correlation coefficient. The difference in the means between the measurements of each parameter was carried out using the *t*-test for independent sample analysis with a significance level of 0.05 (5%) or lower.

Lin's concordance correlation coefficient (r_{ccc}) generates the precision (Pearson's ρ) and accuracy (bias corrected factor, C_b) and was used as an indicator for the strength of concordance between measurements. Accuracy refers to the ability to measure a body measurement close to its true value, whereas precision refers to the spread of repeated measurements. The values ≥ 0.99, 0.95–0.99, 0.90–0.95, and ≤ 0.90 reflect perfect, substantial, moderate, and poor agreement, respectively.

Passing-Bablok regression test was applied to generate the regression equations and estimate the constant, proportional, and random bias by interpreting the intercept, slope, and residual standard deviation values using the 95% CI for each case.

Bland–Altman test was carried out by plotting the difference between the two compared body measurements against the mean of the two measurements. This method evaluates the agreement between the two measurement methods instead of validating the experimental method against the reference method. As a measure of precision, the 95% limits of agreement were admitted.

Results

The proposed method was accurate ($v^2 = \pm 0.045\%$), strongly correlated with the reference method ($r > 0.997$, $P < 0.001$), and had low coefficient of variation (CV < 3.80%) (Fig. 3).

The body measurements obtained by the digital image analysis were very accurate compared to reference values (Table 1). Eleven of twenty-one body measurements obtained by the digital image analysis method were very accurate in relation to reference values ($P \geq 0.05$): total body length (TL), scapular ischial length (SIL), height at withers (HW), height at the hump (HH), width at trochanter (WT), bi-ischial width (IsW), chest depth (CD), length of the posterior limb (LPL), neck length (NL), hump length (HuL), and hump width (HuW) with a respective mean of 327.615 cm, 134.18 cm, 171.99 cm, 189.85 cm, 41.93 cm, 25 cm, 71.51 cm, 152.99 cm, 80.71 cm, 49.68 cm, and 26.75. Compared to the reference method, the proposed method underestimated LPL (− 1.23 cm) and NL (− 0.36 cm) but it overestimated the following parameters: TL (1.17 cm), SIL (+ 0.3 cm), HW (+ 0.91 cm), HH (+ 0.29 cm), WT (+ 0.29 cm), IsW (+ 0.12 cm), CD (+ 0.36 cm), HuL (+ 0.52 cm), HuW (+ 1.97 cm). Moreover, the CV of the parameters WT, IsW, CD, NL, HuL, and HuW is relatively high (3.46 to 5.97%). The determination of the other parameters HR, IW, SW, LAL, NW, HuH, length of the head (LH), HeW, ear length (EL), and TAL by the two measurement methods revealed that they are significantly different ($P = 0.02$ to 0.000) and the CV is between 2.77 and 8.48%. The scatter plots of these parameters showed how the data was plotted for each method (Sup. Figure 1).

The concordance analysis between the image analysis and the reference method for the body measurements of the studied camels was carried out by interpreting Lin's coefficient. Table 2 shows the results for all studied variables, and the graphical presentation of the results is reported in Supplementary Fig. (2), which displays the graphs for the other variables. It is easy to see that the image analysis provides results that are perfectly in agreement with the reference method for LT justified by a positive Lin correlation coefficient close to 1 and confirmed by a close Pearson and C_b correlation coefficient close to 1. A similar finding was obtained for all other studied parameters except for EL (Lin coefficient = 0.269, Pearson coefficient = 0.346, $C_b = 0.779$).

Lin's concordance correlation coefficients (r_{ccc}) with 95% confidence intervals (95% CI), precision (Pearson ρ) and accuracy (bias correction factor, C_b) are reported (See Table1 for variables abbreviation).

Figure 4 represents the Passing and Bablok regression line, illustrating the correlation existing between the measurement of the total length ($N = 59$) by the reference method (TL_R) and image analysis (TL_IA). The equation

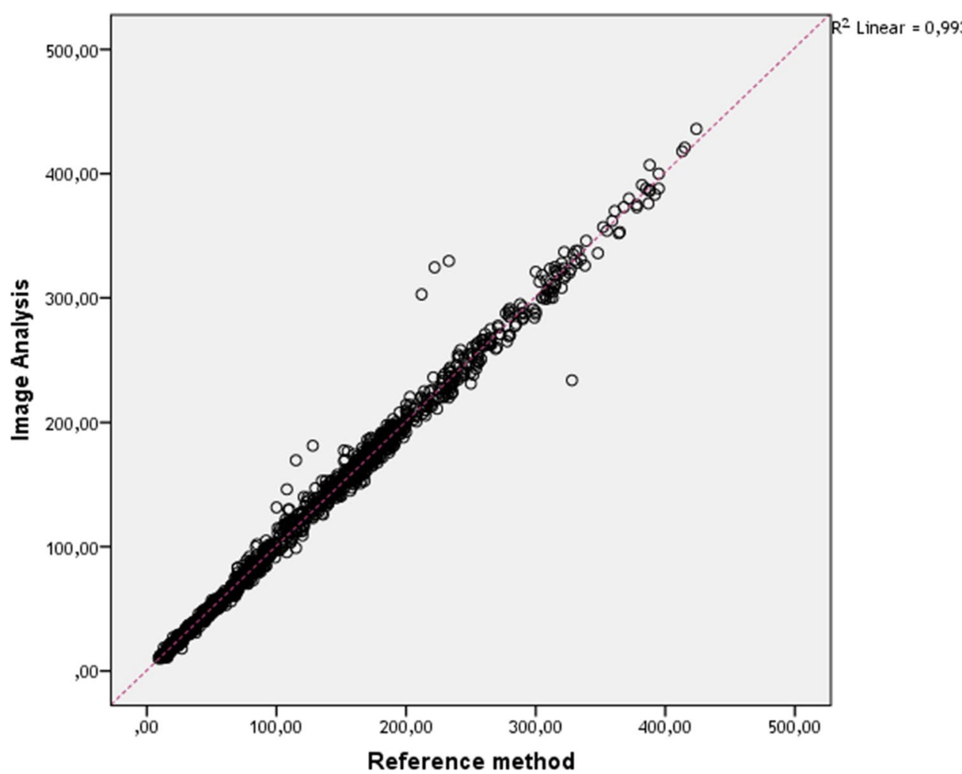

Fig. 3 Relationship between camel body measurements obtained by image analysis and the reference method. The dashed diagonal line is the equality line, where $y = x$. Statistics: reference method = 104.81 cm; image analysis = 105.57 cm; mean = 105.19 cm, $y = 1.002x - 0.596$, $R^2 = 0.993$, $r = 0.997$, $P < 0.001$, CV = 3.80%

Table 1 Linear body measurements of camels ($n=59$), relative error (RE), relative error of variance (v^2), and Pearson's correlation coefficient (r) between reference and image analysis results

Variable	Reference method	Image analysis	Mean	RE	v^2	r	CV (%)	P-value
TL	327	328.23	327.615	−1.17	−5.44	0.978	1.71	0.2535
SIL	134.03	134.33	134.18	−0.22	−1.75	0.984	1.62	0.4722
HW	171.54	172.45	171.995	−0.53	−2.66	0.974	1.56	0.0571
HH	189.71	190	189.855	−0.15	8.89	0.962	1.58	0.4817
HR	168.17	170	169.085	−1.09	−8.60	0.929	3.29	0.0067
IW	28.1	28.71	28.405	−2.17	−31.45	0.879	4.82	0.0125
WT	41.79	42.08	41.935	−0.69	−16.48	0.926	3.7	0.3117
IsW	24.94	25.06	25	−0.48	−11.87	0.924	5.16	0.6173
CD	71.33	71.69	71.51	−0.50	−22.05	0.951	3.46	0.4451
SW	42.71	43.42	43.065	−1.66	5.36	0.943	3.75	0.0127
LAL	144.35	142.16	143.255	1.52	−8.40	0.934	3.11	0.0021
LPL	153.61	152.38	152.995	0.80	−4.15	0.958	2.45	0.0628
NL	80.89	80.53	80.71	0.45	−0.05	0.938	3.61	0.5078
NW	25.62	26.07	25.845	−1.76	−4.49	0.922	4.32	0.0257
HuH	20.96	21.73	21.345	−3.67	−20.42	0.938	7.12	0.0035
HuL	49.42	49.94	49.68	−1.05	−4.16	0.962	3.82	0.1135
HuW	25.77	27.74	26.755	−7.64	−22.66	0.943	5.97	0.8918
LH	51.2	50.27	50.735	1.82	−9.02	0.817	2.77	0.0001
HeW	22.76	23.74	23.25	−4.31	8.44	0.793	5.86	0.0033
EL	12.3	11.74	12.02	4.55	66.35	0.272	8.48	0.0034
TaL	66.61	64.62	65.615	2.99	1.39	0.958	4.69	0.0001

TL total body length, *SIL* scapular ischial length, *HW* height at withers, *HH* height at the hump, *HR* height at rump, *IW* bi-iliac width, *WT* width at trochanter, *IsW* bi-ischial width, *CD* chest depth, *SW* width of the shoulders, *LAL* length of the anterior limb, *LPL* length of the posterior limb, *NL* neck length, *NW* neck width, *HuH* hump height, *HuL* hump length, *HuW* hump width, *LH* length of the head, *HeW* head width at occipital level, *EL* ear length, *TaL* tail length.

for the regression line is as follows: TL_IA = −5.66 + 1.024 TL_R with 95% CI of the systemic difference = −19.21 to 5.26 and 95% CI of the slope = 0.96 to 1.03 and $R^2=0.95$ ($P<0.0001$). Data were plotted near the equality line and 95% CI of the y-intercept of the slope reveals that there is no systematic difference (0 located outside the 95% CI of the y-intercept) or proportional difference (1 located outside the 95% CI of the slope) between the two means of measurement. Reference and estimated methods produced accurate results for all the morphological parameters studied, with the main observations of no significant systematic difference [−7.31; 9.61] and a proportional difference which goes from 0 to 21% (Sup. Figure 3). Furthermore, only the EL study showed high systematic and proportional bisection values of around 7.66 cm and 67%, respectively (Sup. Figure 3).

Figure 5 represents the results of the Bland–Altman for comparison between the reference method and image analysis for the camel's TL. The Bland–Altman analysis diagram and the calculation of agreement limits show that the average of the differences in TL is $d=1.16$, measured by each of the two methods. The agreement limits = [−14.1; 16.43]. TL_IA turns out to be a little higher than TL_R. The differences in the measurements of two samples are situated above the upper agreement limit and one sample is below the lower agreement limit, giving a concordance of 94.91% (Fig. 5). By observing the results of the rest of the morphological parameters, we find that there is no bias between measurements and the narrow limits of agreement for the LH. For the rest of the variables, there is usually a low bias between measurements and narrow limits of agreement concordance ranging between 93.22 and 98.3% (Sup. Figure 4).

Discussion

The present study investigated the effectiveness of the image analysis method by checking the hypothesis that the mentioned method offers a fine, precise, non-subjective analysis of linear body measurement in dromedary camels. The body measurement technologies is still at the beginning of experimentation in the camel species (Iglesias et al., 2020; Çağlı and Yılmaz 2021) compared to cattle (Negretti et al., 2008; Bewley et al., 2008; Fischer et al., 2015; Kuzuhara et al., 2015; Le Cozler et al., 2019; Ruchay et al., 2020; Kojima et al 2022), equines (Freitag et al., 2021), pigs (Schofield et al., 1999; Zhang et al., 2021), and sheep (Zhang et al., 2018a, b). This technology would be highly recommended to assess camels' morphological changes and body condition

Table 2 Concordance correlation analysis between the body measurement methods (reference method and image analysis method; $n=59$)

Variable	Lin's r_{ccc} (95% CI)	Precision ρ	Accuracy C_b
TL	0.987 (0.978 to 0.992)	0.988	0.999
SIL	0.991 (0.984 to 0.994)	0.991	0.99
HW	0.987 (0.978 to 0.992)	0.988	0.999
HH	0.988 (0.980 to 0.992)	0.989	0.998
HR	0.9668 (0.944 to 0.980)	0.967	0.999
IW	0.936 (0.896 to 0.961)	0.944	0.991
WT	0.927 (0.882 to 0.955)	0.931	0.995
IsW	0.948 (0.915 to 0.968)	0.95	0.998
CD	0.95 (0.92 to 0.969)	0.956	0.994
SW	0.936 (0.896 to 0.961)	0.943	0.993
LAL	0.969 (0.949 to 0.981)	0.974	0.994
LPL	0.976 (0.960 to 0.985)	0.977	0.998
NL	0.964 (0.940 to 0.978)	0.964	0.999
NW	0.941 (0.903 to 0.964)	0.945	0.994
HuH	0.947 (0.917 to 0.968)	0.959	0.988
HuL	0.980 (0.9679 to 0.9884)	0.981	0.999
HuW	0.952 (0.922 to 0.970)	0.956	0.994
LH	0.954 (0.925 to 0.972)	0.964	0.989
HeW	0.792 (0.678 to 0.869)	0.816	0.97
EL	0.269 (0.015 to 0.444)	0.346	0.779
TaL	0.947 (0.914 to 0.968)	0.959	0.987

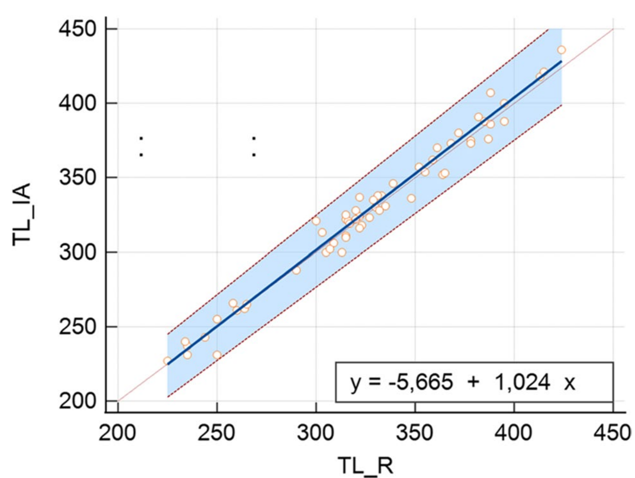

Fig. 4 Passing-Bablok regression for analysis of relationship between camel spiral circumference obtained by reference method (TL_R) and image analysis (TL_IA). The blue diagonal line indicates the equality line, where $y=x$. Statistics: TL_R = 327.06 cm; TL_IA = 328.23 cm; mean = 327.64 cm; SEM = 6.57, intercept = −5.66 (95% CI = −19.21 to 5.26), slope = 1.024 (95% CI = 0.96 to 1.03), $R^2=0.95$, $P<.0001$, CV = 1.71%

during the different stages of lactation and also to determine the conformation, the profile, and the format of camels intended for slaughter or the monitoring of young animals in growth. Finally, this technology is also interesting for determining the animals' live weight when prescribing drugs or calculating individual needs when formulating rations.

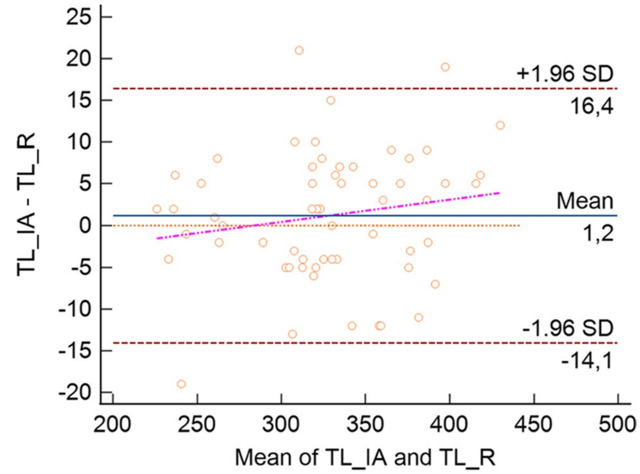

Fig. 5 Bland–Altman plot analysis for comparison of total length (TL) obtained by reference method (TL_R) and image analysis (TL_IA). The dashed lines are upper and lower limit of agreement, the solid line is the mean difference (bias). Statistics: mean difference = 1.16 (95% CI = −0.86 to 3.19); P (H0: mean = 0): 0.25; lower limit = −14.1 (95% CI = −17.58 to −10.60); upper limit = 16.43 (95% CI = 12.94 to 19.92)

The effectiveness of the image analysis was evaluated in the present study by determining the relative error of variance, concordance correlation, and possible sources of bias in the results of the manual and image analysis methods for each body measurement. The morphological criteria consider the animal in its length, width, height, and depth by examining the images taken from the profile, front, and behind positions. In other hand, the linear regression between all the measurements taken by the reference method and those obtained by image analysis revealed that the results of the two methods are quite correlated (high R^2; $P<0.001$). However, high correlation does not necessarily mean agreement since the correlation coefficient cannot detect systematic bias (McAlinden et al., 2011 2011). The CV of these parameters is less than 10%. This indicates the low variability of the quantitative body characteristics measured several times compared to the mean of this characteristics calculated from these same measurements. A non-significant difference in the mean values between the two body measurement methods was recorded for eleven parameters ($P>0.05$). Recently; Çağlı and Yılmaz (2021) have compared the body measurements between manual measuring method and photographic (2D) and 3D methods in dromedary species. They showed that the accuracy of image analysis (2D) compared to manual measurements was lower, indicated by a significant difference between the results of the two methods for height at withers, back height, rump height, body length, shoulder width, and rump width (Çağlı and Yılmaz 2021). According to these authors, only rump width was statistically non different between the two methods (Çağlı and Yılmaz 2021). These results are in contrast to our findings except for the shoulder width. In addition, we have found that the results of the following parameters were not statistically different: chest depth, width at the trochanter, length of the posterior limb, neck length, hump length, and hump width. Differences between our results and those obtained by Çağlı and Yılmaz (2021) would be due to the image analysis process. However, the 3D image analysis is a more reliable, easy, and practical method for camel body method only for two parameters, which are brisket height and abdominal height (Çağlı and Yılmaz 2021). In cattle, previous reports indicate that the body measurements using photographic support provide good precision (correlation between 0.78 and 0.89 for the chest depth, hip width, and circumference chest) and also good repeatability and reproducibility (CVr = 2.91% and CVR = 3.95%, respectively) except for Ischial Width, where both Ingenera and Morpho 3D devices do not give reliable results for this parameter (Fischer et al. 2015; Le Cozler et al. 2018). Analyses of the repeatability and reproducibility of zoobiometry on photographic images in dromedaries are not available yet.

The mean comparison and coefficient of variation level of manual measurements and image analysis should be taken with caution as they do not provide proper conclusions. Indeed, the two averages can be equal to two completely discordant series. It compares the means of two samples, and the results will reveal a constant but not proportional difference between the two sets of measurements (Bilić-Zulle 2011). The CV < 10% does not necessarily indicate that the *N* values measured on an individual are close to each other. Likewise, the correlation between the values of body measurement methods could be significantly high, but the two methods are not concordant. Correlation for linear regression presumes that comparative method results are measured without error (Linnet 1993). It describes the linear relationship between two sets of data but not their agreement (Udovičić et al., 2007) and it does not detect if there is a constant or proportional difference between the two methods. Therefore, we analyzed the correlation between body measurement methods using Lin's concordance on individuals studied only once by the same operator to determine the agreement between methods (Lin 1989; Barnhart et al., 2007). Furthermore, the graphical method of Bland and Altman was used because it is based on the definition of the concordance between two series of measurements (Bland and Altman, 1986). The two series are concordant if one does not overestimate or underestimate the other significantly. The Bland–Altman analysis enables the determination of systematic bias between manual measurement as a reference method and an image analysis method by calculating the mean difference between measurement results. It allows the calculation of limits of agreement, which allows the estimation of the total bias consisting of systematic and random bias (Bland and Altman 1986, 1999).

In the current study, we observed a perfect level of Lin's coefficient of concordance for all morphological parameters except EL. This indicates that the differences between the abscissa (image analysis method) and ordinate (reference method) points and the 45° line (line of equality) are small, which are represented by C_b values (accuracy) close to 1 (Sup. Figure 2). It was also observed that there is usually a low bias between measurements and narrow limits of agreement concordance ranging between 93.22 and 98.3% (Sup. Figure). In the literature, some studies implemented such data analysis methods to describe an agreement between methods used for body measurements evaluation, claw conformation, udder traits, and body composition in dairy cattle (Alawneh et al., 2011; Song et al., 2014; Laven et al., 2015; Bell et al., 2018; Shorten 2021). Similar approaches were also used to estimate the concordance to predict body fat percentage and body mass index categories in humans using different methods and devices (Affuso et al., 2018; Kogure et al., 2020; Lahav et al., 2021). However, to the best of our knowledge, no such analysis is available to evaluate the accuracy of different body measurement methods in dromedary camel.

Since measurement errors had to be assumed in both comparison and testing methods, the Passing-Bablok regression was preferred over ordinary linear regression (Passing and Bablok 1983). The Passing and Bablok regression analysis allows valuable estimation of the analytical methods' agreement and possible systematic bias between them. It is robust and non-sensitive to the distribution of errors and data outliers (Bilić-Zulle 2011). Reference and estimated methods produced accurate results for all studied morphological parameters. Based on the reported 95% limits of agreement, the slope reveals that there is no systematic difference [− 7.31; 9.61] and also no proportional difference (from 0 to 21%) between the two measurement means (Sup. Figure 2). Only the EL study showed high systematic and proportional bisection values of around 7.66 cm and 67%, respectively (Sup. Figure 3). Based on similar analysis results performed by Zhang et al. (2018a), it was concluded that visual image analysis–based method is effective, and it is especially suitable for sheep feeding in an intensive and large-scale way.

The present study showed that the use of image analysis for measuring linear body traits from camel photos taken in profile, front, and behind positions allowed us to obtain results with low coefficients of variation and high correlation apart from the ear length. All statistical analyses confirmed a very good concordance between the two series of measurements, with low bias and no systematic or proportional difference between the two measurement methods.

To conclude, the current study clearly showed that the numerical method can estimate nearly all the measurements, with high precision. These results indicate that the image body measuring method is easier to implement than the manual method and also has the advantages of less workload and impersonal impartiality at high speed while working in safety, especially in difficult conditions. The next step of our study would be to improve the conditions for taking photos so we could get a better magnification of the technique.

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Author contribution G.D.E. conceived and designed the study and performed the experiments; G.D.E. and L.R analyzed the data and G.D.E., L.R., C.F., and G.S.B.S. wrote and corrected the paper. All authors read and approved the manuscript.

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Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics declarations The camels were studied according to the ethical principles of animal experimentation and international guidelines for animal welfare (Terrestrial Animal Health Code 2018, Sect. 7. Art 7.5.1) and national executive decree No. 95–363 of November 11, 1995 (Algeria).

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

References

Affuso, O., Pradhan, L., Zhang, C., Gao, S., Wiener, H.W., Gower, B., Heymsfield, S.B and Allison, D.B., 2018. A method for measuring human body composition using digital images. *PLoS One*, ;13(11), e0206430.

Al-Atiyat, R.M., Suliman, G., AlSuhaibani, E., El-Waziry, A., Al-Owaimer, A. and Basmaeil, S., 2016. The differentiation of camel breeds based on meat measurements using discriminant analysis. Tropical Animal Health and Production, 48(5), 871–878.

Alawneh, J.I., Stevenson, M.A., Williamson, N.B., Lopez-Villalobos, N., Otley, T., 2011. Automatic recording of daily walkover liveweight of dairy cattle at pasture in the first 100 days in milk, Journal of Dairy Science, 94(9), 4431-4440.

Alhajeri, B.A., Alhaddad, H., Alaqeely, R., Alaskar, H., Dashti, Z. and Maraqa, T., 2021. Camel breed morphometrics: current methods and possibilities, Transactions of the Royal Society of South Australia. DOI: https://doi.org/10.1080/03721426.2021.1889347

Ayadi, M., Aljumaah, R.S., Samara, E.M., Faye, B. and Caja, G., 2016. A proposal of linear assessment scheme for the udder of dairy camels (*Camelus dromedarius*). Tropical Animal Health and Production, *48*(5), 927–933.

Barnhart, H.X., Lokhnygina, Y., Kosinski, A.S. and Haber, M 2007. Comparison of concordance correlation coefficient and coefficient of individual agreement in assessing agreement. Journal of Biopharmaceutical Statistics, 17(4), 721-38.

Bell, M.J., Mareike, M., Marion, S. and Robert, P., 2018. Comparison of Methods for Monitoring the Body Condition of Dairy Cows. Frontiers in Sustainable Food Systems, 2, 80.

Bewley, J.M., Peacock, A.M., Lewis, O., Boyce, R.E., Roberts, D.J., Coffey, M.P., Kenyon, S.J. and Schutz, M.M., 2008. Potential for estimation of body condition scores in dairy cattle from digital images. Journal of Dairy Science, 91 (9), 3439–3453.

Bilić-Zulle, L., 2011. Comparison of methods: Passing and Bablok regression. Biochemia Medica. 21, 49-52.

Bland, J.M. and Altman, D.G., 1986. Statistical method for assessing agreement between two methods of clinical measurement. Lancet, i:307–310.

Bland, J.M. and Altman, D.G., 1999. Measuring agreement in method comparison studies. Statistical Methods in Medical Research, 8(2), 135–160.

Çağlı, A. and Yılmaz, M., 2021. Determination of some body measurements of camels with three-dimensional modeling method (3D). Tropical Animal Health and Production, 53, 554.

Fischer, A., Luginbuhl, T., Delattre, L., Delouard, J. M. and Faverdin, P., 2015. Rear shape in 3 dimensions summarized by principal component analysis is a good predictor of body condition score in Holstein dairy cows. Journal of Dairy Science, 98 (7), 4465 - 4476.

Freitag, G.P., de Lima, L.G.F., Jacomini, J.A., Kozicki, L.E. and Ribeiro, L.B., 2021. An Accurate Image Analysis Method for Estimating Body Measurements in Horses. Journal of Equine Veterinary Science, 101, 103418.

Gherissi, D.E., Afri-Bouzebda, F., Bouzebda, Z. and Lamraoui, R. 2014. Morphometric variations and endocrine changes of the one-humped male camel in relation to reproductive activity. Ruminant Science, 3(1), 9-18

Gherissi, D.E., Afri-Bouzebda, F., Bouzebda, Z., 2018. Seasonal changes in the testicular morphology and interstitial tissue histomorphometry of Sahraoui camel under Algerian extreme arid conditions. Biological Rhythm Research, 49 (2), 1744-4179.

Gherissi, D.E., Boukhili, M. and Gherissi, A., 2020. Genital histomorphometrical evaluation and survey on reproductive traits of male camel (*Camelus dromedarius*) in relation to the pubertal age under extreme arid conditions. Asian Journal of Agriculture and Biology 8(4): 436-446

Iglesias, C., Navas, F. J., Ciani, E., Arbulu, A. A., González, A., Marín, C. and Mérida, S.N., 2020. Zoometric characterization and body condition score in Canarian camel breed. Archivos de zootecnia, 69(265), 102–107.

Kamili, A., Bengoumi, M. and Faye B., 2006. Assessment of body condition and body composition in camel by barymetric measurements. Journal of Camel Practice and Research,13(1), 67-72.

Kang, X., Zhang, X.D. and Liu, G., 2020. Accurate detection of lameness in dairy cattle with computer vision: A new and individualized detection strategy based on the analysis of the supporting phase. Journal of Dairy Science, 103(11), 10628-10638.

Kashiha, M.A., Green, A.R., Sales, T.G, Bahr, C., Berckmans, D. and Gates, R.S., 2014. Performance of an image analysis processing

system for hen tracking in an environmental preference chamber. Poultry Science, 93(10), 2439-2448.
Kogure, G.S., Silva, R.C., Ribeiro, V.B., Mendes, M.C., Menezes-Reis, R., Ferriani, R.A., Furtado, C.L.M. and Reis, R.M.D. 2020. Concordance in prediction body fat percentage of Brazilian women in reproductive age between different methods of evaluation of skinfolds thickness. The Archives of Endocrinology and Metabolism, 64 (3), 257-268.
Kojima, T., Oishi, K., Aoki, N., Matsubara, Y., Uete, T, Fukushima, Y., Inoue, G., Sato, S., Shiraishi, T., Hirooka, H. and Masuda T., 2022. Estimation of beef cow body condition score: a machine learning approach using three-dimensional image data and a simple approach with heart girth measurements. Livestock Science, 256, 104816.
Kuzuhara, Y., Kawamura, K., Yoshitoshi, R., Tamaki, T., Sugai, S., Ikegami, M., Kurokawa, Y., Obitsu, T., Okita, M., Sugino, T., Yasuda, T., 2015. A preliminarily study for predicting body weight and milk properties in lactating Holstein cows using a three-dimensional camera system. Computers and Electronics in Agriculture, 111, 186-193.
Lahav, Y., Goldstein, N. and Gepner, Y. Comparison of body composition assessment across body mass index categories by two multifrequency bioelectrical impedance analysis devices and dual-energy X-ray absorptiometry in clinical settings. European Journal of Clinical Nutrition, 75, 1275–1282
Laven, L.J., Wang, L., Regnerus, C. and Laven, R.A. 2015. Measuring Claw Conformation in Cattle: Assessing the Agreement between Manual and Digital Measurement. Animals, 5, 687-701.
Le Cozler, Y., Allain, C., Faverdin, P., Delattre, L. and Delouard, J.M. 2018. L'imagerie 3d, un outil pour estimer les caractéristiques corporelles des animaux. D'après C. Allain, A. Caillot, L. Depuille, P. Faverdin, J M Delouard, et al. 2018. : Utilisation d'un dispositif d'imagerie en 3D pour modéliser la forme complète de bovins laitiers et mesurer de nouveaux phénotypes morphologiques. 24. Rencontres autour des recherches sur les ruminants (3R), 2018, NA, France.
Le Cozler Y., Allain, C., Caillot, A., Delouard, J.M., Delattre, L., Luginbuhl, T. and Faverdin, P., 2019. High-precision scanning system for complete 3D cow body shape imaging and analysis of morphological traits. Computers and Electronics in Agriculture, 157, 447-453.
Lin, L., 1989. A concordance correlation coefficient to evaluate reproducibility. Biometrics, 45:255–268.
Linnet, K., 1993. Evaluation of regression procedures for methods comparison studies. Clinical Chemistry, 39, 424-32.
McAlinden, C., Khadka, J. and Pseudovs, K., 2011. Statistical methods for conducting agreement (comparison of clinical tests) and precision (repeatability or reproducibility) studies in optometry and ophthalmology. Ophthalmic and Physiological Optics, 31, 330–338.
Meghelli, I., Kaouadji, Z., Yilmaz, O., Cemal, I., Karaca, O. and Gaouar, S.B.S., 2020. Morphometric characterization and estimating body weight of two Algerian camel breeds using morphometric measurements. Tropical animal health and production, 52 (5), 2505-2512
Negretti, P., Bianconi, G., Bartocci, S., Terramoccia, S. and Verna, M., 2008. Determination of live weight and body condition score in lactating Mediterranean buffalo by Visual Image Analysis. Livestock Science, 113, 1–7.
Passing, H. and Bablok, W., 1983. A new biometrical procedure for testing the equality of measurements from two different analytical methods. Application of linear regression procedures for method comparison studies in Clinical Chemistry, Part I. Journal of Clinical Chemistry and Clinical Biochemistry, 21,709–720.
Ruchay, A., Kober, V., Dorofeev, K., Kolpakov, V. and Miroshnikov, S., 2020. Accurate body measurement of live cattle using three depth cameras and non-rigid 3-D shape recover., Computers and Electronics in Agriculture, 179, 105821.
Schofield, C.P., Marchant, J.A., White, R.P., Brandl, N. and Wilson, M., 1999. Monitoring Pig Growth using a prototype imaging system. Journal of Agricultural Engineering Research, 72, 205-210.
Sénèque, E., Lesimple, C., Morisset, S. and Hausberger, M., 2019. Could posture reflect welfare state? A study using geometric morphometrics in riding school horses. PLoS One, 14(2),e0211852.
Shorten, P.R., 2021. Computer vision and weigh scale-based prediction of milk yield and udder traits for individual cows. Computers and Electronics in Agriculture, 188, 106364.
Song, X., Schuttea, J.J.W., Van der Tolb, P.P.J., Van Halsemab, F.E.D. and Groot Koerkampa P.W.G., 2014. Body measurements of dairy calf using a 3-D camera in an automatic feeding system. Proceedings International Conference of Agricultural Engineering, Zurich, 06–10.07.2014 – www.eurageng.eu. Ref: C0467
Udovičić, M., Baždarić, K., Bilić-Zulle, L. and Petrovečki, M., 2007. What we need to know when calculating the coefficient of correlation? Biochemia Medica, 17, 10-15.
Viazzi, S., Bahr, C., Schlageter-Tello, A., Van Hertem, T., Romanini, C.E.B., Pluk, A., Halachmi, I., Lokhorst, C. and Berckmans, D., 2013. Analysis of individual classification of lameness using automatic measurement of back posture in dairy cattle. Journal of Dairy Science, 96(1), 257–266.
Yahaya, A., Olopade, J.O., Kwari, H.D. and Wiam, I. M., 2012. Osteometry of the skull of one-humped camels. Part I: Immature animals. Italian Journal of Anatomy and Embryology, 117 (1), 23–33.
Zhang A.L.N., Wu, B.P., Jiang, C.X.H., Xuan, D.C.Z., Ma, E.Y.H and Zhang, F.Y.A. 2018a. Development and validation of a visual image analysis for monitoring the body size of sheep, Journal of Applied Animal Research, 46(1), 1004-1015
Zhang, A.L., Wu, B.P., Wuyun, T.C., Jiang, X.D., Xuan, E.C. and Ma, F.Y. 2018b. Algorithm of sheep body dimension measurement and its applications based on image analysis. Computers and Electronics in Agriculture,153, 33-45
Zhang, J., Zhuang, Y., Ji, H. and Teng, G., 2021. Pig Weight and Body Size Estimation Using a Multiple Output Regression Convolutional Neural Network: A Fast and Fully Automatic Method. Sensors, 21, 3218.
Zhao, K.X. and He, D.J., 2015. Target detection method for moving cows based on background subtraction. International Journal of Agricultural and Biological Engineering, 8(1), 42-49.

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