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A QUANTITATIVE STUDY ON THE TRACHEA OF YOUNG ARABIAN CAMELS *(Camelus dromedarius)*

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ABSTRACT

The objective of this study was to report comprehensive quantitative morphometric measurements of the trachea of young camels *(Camelus dromedarius)*. Tracheas from 15 young male camels aged between 9 to 12 months were used to measure the length, number of tracheal cartilage rings, inner and outer diameters and thickness of the cartilage rings at four different tracheal regions (cranial cervical, middle cervical, thoracic inlet and intrathoracic). Furthermore, cross sectional area (CSA) of the tracheal rings were measured by two methods; a mathematical equation and a digital image analysis. The mean length of the trachea was 87 ± 0.83 cm, while the mean number of the cartilage rings was 77.1 ± 0.35. Diameters of the cartilage ring were smallest at the thoracic inlet region due to changes in tracheal direction and the narrow bone-surrounded thoracic inlet where the trachea enters the thoracic cavity. The ratios of the inner transverse to inner vertical and the outer transverse to outer vertical diameters ranged between 1.08 and 1.34. This indicates that the shape of the trachea in these young camels is near-circular. The CSA measurements obtained by the digital image analysis were 11-14% smaller than the CSA calculated by the mathematical equation ($P < 0.01$). Using digital image analysis to measure the CSA of tracheal rings provides accurate and reliable measurements. The CSA and cartilage thickness were smallest and thinnest at the thoracic inlet, respectively. This may be an important predisposing factor for tracheal disorders at this region.

Key words: Camel, cartilage, diameter, disease, trachea

The trachea provides a path for conducting air from the larynx to the lungs. It extends from the level of the middle of the axis to a point between the fourth and fifth thoracic vertebrae (Kumar *et al*, 1992; Dyce *et al,* 2002). Depending on the animal species, the trachea is composed of variable numbers of uncollapsible tracheal cartilages which (makes) make this organ suitable for its physiological functions (Dyce *et al,* 2002). Normal values of tracheal lumen diameter are available in the literature for Indian Buffalo (Peshin and Prakash, 1975), horse (Art and Lekeux, 1991), adult Indian camel (Kumar *et al,* 1992), dogs (Dapanoglu *et al*, 2001), sheep foetus (Kalache *et al,* 2001), and rabbit (Loewen *et al,* 2001). Tracheal dimensions play an important role in the efficiency of breathing and normal ventilation during anaesthesia; secondly, selection of appropriate size endotracheal tube in animals undergoing inhalation anaesthesia and percutaneous insertion of a tracheostomy depends on the tracheal diameter (Mortola and Fisher, 1980; Behl and Watt, 2005). Tracheal pressure necrosis, irritation, oesophageal-tracheal fistula and tracheal stenosis have been reported as a consequence of inappropriate selection of tracheal tubes (Bock *et al,* 2000). In addition, the animal's ability to breathe was reported to be affected by several surgical and non-surgical diseases such as tracheal hypoplasia, tracheal collapse, trauma, and tracheal stenosis (Salisbury *et al,* 1990; Coyne and Fingland, 1992; Watt, 1992).

While tracheal dimensions have been reported in adult Indian camel (Kumar *et al,* 1992), no reports could be cited in the literature regarding tracheal morphometric measurements in either adult or young Arabian camel *(Camelus dromedarius)*. The purpose of this study was to report comprehensive quantitative morphometric characteristics of the trachea of the normal young one-humped Arabian camel. Those morphometric characteristics include tracheal length, number of tracheal cartilages, and the diameter of the tracheal lumen at different locations along the course of the trachea. In addition, the efficiency of using digital image analysis as a mean to measure the cross sectional area of tracheal lumen was evaluated.

Materials and Methods

Tracheas of 15 young male camels ages ranged 9 to 12 months were obtained from a commercial slaughterhouse. Lengths of the trachea were

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measured from the cranial border of the first tracheal ring to the tracheal bifurcation. In addition, the number of tracheal rings were also counted.

By incising the tracheal annular ligaments, the outer transverse (OT), inner transverse (IT), outer vertical (OV) and inner vertical (IV) diameters and cartilage thickness of the left (CTL), right (CTR) and ventral (CTV) midpoints were measured at the level of each tracheal ring with the aid of a digital micrometric caliper (Fig 1). In addition, the ventral width of the tracheal rings (CWV) was measured.

The cross-sectional area (CSA) was calculated using two different techniques; first technique by a mathematical equation [CSA = (IV/2) x (IT/2) x 3.14] reported by Dapanoglu *et al* (2001) The other technique by comparing the lumen of tracheal ring to a known object cross-sectional area using the Photoshop CS2 software (San Joes, CA, 96933, USA). Briefly, digital images of tracheal rings of different tracheal regions and a known object cross sectional area were captured using a Sony© cyber shot digital camera (MKM, Minokamo, Japan). Following selection of the luminal area of the tracheal rings using the command magnetic lasso tool, the pixel numbers were obtained using the command Histogram (expanded view). Cross-sectional areas were expressed by the computer as Pixel per mm^2. Results were directly imported into a spreadsheet program (Excel, Microsoft Inc., Redmond, WA) for analysis. The conversion factor was determined by calculating the number of pixel per mm^2 of the known object cross-sectional area. Each mm^2 of the digital image equaled to 1180 pixels. The calculated areas were multiplied by a conversion factor of $8.47e^{-4}$ to determine the cross-sectional area of each tracheal ring in mm^2. To further confirm our results, we used image analysis software (Image J, NIH Image software, USA).

Furthermore, to evaluate whether formalin fixation affects tracheal parameter measurements, tracheal rings from each region were fixed in 10% neutral buffered formalin for 24 hours and the same tracheal parameters were measured and compared to those parameters measured before formalin fixation.

All data were presented as Mean ± SEM. All data were subjected to statistical analysis by dividing the trachea into 4 regions; cranial cervical (CCR), middle cervical (MCR), thoracic inlet (TIR) and the intrathoracic (ITR). These regions were located between 1-24, 25-48, 49-62, 63-78 tracheal rings, respectively. Comparisons between regions were made using one-way analysis of variance followed by a Bonferroni multiple range tests. Statistical analyses were performed using Graphpad Prism for windows (Graphpad, San Diego, CA, 95919, USA).

Results

The average tracheal length from the first to the last tracheal ring was 87 ± 0.83 cm and the number of the tracheal rings varied from 75-81 with a mean value of 77.1 ± 0.35. Tracheal ring fusion with neighbouring rings was observed within all different tracheal regions. The number of tracheal ring fusions was not consistent in the specimens examined. Fusion of the tracheal rings occurred mostly in the cranial cervical region.

The mean values of OV, OT, OT/OV, IV, IT and IT/IV for the 4 regions of the trachea are summarised in table 1. The diameters of IV and OV decreased caudally to the level of the thoracic inlet region while

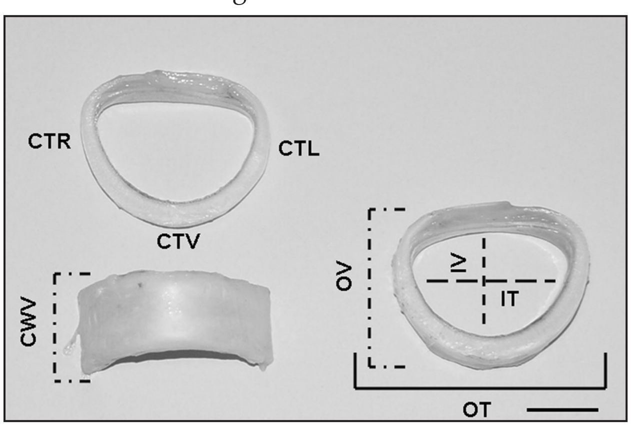

Fig 1. Images represent where the inner transverse (IT), outer transverse (OT), inner vertical (IV) and outer vertical (OV) diameters and the cartilage thickness of the left (CTL), right (CTR) and ventral CTV) midpoints of the tracheal ring were measured.[1]

1 Bar = 10 mm.

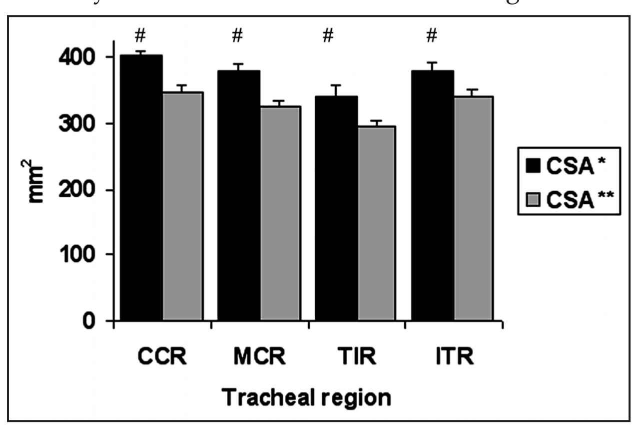

Fig 2. A comparison between the CSA from the 4 tracheal regions (cranial cervical (CCR), middle cervical (MCR), thoracic inlet (TIR) and the intrathoracic (ITR) calculated using two different techniques.

1 #, P<0.01; - , standard error of mean (SEM).

Table 1. Mean values (MV) of the outer vertical (OV), outer transverse (OT), inner vertical (IV), inner transverse (IT), and ratios of OT/OV and IT/IV in the 4 regions of the trachea; cranial cervical (CCR), middle cervical (MCR), thoracic inlet (TIR) and the intrathoracic (ITR).[1]

	CCR			MCR			TIR			ITR			
	N	MV	SEM	N	MV	SEM	N	MV	SEM	N	MV	SEM	F
OV (mm)	15	28.8	0.70	15	25.3	0.51	9	24.8	0.38	9	26.3	0.73	9.12**
OT (mm)	15	31.2	0.37	15	31.3	0.23	9	30.1	0.36	9	31.9	0.45	5.48*
OT/OV	15	1.1	0.25	15	1.2	0.21	9	1.2	0.17	9	1.2	0.31	5.27*
IV (mm)	15	21.2	0.60	15	19.4	0.44	9	18.7	0.35	9	20.1	0.74	3.94*
IT (mm)	15	24.9	0.54	15	25.8	0.40	9	24.6	0.46	9	26.8	0.45	5.49*
IT/IV	15	1.2	0.39	15	1.3	0.31	9	1.3	0.29	9	1.3	0.35	7.06**

[a] SEM, standard error of mean; F, Fisher exact test; *, P<0.05; **, P<0.01; N, number of tracheal cartilages.

they increased in the intrathoracic region. The highest values of OV and IV were at CCR (28.81 ± 0.70 mm and 21.22 ± 0.60 mm) and the lowest values were at TIR (24.78 ± 0.38 mm and 18.67 ± 0.35 mm). The diameters of OT and IT increased caudally to the level of the intrathoracic region while they decrease in the thoracic inlet region. The highest values of OT and IT were at ITR (31.91 ± 0.45 mm and 26.80 ± 0.45 mm) and the lowest values were at TIR (30.11 ± 0.36 mm and 24.57 ± 0.46 mm). The ratios of IT/IV and OT/OV are almost the same and lie between 1.08 and 1.34 in all regions. All data are highly significant among the four regions as confirmed by one-way analysis of variance.

The CSA decreased caudally to the level of the thoracic inlet region while increased in the intrathoracic region. The highest value of CSA was at CCR (402.1 ± 6.56 mm^2) and the lowest value was at TIR (341 ± 17.27 mm^2). All data were highly significant among the 4 regions as confirmed by one-way analysis of variance. The CSA measurements obtained by the digital image analysis were 11-14% smaller (P < 0.01) than the CSA calculated by the mathematical equation (Fig 2). All data were highly significant among the 4 regions as confirmed by one-way analysis of variance.

Table 2 represents the mean values of the cartilage thickness for the right, left and ventral midpoints and the ventral width of the tracheal ring. The cartilage thickness at the right (2.1 ± 0.07 mm) and left (2.15 ± 0.07 mm) midpoints was similar and is thinnest at the thoracic inlet. The cartilage thickness at the ventral midpoint decreased caudally to the level of the thoracic inlet region while it increased in the intrathoracic region. The highest value was at the cranial cervical region (3.92 ± 0.19 mm) and the lowest was at the thoracic inlet region (3.14 ± 0.14 mm). The ventral width of the tracheal ring decreased gradually from the cranial cervical region to the thoracic inlet region with the highest value at the cranial cervical region (13.66 ± 0.56 mm) and the lowest value at the thoracic inlet region (9.63 ± 0.22 mm). All data were highly significant among the 4 regions as confirmed by one-way analysis of variance.

Discussion

The number of the tracheal rings varied from 75-81 with a mean value of 77.1 ± 0.45. Similar values were reported previously for the adult Indian camels (Kumar *et al,* 1992). The variation in numbers of tracheal rings between specimens was due to individual anatomical variations. The average tracheal length from the first to the last tracheal ring was 87 cm ± 0.83. We are the first to report the tracheal length in young male camels of this age group (9 to 12 months old).

Tracheal ring fusion with adjacent rings was observed within all different tracheal regions. Although, the number of the tracheal ring fusions was not consistent in the specimens examined, fusion of the tracheal rings occurred mostly in the cranial cervical region. It has been suggested that tracheal rings of this region are most affected by neck movements resulting in its fusion over time (Morgan *et al,* 1986).

When the OV, OT, IT, IV diameters and CSA were measured before and after fixation with formalin and analysed statistically, there was no significant difference (P > 0.05) in these measurements. These results (are) were similar to the results obtained previously by Dapanoglu *et al* (2001). The mean ratios of IT/IV and OT/OV lie between 1.08 and 1.34. These values are important in the determination of the shape and the uniformity of the trachea. These results indicate that the trachea has a near-circular CSA in camel. It has been suggested that if the ratio of IT/IV

Table 2. Mean values of the cartilage thickness of the left (CTL), right (CTR) and ventral CTV) midpoints and ventral width of the tracheal ring (CWV) in the 4 regions of the trachea; cranial cervical (CCR), middle cervical (MCR), thoracic inlet (TIR) and the intrathoracic (ITR).[2]

	CCR			MCR			TIR			ITR			
	N	MV	SEM	*N*	MV	SEM	*N*	MV	SEM	*N*	MV	SEM	F
CTR (mm)	15	2.6	0.10	15	2.3	0.12	9	2.1	0.07	9	2.2	0.13	5.51*
CTL (mm)	15	2.5	0.08	15	2.2	0.09	9	2.2	0.07	9	2.2	0.16	3.46*
CTV (mm)	15	3.9	0.19	15	3.4	0.22	9	3.1	0.14	9	3.2	0.21	4.34*
CWV (mm)	15	13.7	0.56	15	12.1	0.68	9	9.8	0.67	9	9.6	0.22	12.3**

[a] SEM, standard error of mean; F, Fisher exact test; *, P<0.05; **, P<0.01; *N*, number of tracheal cartilages.

and OT/OV are less than 1.3 then the trachea would assume a circular CSA (Art and Lekeux, 1991).

Measurement of the actual CSA is the preferred technique for estimating the percentage of luminal stenosis because this measurement is accurate irrespective of the shape of the tracheal lumen (Dapanoglu *et al*, 2001). In this study, we used two methods to measure the CSA. The first method is a mathematical equation reported before (Dapanoglu *et al*, 2001), while the other method by digital image analysis. There was a discrepancy between the CSA measurements obtained by the two methods. The CSA measurements obtained by the digital image analysis were 11-14% smaller than the CSA calculated by the mathematical equation. The digital image analysis appears to provide accurate and reliable results. It directly measures tracheal cross sectional area. More importantly, because the method is computerised, a large number of tracheal cross sectioned areas can be simultaneously and reliably measured.

In this study, the lowest values for both the diameters and the CSA were seen at the level of the thoracic inlet. At this level, the CSA was 14, 9.1 and 13.7% smaller than that in the cranial cervical, the caudal cervical and intrathoracic regions, respectively. Similar observations were reported in the trachea of dogs (Dapanoglu *et al*, 2001). Two explanations have been suggested for these results: First, the trachea runs caudoventrally in the cervical region up to the thoracic inlet where it is slightly curved and then runs caudodorsally into the thoracic cavity. At the thoracic inlet, the curvature of the trachea causes a narrowing of the tracheal lumen. Second, the thoracic inlet is relatively small and bounded by bones such as the first thoracic vertebra, sternum and the first pair of ribs. At this level, the trachea runs alongside the oesophagus and the longus colli muscles. These structures compress the trachea and could alter its diameter (Dapanoglu *et al*, 2001).

Results of this study clearly indicate that the cartilage thickness at the right and left midpoints is thinner at the level of the thoracic inlet than in other regions of the trachea. It has been reported that thinner cartilage rings contain reduced amounts of glycosaminoglycan and water; therefore, lower levels of these substances are responsible for the weakened, flaccid character of the cartilage (Dallman and Brown, 1984). Although, tracheal collapse has not been reported in dromedarian camels, this finding suggests that tracheal collapse would occur most likely at the thoracic inlet in young camels.

Our results provide surgeons and anaesthetists with valuable information about the tracheal length, cartilage numbers and thickness in different regions in young dromedarian camels. A new method for determining tracheal cross sectional area using digital image analysis has been reported. This method allows a large number of tracheal cross sectional areas to be measured rapidly and accurately with computer hardware and software that are readily available. Computer image analysis should provides another useful tool for studying and determining the diameter and cross sectional areas of different organs.

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