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Use and Repeatability of 3D Light Scanning to Measure Transverse Dorsal Profile Size and Symmetry in the Thoracic region in Horses

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ABSTRACT

Equine epaxial muscle size, thoracolumbar profile and symmetry in horses is of clinical interest due to relationships with pain and pathology. Flexible-curve rulers have previously been used to gather reliable, objective measures of thoracic profile, however 3D light-scanning offers a potential non-contact alternative method to estimate cross sectional area (CSA) of the region. 3D light-scans of the thoracic epaxial region were taken from ten endurance horses (7 geldings, 3 mares; 8±2 years). Total CSA of the combined epaxial musculature, using computer software, was calculated at scapula and T18 levels (depth: 15cm). Intra and inter-rater (n=3) reliability of CSA measurements was assessed using Friedman's analyses and *post-hoc* Wilcoxon rank tests (three repeated measures). Intraclass correlation estimates (ICC±95% confidence intervals (CI)) were calculated (mean-rating, absolute-agreement, 2-way mixed-effects model). Paired t-tests assessed differences between right and left areas. No significant differences existed for transverse plane-cuts (scapula, T18 P>0.05) between light-scans. Right and left areas were significantly different at the withers (p=0.012) with the left side larger in 70% of scans, but no significant differences were found between sides at T18. No differences existed for different plane-cuts of the same horse (p=0.53; ICC: 0.76; CIs: 0.43-0.92). While reliability was reduced between all raters (p=0.02; ICC: 0.70; CIs: 0.56-0.82), no significant differences occurred between 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 was interpreted as good/excellent. The results suggest 3D light-scanning is an objective, non-invasive method to record size and symmetry of the epaxial region in horses and warrants validity testing against current measurement methods such as the flexible-curve ruler.

Keywords: Equine, horse, objective, thoracic spine, outcome measurement, reliability

INTRODUCTION

Epaxial muscle size in horses is of interest to veterinary surgeons and physiotherapists due to their relationship with pain and pathology. Muscle atrophy has been reported in the presence of overriding spinous processes (Coomer *et al*., 2012), sacroiliac dysfunction (Barstow and Dyson, 2015) and as a result of poorly fitting saddles (Greve *et al*., 2015). Assessment of size and symmetry of epaxial muscles is often undertaken subjectively during a clinical examination (Tabor and Williams, 2018) to assess for pathology related muscle atrophy and asymmetry. Methods to quantify muscle size in a categorical manner (Walker *et al.,* 2016) and using tools such as ultrasound imaging (cross sectional area – Stubbs *et al*., 2010; Tabor, 2015; de Oliveira *et al*., 2015; and thickness – Lindner *et al*., 2010, Abe *et al.,* 2012; de Oliveira *et al*., 2015) have been shown to be reliable. However, ultrasound imaging requires the use of expensive and time-consuming methods as well as clipping/shaving of the haircoat overlying the muscles of interest, which can generate significant owner resistance especially in the competition horse due to cosmetic reasons. External dimensions can be traced non-invasively using a flexible curve ruler (FCR) and reliability testing indicates that the data are accurate and repeatable when using a strict consistent technique. The FCR has been used to document thoracic muscle shape, finding changes associated with exercise and saddle fit (Greve and Dyson, 2013; Mackechnie-Guire *et al.*, 2018). Objectively assessing muscle size and symmetry in other regions of the equine spine affected by pathology (for example: lumbar spinous process impingement, articular facet joint disease, lumbosacral region pain and ilial fracture) would be valuable, but to date use of the FCR has not been validated beyond the thoracic region.

Three-dimensional (3D) light-scanning as a method of data collection is new in its application for horses but has been suggested to be reliable for measuring equine trunk and limb volumes (Johnson and Symons, 2020 & Valberg *et al.,* 2020) and could potentially be used to record the dorsal profile of horses. Although unable to collect data on individual muscle dimensions, like the FCR, it may be useful to objectively measure total epaxial muscle cross section area in an efficient and non-invasive manner. The advantages in comparison to tools such as the FCR and ultrasound imaging are the ability to collect and store data of the profile of an object and manipulate the image at a later stage, to analyse multiple sites that the whole data contains. Additionally, a benefit is that there is no requirement for clipping hair or for physical contact with a horse.

3D light-scanning is the process of collecting data from the surface of a physical object which accurately describes its shape in 3D dimensions (Wells *et al*., 2008); the digital scan data obtained can then be used to construct, manipulate and analyse a 3D model. Many different techniques are available for obtaining the 3D surface coordinates, including contact and non-contact methods. Most 3D scanners are based on non-contact methods and include laser time-of-flight cameras and laser triangulation 3D cameras. Laser triangulation is commonly used with small objects placed on a rotating platform around which the lasers which both emit and receive light are based, they cope poorly with reflective surfaces and has a range of only several metres. Time-of-flight cameras are suited to applications involving distances in the order of kilometres, but have slow capture rates which is not an issue for static objects but can be problematic with a subject that has any movement.

Structured-light 3D scanners project a pattern of light onto the object to be scanned and the deformation of the light on the subject is recorded by a camera. Systems that do not emit radiation in order to scan objects are referred to as passive systems and these usually detect either visible light or infra-red. Photometric 3D imaging systems are commonly based on a single camera but multiple images under different lighting conditions or positions are obtained. Photogrammetry is a technique based on the analysis of multiple images of an object taken at different angles and the data obtained are used to generate a 3D point cloud in which each point has its own unique X, Y & Z coordinate. This in turn can be used to construct a 3D mesh which can be analysed digitally.

The reliability of the FCR to record thoracic region profile size has been tested at three levels of this spinal region (Greve and Dyson, 2013; Mackechnie-Guire *et al.,* 2018) however 3D light-scanning has only been tested for whole body and limb volume in horses (Johnson and Symons, 2020 & Valberg *et al.,* 2020). To further explore the potential use of 3D light scanning in horses, the aim of this study was to investigate reliability of repeated measurements of the thoracic region morphology and symmetry with 3D light-scanning.

MATERIALS & METHODS

A convenience sample of ten Arabian endurance horses in full-training and competing at FEI CEI*** level with the same trainer and at the same stables were recruited for the study; 3 mares and 7 geldings with a mean age 8±2 years. All horses were considered by the trainer and the attending veterinary surgeon to be free of lameness or obvious musculoskeletal asymmetry and scanning was undertaken in a familiar environment.

Scanning equipment

A variety of light-scanning systems were initially evaluated for this application including the Artec Eva (Rue des Peupliers, L-2328, Luxembourg), Sense (3D Systems Inc, Herndon, VA, USA), Scandy Pro (Andrew Higgins Blvd., New Orleans, LA 70119, USA) and the Occipital Structure Sensor Mark I Occipital Inc, Boulder, Colorado, 80302, USA. The Artec Eva and Sense light-scanners require wired connection to a laptop or PC whilst the Structure Sensor is mounted on an IPad and the Scandy Pro is an App based on the IPhone. The Structure Sensor was considered to perform the best in pilot trials comparing the different systems for this application.

Images were obtained using a Structure Sensor (ST01) mounted on an 11inch IPad Pro with the Structure Sensor Bracket (Model SA21) (Occipital Inc, Boulder, Colarado, 80302, USA). Images from the IPad were fed to Skanect Pro Software (V1.1, Occipital Inc) running on a Lenovo Ideapad 500 laptop. Connection between the IPad and the laptop was via a 300Mbps 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 manufacturers' 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 & Colour; Uplink Colour Gain: Locked on Record. The specific scan settings were set as: Scene: Body; Bounding Box: 1.8 metres; Aspect Ratio: Normal. Scanning was initiated and terminated on the IPad.

3D light-scan collection

A consistent scanning protocol was used to obtain each image. The horses were brought into a familiar large room (dimensions: 10m x 10m) with minimal natural light and lit by fluorescent strip lighting. The room was approximately 50m from the horses' stables. All horses had undertaken training ~4h before scanning. White polystyrene hemispherical markers (20mm diameter; Pllieay, Wangtanggongyequ Xingao Road, Nanshan District, Shenzhen Guangdong 518055 CN) were attached using double sided carpet tape (3M, Saint Paul, Minnesota, USA) to the caudal aspect of the left and right scapula (identified by palpation) with the horse stood square/fore and hind feet parallel. 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. The handler was instructed to hold the horse straight and with the head in a neutral position. All marker placement and light-scans were undertaken by the same author (DM) in one single session and initiated with the IPad which was held with the camera facing the right-side of the horse at a distance of approximately 1.5m, with the middle of the IPad at the height of the back. This resulted in the whole of the horse being in the field of view, except for the head and upper neck. Whilst recording, the operator moved towards the horse raising the IPad up by approximately 50cm to image the back. The IPad was then lowered to the height of the horse's back and whilst the operator walked around the back of the horse to view the left-side. The IPad was moved slowly in order to capture continuously and took around 20 seconds to complete a full scan which included the limb above the carpus and hock, the quarters, trunk and lower neck (Figure 2). If a horse moved during the light-scan, the light-scan was terminated and repeated. After each light-scan the quality of the image was viewed on the laptop prior to acceptance. After each successful light-scan, horses were walked in a small circle (10m approximate diamater) and repositioned for the next light-scan. Each horse was light-scanned three times.

Accepted light-scans were saved as Skanect format *.skn files and exported as unprocessed *.stl files for further analysis. The export settings were: Format: STL; Colours: Per-Vertex; Number of Faces: 22130; Scale: metres; Colour Space: sRGB. STL files were imported into Meshmixer (V3.5.474, 2017, Autodesk Inc, San Rafael, California, United States) (Valberg *et al.*, 2020) and edited to remove any background and areas not of interest (e.g. lower leg, head and mid-neck). A wireframe was applied to the images, then processed images were saved as Meshmixer files (*.mix). Example images are shown in Figures 1 and 2.

[Figure 1 & 2]

3D light-scan analysis:

The 3D light-scans were coded and analysed blinded to the horse or number of the repeat. Each image was rotated to the sagittal view and the software's slicing tool was used to divide the shell into three sections (cranial shell, thoracic shell and caudal shell). To achieve this a transversely orientated plane-cut was taken at the level of the marker of the left caudal scapula and a second transverse plane cut was take at the level of the marker at T18. The cranial and caudal shells were then removed to provide a thoracic section. This section was orientated first to the cranial view and then to the caudal view, with a measure of known length provided by the software placed across the shell, saved to export as a jpeg and then transferred to ImageJ (Rueden *et al.*, 2017) for further analysis. Within ImageJ, the measure of known length was used to calibrate and apply a 15cm vertical line from the dorsal midpoint of the shell. The boundary of the border of the horse's transverse profile, and the 15cm vertical line was traced, and the software provided a 2D area of the plane-cut (Figure 3) for the left and the right sides of the image. Total cross-sectional area from the most dorsal point to 15cm ventrally was then calculated at scapula and T18 levels. To test intra-rater reliability, eight light-scans were entered into the sample for repeated measuring but coded and blinded to the primarily analyst (GT). To test inter-rater reliability ten scans were randomly selected for analysis by two further raters (DM / JW).

[Figure 3]

Statistical Analysis: Data were initially analysed for cross sectional area difference between sides and horses. Data met the requirements for non-parametric distribution, therefore further non-parametric analyses were undertaken using SPSS statistical package version 26 (SPSS Inc, Chicago, IL). Friedman's analyses assessed intra- and inter-rater (n=3) reliability. Intraclass correlation estimates (ICC) and their 95% confidence intervals (CI) were calculated based on a mean-rating (k =

3), absolute-agreement, 2-way mixed-effects model. ICC values less than 0.5, between 0.5 and 0.75, between 0.75 and 0.9, and greater than 0.90 were used to indicate poor, moderate, good, and excellent reliability, respectively (Koo and Li, 2016). To assess for differences between right and left cross-sectional areas at the level of the withers and T18, Wilcoxon signed rank tests were used. For all tests, significance was set at $p<0.05$.

RESULTS

A total of 31 3D light-scans were obtained from the 10 horses and coded to allow blinded review. Nine light-scans were not submitted for further analysis due to incomplete imaging in the thoracic region (n=5), or the horse's mane covering the withers region and therefore altering the dimension of the slice (n=4). A total of 23 images were used for analysis which included the eight repeated light-scans used for intra-rater testing.

Intra-tester reliability

From the 23 scans, three transverse plane-cuts at the withers level and three at T18 were collected by a single blinded author (GT) and measured three times to collect cross-sectional area data for the left and the right sides at the two levels (withers and T18). There was no significant difference between the three repeated measures of three transverse plane-cuts of the same scan, at the withers level ($\chi2(2)=5.415$, $p=0.067$; ICC: 0.998; CIs: 0.998-0.999) or between the means of the repeats on each transverse plane-cut ($\chi2(2)=0.209$, $p=0.901$; ICC: 0.989; CIs: 0.983-0.994). Similarly, no significant differences were found at the level of T18 between the three repeated measures of three transverse slices of the same plane-cut ($\chi2(2)=0.307$, $p=0.858$; ICC: 0.993; CIs: 0.991-0.995) or between the means of the three repeated measured of three transverse plane-cuts of the same image ($\chi2(2)=1.870$, $p=0.393$; ICC: 0.983; CIs: 0.973-0.990).

In contrast, a significant difference between the cross-sectional area of the right and left sides was found, with 69.6% (n=16) of scans being larger on the left side at the withers ($t_{(22)}=2.734$, $p=0.012$). However, no significant difference occurred at the level of T18 ($t_{(22)}=-0.731$, $p=0.473$; Right side larger in 60.9%, n=14). Repeated measures from the different scans of the same horse did not show any significant difference ($\chi2(2)=1.286$, $p=0.526$; ICC: 0.759; CIs: 0.429-0.915). Therefore, intra-rater reliability for measuring cross-sectional area of the thoracic profile from 3D light-scans was considered good (ICC values between 0.75 and 0.9) to excellent (ICC values greater than 0.90) (Koo and Li, 2016).

Inter-tester reliability

While reliability was reduced to moderate between the three raters ($p=0.02$; ICC: 0.70; CIs: 0.56-0.82), no significant differences occurred between the assessors (n=2) who were experienced in using the software (p=0.88; ICC: 0.90; CIs: 0.82-0.95). Inter-rater reliability with experienced analysts was therefore considered to be good (Koo and Li, 2016).

DISCUSSION

The reliability of measurements of thoracic profile cross-sectional area from images obtained from 3D light-scanning was simple and non-time consuming and was shown to be good to excellent with a single rater, and good between two experienced raters. The application of this technology could be an alternative to the FCR for the thoracic region, plus provide data capture for analysis in additional regions of the horse's spinal profile. Although requiring access to the equipment (Ipad and camera) the additional benefit is the tool being non-invasive and non-contact.

While no significant difference occurred at T18, significant differences in the size of the left and right sides of the plane-cuts were found at withers level. As the horses were stood stationary, with the feet parallel and their head in a neutral position these asymmetries are thought to reflect actual size differences in the profile at this thoracic level. In Greve and Dyson's (2013) study of back dimensions in sports horses, 41.3% had asymmetries, in this study a higher proportion of light-scans showed asymmetry. All ten horses were sound and training and competing at CEI*** FEI level. Further studies into trunk profile asymmetry with concurrent inertial motion sensor kinematic analysis of gait asymmetry would be of value to assess for underlying reasons for these differences. A large proportion of horses in ridden work are reported to movement asymmetries above previously reported asymmetry thresholds during straight line trot (Rhodin *et al.,* 2017), the extent of thoracic profile asymmetry at the time of gait analysis, or over a longitudinal period would be of interest to document potential compensatory changes.

At this stage the measurements, whilst showing reliability, do not infer validity (Mokkink *et al*., 2010). However, the repeated measures from horses that were repositioned suggests that this tool could be useful for assessing longer-term change in thoracic profile. Continued exploration of reliable and valid outcome measures, which can be integrated into routine assessment of horse's backs provides scope for equine professionals such as saddlers and physiotherapists to have records of changes over time linked to training, development or rehabilitation (Tabor *et al.,* 2020).

The FCR has been used to detect changes in shape of the epaxial region (Greve and Dyson, 2013; Mackechnie-Guire *et al.*, 2018), but this does require manual contact with the horse and is more time-consuming at the point of data collection. However, there is the potential for errors to occur in the process of transferring the shape from an FCR onto paper (Shakeshaft and Tabor, 2020), as well as fatigue of the FCR materials (Greve and Dyson, 2013). If 3D light scanning is taken forward to be tested against these previously validated tools it could be used to gather data on back shape changes over time. The advantage of the 3D light-scanning method is that once the light-scan is stored electronically, any region of the image can be assessed for dimensions such as the profile of the hindquarter muscle bulk or at spinal level. This may be of interest if outcomes from interventions such a surgery for kissing spines are being documented. Understanding that spinal pathologies do present with atrophy of epaxial muscles (Coomer *et al.,* 2012), the rehabilitation monitoring could include thoracic profile recording. 3D light scanning also has wider potential benefits; it can be used to capture data from the whole horse to form complete records, such as the dimensions of the limbs and any swelling (Johnson and Symons, 2019), and therefore could be seen as a more complete method to document ongoing changes in a horse than the FCR. The digital nature of the data could also allow for software development to analyse and contrast different light-scans to offer ongoing objectivity during clinical assessment.

Limitations

Once the 3D light-scans were collected and assessed *post-hoc*, a number were rejected for inclusion due to either the shell being incomplete or the horse's mane affecting the external shape of the shell. This needs to be addressed at the time of data collection but with further training and skills development as well as increased experience of the operator, this should not limit future studies. It should also be noted that external methods of documenting the thoracic profile of horses do not reflect change in the deeper musculature such at the multifidus muscle (Tabor, Johannson and Randle, 2012). However, other methods such as the FCR do not present this benefit either, and more laborious and expensive ultrasound-imaging is required for this (Stubbs et al., 2010). The light-scans collected for this study, as a proof-of-concept trial, were not compared to a gold standard ultrasound imaging or with the FCR. As the reliability of the process from collecting the light-scan to measurement has been shown to be good/excellent the validity of the tool can now be assessed. As part of this process the ability to detect changes in dimension of the thoracic profile, over time, could also be assessed

CONCLUSION

These results suggest 3D light-scanning is an objective, non-invasive method to record size and symmetry of the thoracic epaxial region in horses, and this data collection method now warrants validity testing against gold-standard imaging to support future use in clinical practice. Reliability of repeated measurements of thoracic profile cross-sectional area and symmetry acquired from 3D light-scans were shown to be good to excellent with a single rater and moderate to excellent with multiple experienced raters.

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