

Comparison of Transverse Thoracolumbar Angles in Dressage and Endurance Horses Using 3D Light Scanning and Comparison with Commercial Saddle Gullet Angles

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Abstract

The thoracolumbar profile is of interest in relation to saddle design and saddle fit. Flexible-curve rulers have previously been used to gather thoracolumbar profiles in horses; however, 3D light scanning offers a potential non-contact alternative method to estimate the cross-sectional shape of the region in greater detail. The aims of this study were to (1) describe the thoracolumbar profiles of endurance and dressage horses using 3D light scanning and (2) compare the wither profiles to saddle manufacturers' gullet bar angles. 3D light scans of the thoracolumbar region were obtained from 23 fit and competing Arabian endurance horses and 21 dressage horses of mixed breed competing at advanced or higher, each from two different stables. Markers were placed by palpation on the caudal scapula (V1) and T18 (V4). Images were imported into Meshmixer. A transversely oriented plane cut was taken at the level of the marker of the left caudal scapula, perpendicular to the back surface (V1), and at the level of the marker at T18. Two further cuts were made at the base of the withers (V2) and the lowest point/midpoint of the back (V3). The mean transverse back angle at V1 was $87 \pm 8^\circ$ for the endurance horse sample and $99 \pm 10^\circ$ for the dressage horse sample ($P < 0.0001$), and at V4 was $141 \pm 7^\circ$ (endurance) and $144 \pm 6^\circ$ (dressage) ($P < 0.0001$). For both endurance horses and dressage horses, there was a significant effect of location on back transverse angle (V1 to V4; $P < 0.001$), with V1 the narrowest and V4 the widest. While there is little consistency in what gullet angle a "medium" gullet bar would actually be, the range of angles measured at the shoulder in the present study reflects the most common gullet sizes offered by six manufacturers of English saddles.

Keywords

Back; equestrian; riding; equine; morphometry

1. Introduction

Knowledge of the back shape is important for saddle design and saddle fitting. Traditionally, saddle fitters, saddle makers, and researchers have used flexi-curves to take templates of horses' backs for different purposes [1–4]. In addition, a number of commercial systems exist for obtaining back dimensions, including physical/mechanical systems [5] and smartphone-based light scanning systems (HorseShape

Smart 3D Scan App, TZK, TechnologieZentrum Koblenz, Universitätsstr. 3, 56070 Koblenz, Germany).

Three-dimensional (3D) light scanning as a method of data collection is still a relatively new approach in its application to horses, but has been suggested to be reliable for measuring trunk and limb volumes [6,7], transverse epaxial muscle symmetry in the thoracolumbar region [8], and general body morphometry [9,10].

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Light scanning technologies have become fundamental in diverse scientific and industrial fields, including 3D modeling, biomedical imaging, and quality assurance. Traditional methods, such as laser scanning, structured light scanning, and time-of-flight (ToF) scanning, each offer unique advantages. Laser scanners use coherent beams to map surfaces with high precision, which is especially effective over longer distances [11]. Structured light systems project known patterns onto surfaces and analyze distortions to generate high-resolution 3D models, making them well suited for capturing detailed geometries [12]. ToF scanners measure the travel time of light pulses to reconstruct depth information, enabling rapid scanning over large areas, albeit with generally lower resolution [13]. More recently, the proliferation of smartphone-based scanning technologies has significantly expanded access to 3D scanning. Many modern smartphones are now equipped with front-facing cameras capable of depth sensing through structured light, and increasingly with LiDAR sensors that use ToF principles to generate depth maps in real time [14]. These mobile systems, while typically less accurate than professional-grade equipment, offer portability, affordability, and real-time feedback, making 3D scanning more accessible than ever before.

The aims of the present study were to use the previously established technique by Tabor *et al.* [8] to obtain scans of two sets of endurance and two sets of dressage horses in order to characterize the thoracolumbar transverse angles at the level of the caudal aspect of the shoulder and the base of the withers, lowest/midpoint of the back, and T18 with respect to position and horse type/use. In addition, a secondary aim was to compare the wither profiles to saddle manufacturers' gullet bar angles. Alignment between the range of angles measured at the withers and the range of angles offered by saddle manufacturers was anticipated.

2. Materials and Methods

2.1. Horses

A convenience sample of 23 Arabian endurance horses in full training and competing at FEI CEI*** levels with two different trainers, and 21 dressage horses competing at Advanced or higher at two stables, were recruited for the study (Table 1). All horses were considered by the trainer and the attending veterinary surgeon to be free of overt lameness or obvious musculoskeletal asymmetry. Scanning was undertaken in rooms or locations with which all horses were familiar.

Table 1: Signalment of horses used in the present study (m = mare; g = gelding).

Stable	n	Sex	Age	Breed
Endurance 1	16	4m/12g	8 ± 2	Arabian
Endurance 2	7	4m/3g	11 ± 3	Arabian
Dressage 1	15	3m/12g	9 ± 4	Warmblood/Warmblood x Hanoverian
Dressage 2	6	5m/1g	13 ± 1	Warmblood/Warmblood x

2.2. Scanning Equipment

The equipment used for scanning was as described previously by Tabor *et al.* [8]. Images were obtained using a Structure Sensor (STO1) mounted on an 11-inch iPad Pro with the Structure Sensor Bracket (Model SA21) (Occipital Inc., Boulder, Colorado, 80302, USA). Images from the iPad were sent over Wi-Fi to Skanect Pro Software (V1.1, Occipital Inc.) running on a Lenovo Ideapad 500 laptop. The connection between the iPad and the laptop was via a 300 Mbps nano-router in AP mode connected to the laptop (TL-MR3020 ver. 3.2, TP-Link, Unit 2 & 3 Riverview, Cardiff Road, Reading, RG1 8EW, UK). This was found to provide a more stable and reliable connection than connecting directly to the laptop Wi-Fi. The wide-angle lens option supplied with the Structure Sensor was not used, as initial trials suggested the iPad standard camera lenses were adequate. The calibration of the Structure Sensor was performed according to the manufacturer's instructions. The settings in the Skanect Software were: Recording Feedback: CPU; Feedback Quality: Low; Offline Recording: Key Frames; Force QVGA: ON; Track Loss Detection: On; Uplink Mode: Depth & Color; Uplink Color Gain: Locked on Record. The specific scan settings were set as: Scene: Body; Bounding Box: 1.8 meters; Aspect Ratio: Normal. Scanning was initiated and terminated on the iPad.

2.3. 3D Light Scan Protocol

The scanning protocol was as described previously [8]. Briefly, 20-mm white polystyrene hemispherical markers were placed on the caudal aspect of the left and right scapula, and a third marker was attached to the midline of the spine at the cranio-caudal level of T18, identified by palpation from the last rib. Each horse was scanned at a distance of approximately 1.5 m, three times. Files were exported as STL files.

STL files were imported into Meshmixer (V3.5.474, 2017, Autodesk Inc., San Rafael, California, United States). A wireframe was applied to the images, then the processed images were saved as Meshmixer files (.mix). Example images are shown in Figure 1, Figure 2, and Figure 3.

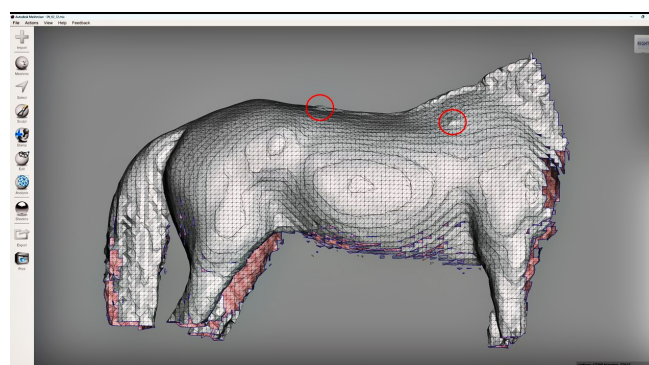


Figure 1: Example of a 3D scan of a horse imported as an STL file into Meshmixer and viewed from the right side, with 20 mm polystyrene markers placed on the caudal scapula and T18, as identified by palpation.

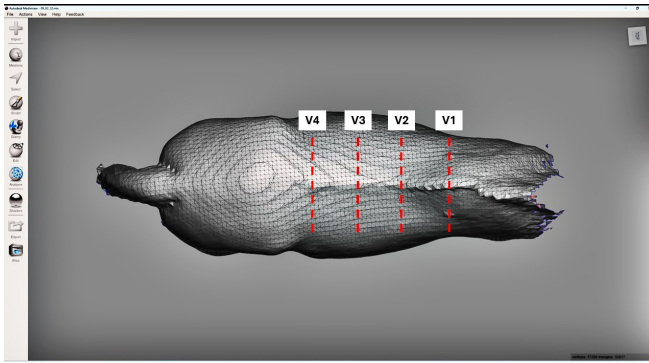


Figure 2: Same horse and file as in **Figure 1**, viewed from above, with the location of transverse plane cuts identified as V1 – caudal scapula; V2 – lowest point of the withers; V3 – midpoint between V2 and V4; and V4 – T18.

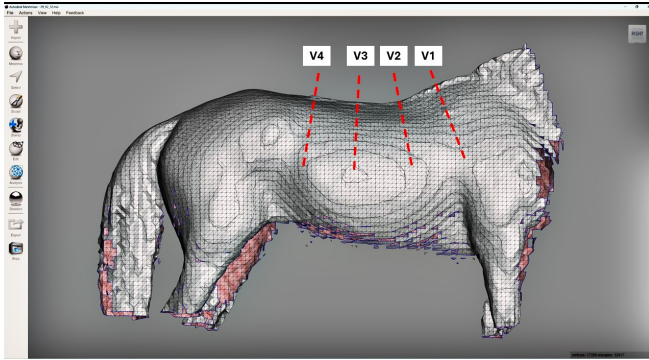


Figure 3: Same horse and file as in **Figure 1** and **Figure 2**, viewed from the right side, with the location and angulation of transverse plane cuts perpendicular to the back identified as V1 – caudal scapula; V2 – lowest point of the withers; V3 – midpoint between V2 and V4; and V4 – T18.

2.4. 3D Image Analysis

Each image was rotated to the sagittal view, and the Meshmixer software's slicing tool was used to divide the shell into four sections deep (V1 to V4). A transversely oriented plane cut was taken at the level of the marker of the left caudal scapula, perpendicular to the back surface (V1), and a second transverse plane cut was taken at the level of the marker at T18 (V4; also perpendicular to the back surface). Two further transverse cuts were made at the base of the withers, i.e., the lowest point/midpoint of the back (V2), and at the midpoint between V2 and V4 (V3), as shown in **Figure 2** and **Figure 3**. Each transverse cut section was saved as a .jpeg file and imported into ImageJ (National Institutes of Health, Bethesda, MD, USA) for determination of back transverse angle (**Figure 4**). The reliability of this approach has previously been reported [8].

In order to compare the measured angles with the ranges of gullet bar angles commonly provided by manufacturers of English saddles, images of gullet bars from six leading brands of English saddles were obtained either from manufacturers' websites or through saddlers. The brands selected were: 1) Kent & Masters, Thorowgood, and Fairfax (which all use the same gullet bar system); 2) Whitaker; 3) Wintec and Bates (which use the same gullet bar system); 4) Premier Equine; 5) GFS Monarch; and 6) Cavaletti. Gullet angles were

calculated in ImageJ. An example of the measurement of the angle of the GFS Monarch extra-wide gullet bar is shown in **Figure 5**.

2.5. Statistical Analysis

Normality of the distribution of data was investigated using the Shapiro–Wilk test. Data were found to approximate a normal distribution; therefore, a parametric approach was used. Comparisons between different stables for dressage and endurance were made using an unpaired t-test. Comparisons between back angles at different longitudinal positions (V1 to V4) within dressage or endurance were made using ANOVA and post-hoc Tukey's test. The relationship between back angles at different locations was investigated using Pearson's correlation. Data are presented as mean $\pm$ SD, and significance was set at $P < 0.05$.

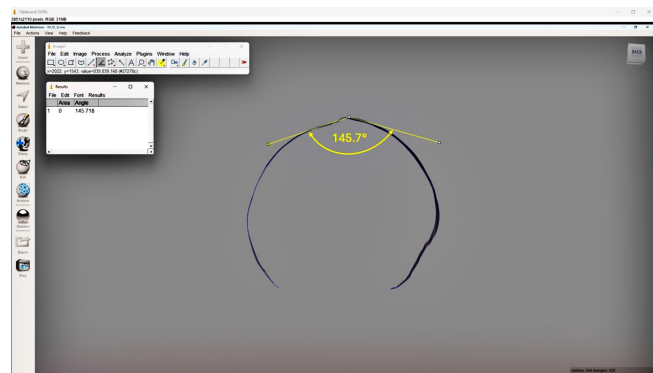


Figure 4: Same horse and file as in **Figure 1**, **Figure 2**, and **Figure 3**, with a transverse plane cut from Meshmixer at T18 (V4) exported as a .jpeg file, and back angle calculated in ImageJ. Image viewed from the cranial aspect. The image section is 20 mm wide (cranio-caudal distance).

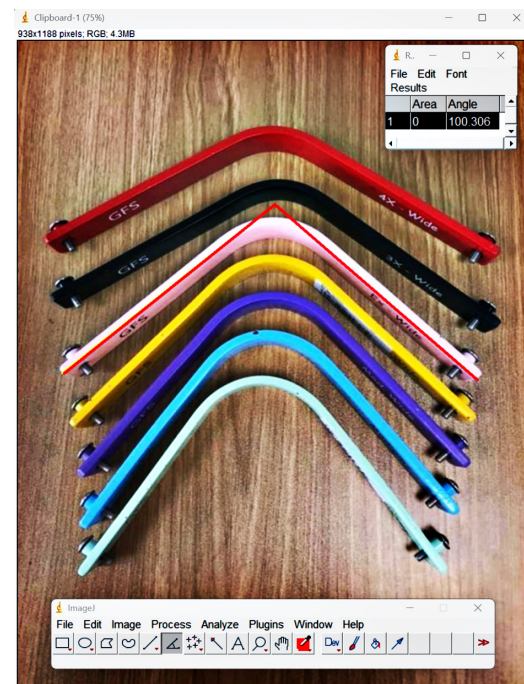


Figure 5: Measurement of the angle (red line) of the GFS Monarch Extra-Wide gullet bar (pink) using ImageJ, indicating an angle of 100.3°.

3. Results

3.1. Back Angles

Successful scans were obtained from all horses. The number of repeat scans required due to scan failure, which was always caused by significant horse movement, was less than 1%. In both populations, the transverse back angle was narrowest at V1 and widest at V4, with the greatest change in angle between V1 and V2, followed by V2 and V3, and the smallest difference between V3 and V4 (**Figure 6**). The mean transverse back angle at V1 was $87 \pm 8^\circ$ for the endurance horse sample and $99 \pm 10^\circ$ for the dressage horse sample ($P < 0.0001$), and at V4 was $141 \pm 7^\circ$ (endurance) and $144 \pm 6^\circ$ (dressage) ($P < 0.0001$).

Overall, there was no significant difference in transverse angles at V1 to V4 between endurance stable 1 or 2, or dressage stable 1 and 2, and data for both endurance stables and both dressage stables were therefore combined for further analysis. For the endurance horses, ANOVA indicated a significant difference due to location (V1 to V4; $F = 85.5$, $P < 0.001$), and also for the dressage dataset (V1 to V4, $F = 83.7$, $P < 0.001$) (**Figure 6**).

3.2. Correlation Between Back Angles at Different Locations Along the Back

Correlation between back angles in endurance horse and dressage horse populations at V1, V2, V3, and V4 is shown in **Table 2**. In both the endurance and dressage samples, there was a strong correlation between the angle at V3 and V4, explaining around 60% of the variance. In neither sample was there a significant relationship between V1 and V4, and no relationship between V1 and V3 in dressage, with only a weak significant correlation for endurance. V2 and V3 and V2 and V4 were significantly correlated in the dressage sample but not in the endurance sample.

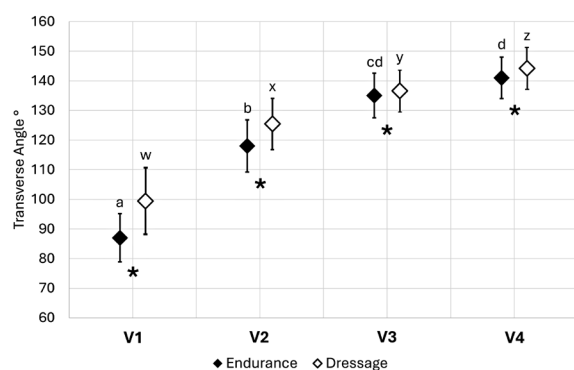


Figure 6: Transverse back angles perpendicular to the back surface at locations V1, V2, V3, and V4 in 23 endurance horses and 21 dressage horses. Mean $\pm$ SD. * indicates endurance significantly different from dressage at least $P < 0.0001$. Within groups (endurance or dressage), locations with different letters are all significantly different, at least $P < 0.0001$ for endurance. V3 versus V4 for endurance = ns ($P = 0.06$). For dressage, all locations were significantly different at least $P < 0.0001$, except V3 versus V4, $P = 0.013$.

3.3. Gullet Bar Angles Used by English Saddle Makers

The gullet bar angles from six English saddle manufacturers are shown in **Table 3**. The greatest variation in measured or manufacturer-reported gullet bar angles was for the larger gullet widths/sizes of medium wide up to 4XW (a range of $9-14^\circ$). Variation was considerably lower for narrow (5°), narrow/medium (8°), and medium (3°). The average increment between gullet bar sizes was $5 \pm 2^\circ$.

When the distribution of gullet bar angles from these six manufacturers, as opposed to how they refer to them in width fittings, is compared with the V1 angles of the endurance and dressage horse sample populations (**Figure 7**), it can be seen that both the endurance horse sample and dressage horse sample span the most common angle range of $80-110^\circ$. This further supports the use of the 3D light scanning approach in the present study.

Discussion

Previously, the reliability of 3D light scanning to estimate the cross-sectional area of the epaxial region of the thoracolumbar spine was reported using the same equipment and methodology as in the present paper [8]. 3D light scans of the thoracic epaxial region were taken from ten endurance horses, representing a sub-sample of horses in the present study. The total cross-sectional area of the combined epaxial musculature was calculated at the level of the scapula and T18. No significant differences were found between the two different assessors experienced in using the software ($P = 0.88$; ICC: 0.90; CIs: 0.82–0.95). Intra-rater reliability for assessing thoracic profile and inter-rater reliability ICC values with experienced analysts were interpreted as good/excellent. These results suggest that 3D light scanning is an objective, noninvasive method to record size and symmetry of the epaxial region in horses and is likely to be more accurate and reliable than the use of flexicurves [8].

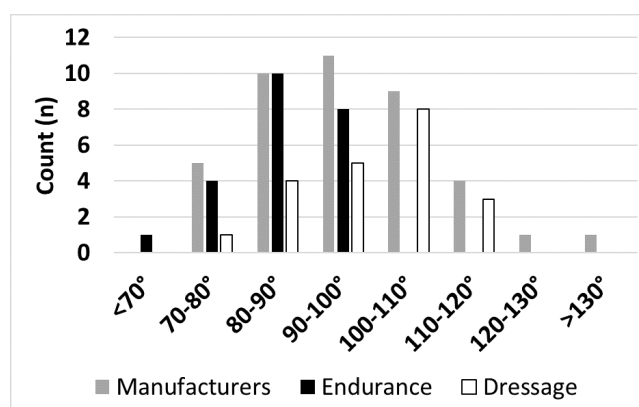


Figure 7: Distribution of gullet bar angles ($^\circ$) reported by manufacturers or calculated using ImageJ, where not reported by the manufacturer for six different brands of gullet bar system, compared with the distribution of V1 angles measured in endurance horses ($n = 23$) or dressage horses ($n = 21$).

Table 2: Pearson's correlation coefficient matrix for endurance (n = 23) and dressage samples (n = 21) at different back locations (V1, V2, V3, and V4).

Endurance (n = 23)					
Variable 1	Variable 2	r	r ²	df	P-value
V1	V2	0.38	0.14	21	ns
V1	V3	0.44	0.20	21	0.034
V1	V4	0.30	0.09	21	ns
V2	V3	0.30	0.09	21	ns
V2	V4	0.28	0.08	21	ns
V3	V4	0.76	0.57	21	P < 0.0001
Dressage (n = 21)					
Variable 1	Variable 2	r	r ²	df	P-value
V1	V2	0.37	0.14	19	ns
V1	V3	0.18	0.03	19	ns
V1	V4	0.03	0.00	19	ns
V2	V3	0.67	0.46	19	0.001
V2	V4	0.67	0.45	19	0.001
V3	V4	0.78	0.62	19	P < 0.0001

Table 3: Gullet bar angles (°) from six English saddle brands, either as reported by the manufacturer or measured from images.

Manufacturers classification	1 Kent & Masters / Thorowgood / Fairfax	2 Whitaker	3 Wintec / Bates	4 Premier Equine	5 GFS Monarch	6 Cavaletti	Mean	SD	%CV	Range	Increment
Narrow			75	77	72		75	2	3.3	5	
Narrow/ Medium	78		82	85	77	81	81	3	4.2	8	6
Medium	87	87	90	86		87	88	1	1.6	3	7
Medium Wide	91	97	92	91	83	88	90	5	5.3	14	3
Wide	95	103	95	97	91	93	96	4	4.1	12	5
Wide / Extra Wide	99						99				4
Extra Wide	106	107	100	102	96	103	103	4	3.9	11	3
Extra Wide / Extra Extra Wide	110						110				7
2XW	120	110	111			109	112	5	4.5	11	2
3XW			122		114		118	6	5.2	9	6
4XW			130		119		125	8	6.3	11	7

External methods for assessing the thoracic profile of horses, such as 3D scanning and flexicurves, do not reflect changes in the deeper musculature, such as the multifidus muscle [15], and ultrasound imaging is required for this [16]. The light scans collected for this study were not compared to a gold-standard ultrasound imaging method or to profiling with a flexicurve. However, collecting and analyzing these images using the techniques described in this study has been shown to be repeatable [8], and as such, the accuracy depends on the intrinsic accuracy of the Skanect system, which is almost certainly more objective than the flexicurve.

The narrowest transverse back angles were found at V1 and the widest angles at V4, which is unsurprising and consistent with conventional saddle design and flexicurve templates. Variance around the mean at each location was also similar, suggesting that there is a relationship between angles within a horse. Furthermore, it is unsurprising that the dressage horse population was found to be wider at all back locations measured, given the difference in body shape between the Arabian horses studied and commonly used in endurance, and the dressage horses, which were Warmblood, Warmblood X, and Hanoverian.

In both the endurance and dressage samples, there was a very strong correlation between the angle measured at V3 and V4, explaining around 60% of the variance in each. However, in contrast, there was no relationship between the angle at V1 and V4 in either the endurance or dressage samples. Conventionally, the gullet width of a saddle is measured at a location approximately three fingers behind the most caudal aspect of the scapula, which would equate to a position between V1 and V2 in the present study. While saddles come in a wide range of gullet angles and shapes, and gullet bars can be changed in many saddles, it is rare to find any saddle that allows adjustment towards the caudal aspect of the saddle. On the basis that, in this sample of horses, there was no evidence of a strong relationship between V1 and V3 or V1 and V4, the potential for saddle makers to provide saddles with varying caudal angles or caudal adjustment may be of interest.

Gullet sizing of English saddles, at least based on this sample of nine brands across six manufacturers, is not standardized. Some manufacturers use a range based on terms such as narrow, medium, wide, and extra wide, but without any specification of the angle, whereas others specify the angle of the gullet bar. However, the most common V1 angles measured in the present study reflect the most common gullet bar angles offered by manufacturers. Knowledge of back angles may potentially assist saddle manufacturers in saddle design and may also be relevant to professionals such as saddle fitters. 3D scanning also has the potential to highlight asymmetry in the area in which the saddle sits, which may again be relevant to saddle fitters, physiotherapists, and veterinary surgeons.

While static imaging of back dimensions may be informative, the "holy grail" is to be able to follow changes in back shape in horses ridden in saddles. Previously, we demonstrated that this is feasible in horses exercised at walk, trot, canter, and gallop on a treadmill without a rider or saddle [17]. More recently, equine back shape change has also been described in standing horses as well as in horses walking

and trotting in hand in an indoor barn under an array of high-speed cameras [18]. However, tracking back shape change in ridden horses at present appears to be extremely technically challenging.

4. Limitations

While 44 horses were scanned in this study, this is still a relatively small sample, and to describe populations accurately would require repeating with much larger numbers. For example, assuming a population of 800,000 horses in the UK, if 5% were Arabian, with a $\pm 5\%$ margin of error and a confidence level of 95%, a sample of ~380 horses would be required. Furthermore, this study did not attempt to validate the accuracy of 3D light scanning against "templating" with flexible rulers, although it can be reasonably anticipated that the 3D approach will be more accurate and reproducible.

5. Conclusions

In conclusion, the present study has demonstrated that thoracolumbar angle increases from the caudal aspect of the shoulder to T18 in samples of both endurance and dressage horses, with the greatest increase from V1 (caudal shoulder) to V2 (lowest point of the withers), and that dressage horses were significantly wider in this region at all locations measured. Furthermore, there was no or weak correlation between V1–V2 angles, where saddles are conventionally fitted, and thoracolumbar angles in the caudal region where the saddle would sit (V3–V4). Finally, while there is little consistency in what gullet angle a "medium" gullet bar would actually be, the range of angles measured at the shoulder in the present study does reflect the most common gullet sizes that are offered by six manufacturers of English saddles. Further studies might investigate the accuracy and repeatability of 3D light scanning apps using mobile phone-based front-facing or rear-facing LiDAR against flexicurve templates as an aid to saddle design, saddle manufacturing, and saddle fitting.

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Authors' Contributions

DM conceived the study, collected the data, analyzed the data, and wrote the manuscript.

Data Availability

Requests to access 3D scans for further collaborative analysis will be considered favorably on a case-by-case basis.

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Conflicts of Interest

David Marlin was compensated financially for his time by Ergon Equine Ltd to conduct this study, analyze the data, and prepare the manuscript.

Ethical Approval

Ethical approval was not required.

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