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Accuracy of radiographic measurements of the Cervical Articular Process Joints of the horse

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Summary

Radiography is the standard imaging technique for diagnosing arthropathy of the caudal cervical articular process joints. Clinical studies used lateral and oblique radiographic views of the caudal cervical spine to determine the size of the articular process joints (APJ), which were then compared to reference values of clinically normal horses. The aim of this study is to evaluate the accuracy of such measurements. The cervical spine of 7 euthanized Warmblood horses, without major clinical alteration of the APJ were aligned and fixed in a neutral position. Lateral, oblique, and tangential radiographs of the lower neck were obtained using standardised technique. The x-ray beam was centered on the APJ of C5/6 and C6/7, respectively. The radiographic measurements were obtained by three different observers. All radiographic measurements were compared to the corresponding anatomical measurements obtained from the boiled out bones. The 95% Confidence Interval (CI) and the 95% Limit of Agreement (LOA) were calculated from the difference between the anatomical measurement and the radiographic measurement. The measurements of the maximum height and the length of the cervical body on the lateral radiographs were the most accurate measurements in this study. All other measurements of the three observers resulted in relatively high 95% CI and wide LOA. On the oblique views, the radiographic measurements show a low accuracy and it appears that radiography underestimates the true size of the APJ. The data of this cadaver study suggests that the range of differences between radiographic and anatomical measurements of cervical articular processes is higher than the differences between normal and diseased horses as proposed by other authors on lateral and oblique radiographs. Therefore, the radiographic measurements and their reference values for normal articular process joints of the lower neck in horses should be used with caution.

Keywords: radiography, articular process joints, neck, measurements, horse

Die Genauigkeit von radiologischen Messungen an Fazettengelenken der Halswirbelsäule beim Pferd

Die radiologische Untersuchung ist das einfachste bildgebende Verfahren zur Beurteilung von Arthropathien der Facettengelenke der Halswirbelsäule. In klinischen Studien wurde aufgrund von radiologischen Messungen auf lateralen Standardaufnahmen und Schrägaufnahmen der kaudalen Halswirbelsäule die Größe der Gelenksfortsätze bestimmt und mit Referenzwerten von gesunden Pferden verglichen. Das Ziel dieser Untersuchung ist es, die Genauigkeit dieser Messmethode zu ermitteln. Die Halswirbelsäule von 7 euthanasierten Warmblutpferden ohne bedeutende Veränderungen an den Facettengelenken wurden in einer neutralen Stellung fixiert. Von den kaudalen Facettengelenken wurden laterale Standardaufnahmen, Schrägaufnahmen und Tangentialaufnahmen mit definiertem Strahlengang angefertigt. Dabei wurde der Zentralstrahl auf die Facettengelenke zwischen 5./6. bzw. 6./7. Halswirbel gerichtet. Die Vermessung der Röntgenbilder wurden von drei verschiedenen Beobachtern durchgeführt. Die Validität der radiologischen Messung wurde anhand der Knochenpräparate überprüft. Von den Unterschieden zwischen der anatomischen und der radiologische Messung wurden der Mittelwert, das 95% Vertrauensintervall und die Limit of agreement berechnet. Die beste Genauigkeit wurde bei der Längen- und Höhemessung der Wirbelkörper auf den seitlichen Aufnahmen erreicht. Alle anderen Messungen der Differenz zwischen Anatomie und Radiologie zeigten eine große Spannbreite des 95% Vetrauensintervall und deutliche Unterschiede zwischen den drei Beobachtern. Bei den Schrägaufnahmen wurde die Größe der Facettengelenke in der Regel unterschätzt. Die interindividuelle Abweichung und die Genauigkeit der Messung an gesunden Halswirbelsäulen von Pferden waren in dieser Studie größer als die durchschnittlichen Unterschiede, welche von anderen Autoren zwischen gesunden und arthrotisch veränderten Gelenksfortsätzen auf lateralen Standardaufnahmen und Tangentialaufnahmen ermittelt wurden. Die in diesen klinischen Studien angewandten Messmethoden sind relativ ungenau und können nicht zur objektiven Beurteilung der Größe der Facettengelenke empfohlen werden.

Schlüsselwörter: Röntgen, Wirbelgelenke, Halswirbelsäule, Größenmessung, Pferd

Introduction

Arthropathy of the caudal cervical (C5-C7) articular process joints (APJ) is recognised as an important cause of ataxia (wobblers disease) in horses secondary to spinal cord compression (*Levine* et al. 2007, *Mayhew* 1999, *Moore* et al. 1992, *Powers* et al. 1986, *Tomizawa* et al. 1994, *Trostle* et al. 1993, *Van Biervliet* 2007). In addition APJ arthropathy has also been documented as a cause of neck pain, neck stiffness (*Dyson* 2003) and forelimb lameness (*Marks* 1999, *Moore* et al. 1992, *Ricardi* and *Dyson* 1993).

Radiography is the principle imaging technique used to assess the caudal cervical spine for evidence of APJ arthropathy and the radiographic anatomy of the normal APJ in horses has been described in detail recently (*Withers* et al. 2009). A radiographic diagnosis of APJ arthropathy is mainly based on observing enlargement of the articular process joints on lateral radiographic views obtained in the standing horse (*Butler* et al. 2008). However accurate interpretation of lateral radiographs is not straightforward due to a current lack of understanding of age related versus disease related changes in the size and appearance of the articular process joints.

In a recent study an objective grading system was introduced for assessment of radiographic changes associated with the caudal articular process joints on lateral views (*Down* and *Henson* 2009). In this study the authors demonstrated that an increase in size of the articular process joints of the caudal cervical APJ (mainly C5/6), may be age related and that enlargement of process joints (both C5/6 and C6/7) should not be assumed to be abnormal in all cases. However they stated that if enlargement of the articular process joints of C5/C6 and C6/C/7 is present in young or juvenile horses, then this may be abnormal.

Hett et al. (2006) also described similar findings in young horses. In their study they showed that in ataxic horses younger than three years with enlarged articular process joints of C5/C6 and C6/C7 the body of the 7th cervical vertebra was on an average 7 mm shorter compared to sound horses. In addition they described a method of measuring the length and the height of the cranial articular process and they used the technique to compare radiographs of 69 horses with and 36 horses without arthrotic lesions of the caudal cervical spine. Based on their study population, which included Warmblood and Thouroughbred horses, they proposed reference values for the normal length of the vertebral body and length and the height of the cranial articular process of C6 and C7. None of these parameters have been tested for accuracy.

A similar study described a technique using oblique radiographs to measure the width of the joint space, and the length and the area of the articular processes of C5/C6 and C6/C7 (*Lautenschläger* 2007). Using the technique the authors compared measurements obtained from radiographs of 60 clinically normal and well rideable horses to those obtained in 20 horses with riding problems and subtle clinical signs associated with lower neck pain. They reported that the width of joint space and area of articular processes, were statistically different between the two groups, however the reliability of those parameters were not evaluated for precision and accuracy.
The aim of this study is to evaluate the accuracy of radiographic measurement of selected parameters of the articular process joint on lateral and oblique views of the caudal neck in cadaver specimens.

Materials and methods

Animals

Necks from 7 skeletally mature horses aged 4-18 years (median 13 years) of various breeds (3 Thoroughbred or Thoroughbred cross, 2 Warmblood, 1 Welsh Pony) were obtained immediately following euthanasia. All horses had been subjected to euthanasia on humane grounds for reasons unrelated to pathology of the cervical region. The necks were sectioned at the atlanto-axial joint and at the junction of the first and second thoracic vertebrae. The first ribs were transected at the level of the vertebral body and the superficial musculature was removed, leaving the ligamentous structures between each of the vertebrae intact. Particular care was taken not to incise the joint capsules of the articular process joints. After dissection, each vertebral column was suspended in axial alignment in a refrigerated room for up to 48 hours prior to the radiographic examination.

Equipment

Computed radiographs (CR MD 4.0 cassettes[1], CR 35X digitiser[2]) were obtained using a gantry mounted x-ray unit (85kW generator[3] and matched tube[4]). Movement of the cassette holder was synchronised with the x-ray tube via an overhead gantry. All data were stored in DICOM 34 standard format and images were reviewed on a medical diagnostic imaging display screen[5].

Radiographic views

Each cervical column was aligned in a neutral position, similar to a horse standing with the head lowered to the level of the shoulder. Cranially the specimens were suspended from a wire placed through the dorsal process of the second cervical vertebra (C2) and caudally by a wire placed through the dorsal spinous process of the first thoracic vertebra (T1). Spherical radiopaque markers of a known diameter were placed at the level of the transverse process on each side of the neck so that the amount of radiographic magnification could be measured using the calibration tool of the image viewer.

Lateral radiographs were obtained centred separately for each of the articulations of interest (C5-6, C6-7) and correct radiographic positioning and perpendicular alignment of the X-ray beam were monitored by fluoroscopy.

Oblique radiographs centred for each of the joints (C5/6, C6/7) at the level of the intervertebral foramen were obtained from both sides of the neck using two different techniques: 1) Latero-50°-ventral to latero-dorsal (*Withers* et al. 2009) and 2) Lateral-40°caudal-45°dorsal to latero-cranio-ventral (*Lautenschläger* 2009, *Studer* 2005).

Radiographic measurements (= image analysis)

Lateral radiographs

On lateral radiographs the measurements described by (*Hett* et al. 2006) were evaluated (Fig. 1). One parameter was modified (M4): In our study we measured the greatest height of the vertebral body rather than the smallest height as proposed by (*Hett* et al. 2006). The radiopaque markers on the left and on the right transverse process were used for calibration. Because it was not possible to distinguish between the left and the right articular process on the lateral radiograph, the magnification factor was adjusted for the midline of the specimen using the average of the two calibration measurements obtained from the left and the right radiopaque markers.

Oblique radiographs

The length and width of the caudal and cranial articular processes were measured on the oblique radiographs (Fig. 2). However it was only possible to measure the width of the articular processes which were projected dorsally to the contralateral side (i.e. Those which were on the side of the x-ray generator when using the oblique technique 1 (Latero-50°-

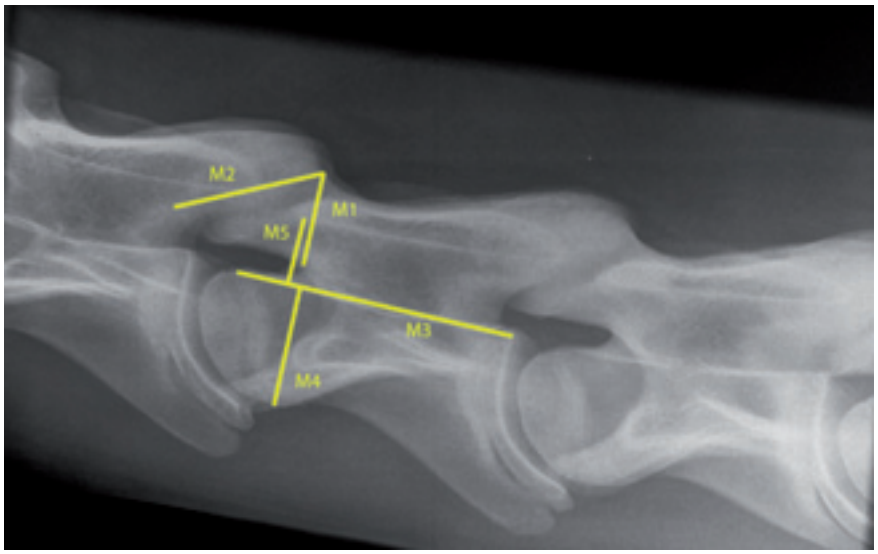

Fig. 1 Measurements proposed by Hett et al. (2006) to assess the size of the APJ and the vertebral body on lateral radiographs of the neck.
M1: The most caudal point of the intervertebral foramen to the highest point of the "neck" of the cranial articular process. M2: The highest point of the "neck" of the cranial articular process to the most cranial point of the cranial articular process. M3: The length of the vertebral body is the distance from the cranial to the caudal extremities, measured at the dorsal aspect of the vertebral body. M4*:The maximum height of the vertebral body at the cranial aspect of the vertebral body. M5: The minimal height of the intravertebral canal measured from the dorsal aspect of the vertebral body to the ventral border of the dorsal laminae. **Hett* et al. 2006 used the minimum height of the vertebral body

ventral to latero-dorsal) and those which were on the side of the detector when using oblique technique 2 (Lateral-40°caudal-45°dorsal to latero-cranio-ventral). For calibration of measurements, the left marker was used for the left APJ, and the right marker for the right APJ, respectively.

All measurements were obtained by three observers. On the latero-lateral view the sections M1 to M5 were measured on C6 and C7. On the four oblique views measurements were taken of the APJ of C5/6 and C6/7, respectively.

Anatomical measurements (= gold standard)

Following radiographic examination all specimens were boiled out to remove the remaining soft tissues and then sectioned along the sagittal midline. Measurements were obtained using vernier callipers. The length of each articular process was measured between the most cranial and most caudal extremities of the articular surface. On the oblique views the width of the articular process was measured perpendicular to the length at the widest location. The height of the neck of the cranial articular process was measured at the level of the cranial vertebral notch. The length of the vertebral body was measured along the ventral surface of the vertebral canal and the greatest height of the vertebral body was measured perpendicular to the length. In addition the height of the vertebral canal was measured at its narrowest point, perpendicular to the ventral surface of the vertebral body.

Data analysis

All radiographic measurements were compared to the corresponding anatomical measurements obtained from the boiled out specimen. A positive difference indicates that the anatomically measured value is greater than the radiographically measured value, i.e. radiography underestimates the true value. A negative difference indicates that radiography overestimates the true value. Results were presented as mean difference with a 95% Confidence Interval (95% CI). The 95% confidence intervals show the likely range of mean differences for this population. For example, in table 2 CaudalC5, Left length, Observer 1, T1-LR: the mean difference is 3.3 but it could lie between - 0.8 and + 7.4. In addition, 95% limits of agreement (LOA) were calculated using the equation: 95% LOA = mean difference ± 1.96 s.d. (*Bland* and *Altman* 1986). The limits of agreement show the estimate of the potential range of difference between the anatomical measurement and the radiographic measurement for a wider population.

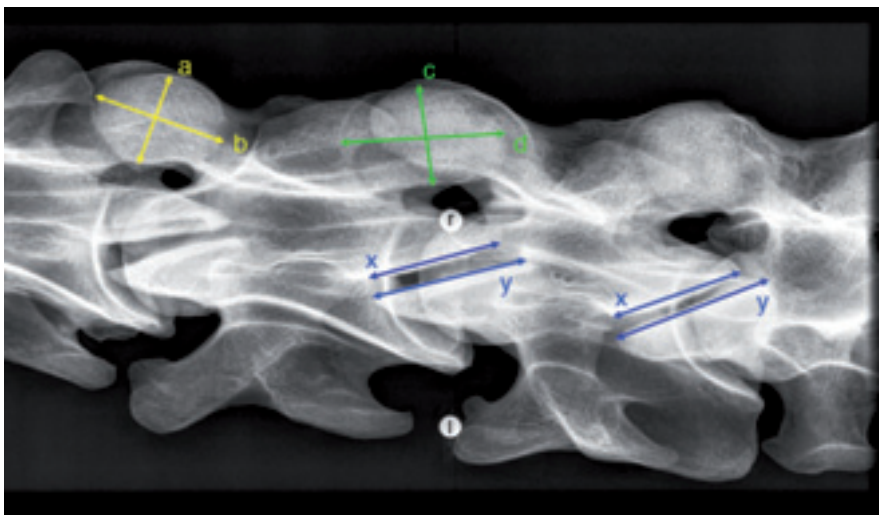

Fig. 2 Measurements of the length and width of the cervical articular processes using the oblique technique 1 (right-50°-ventral to left-dorsal):
a) width of the right cranial articular process,
b) length of the right cranial articular process,
c) width of the right caudal articular process,
d) length of the right caudal articular process,
x) length of the left caudal articular process,
y) width of the left cranial articular process, r) right spherical marker
l) left spherical marker

Results

Lateral radiographs

A summary of the measurements of all three observers is given in Table 1. The measurements of the maximum height (M4) and the length of the cervical body (M5) were the most accurate measurement in this study, because they had the most narrow limits of agreement. It was not possible to differentiate the left APJ from the right APJ on radiographs due to superimposition, therefore radiographically the measurements were compared to the anatomical measurements (length, width, height) of the left, the right and to the average of both APJ, respectively. All these comparisons resulted in relatively high 95% CI and wide LOA.

Oblique radiographs

A representative summary of the results of the comparison of the anatomical with the radiographic measurements of the length and the width of the articular processes of the APJ of C5/C6 is included in Table 2. In general, radiography underestimated the true value of the articular processes. The 95% confidence intervals of all three observers showed a wide range for the mean difference for this population, as well as a wide LOA.

Discussion

Radiographic measurements have been used to assess the size of normal and enlarged cervical APJ in horses on lateral (*Hett* et al. 2006) and oblique (*Lautenschläger* 2010) radiographs. Whilst these studies aimed to establish useful reference values, which could serve as comparative measurements when assessing diseased animals, the accuracy of such measurements has never been evaluated. Our study indicates that measurements of the size of APJ resulted in high 95% Confidence intervals and wide Limits of Agreement. This was true for different observers as well as for different radiographic projections. However, these findings can be deemed to be significant in clinical terms only, because it is not possible to say whether these differences are statistically significant.

On the lateral view (*Hett* et al. 2006), the differences between the reference values of normal horses and horses with enlargement of APJ due to arthropathy (C5/6 and C 6/7) ranged from 7 to 14 mm for the height of the neck of the articular process (M1) and from 3 to 13 mm for the length of the articular process. Our data suggests that the range of differences between measurements obtained by different observers and from using different radiographic techniques in a cadaver study is higher than the differences between normal and diseased horses proposed by (*Hett* et al. 2006). This was also true for the length of the vertebral body (M3), which was the most accurate measurement in our study. Therefore such measurements and guidelines for diagnosis of pathological APJ enlargement have to be used with caution. In addition, the evaluation of the accuracy of the radiographic measurements of the APJ on lateral radiographs is hindered because of the superimposition of the left and the right APJ.

On the oblique views, the radiographic measurements show a low accuracy and it appears that radiography underestimates the true size of the APJ. There was no obvious difference between the two oblique techniques used in this study. Obli-

Table 1 Mean difference between anatomical and radiographic measurements of selected parameters on lateral views of C5/6 and C6/7 of seven horses. (For definitions of parameters, see figure 1). Data is presented as mean difference, 95% Confidence Interval (CI) and limits of agreement for three different observers.

Vertebra	Anatomical measurement	Mean difference (95% CI) [limits of agreement]		
		Observer 1	Observer 2	Observer 3
C6	M1 left	-0.4 (-5.5 – 4.8) [-10.2 – 9.5]	2.1 (-1.1 – 5.4) [-4.1 – 8.3]	0.6 (-2.8 – 4.0) [-5.8 – 7.0]
	M1 right	0.2 (-2.0 – 2.3) [-3.9 – 4.2]	2.7 (-0.2 – 5.6) [-2.8 – 8.2]	1.2 (-1.6 – 3.9) [-4.2 – 6.5]
	M1 average	-0.1 (-3.5 – 3.3) [-6.5 – 6.3]	2.4 (0.2 – 4.6) [-1.9 – 6.7]	0.9 (-1.4 – 3.2) [-3.4 – 5.2]
	M2 left	-0.3 (-4.4 – 3.7) [-8.1 – 7.4]	2.9 (-1.5 – 7.2) [-5.5 – 11.3]	0.9 (-1.1 – 2.9) [-2.8 – 4.6]
	M2 right	-3.1 (-8.0 – 1.8) [-12.3 – 6.2]	0.1 (-2.6 – 2.9) [-5.1 – 5.3]	-1.9 (-4.8 – 1.1) [-7.4 – 3.7]
	M2 average	-1.7 (-5.7 – 2.2) [-9.3 – 5.8]	1.5 (-1.5 – 4.5) [-4.2 – 7.2]	-0.5 (-1.8 – 0.8) [-3.0 – 2.0]
	M3	0.7 (-4.3 – 5.8) [-8.9 – 10.4]	0.02 (-1.6 – 1.7) [-3.1 – 3.2]	3.6 (1.2 – 5.9) [-0.9 – 8.0]
	M4	0.8 (-0.6 – 2.3) [-1.9 – 3.6]	0.4 (-0.9 – 1.6) [-2.0 – 2.8]	1.6 (0.5 – 2.7) [-0.5 – 3.8]
	M5	-0.3 (-1.6 – 1.0) [-2.7 – 2.1]	0.2 (-1.2 – 1.5) [-2.4 – 2.7]	-0.02 (-1.2 – 1.2) [-2.3 – 2.3]
C7	M1 left	-0.8 (-4.2 – 2.5) [-7.3 – 5.6]	2.8 (-0.6 – 6.3) [-3.8 – 9.4]	2.3 (-0.6 – 5.1) [-3.2 – 7.7]
	M1 right	-0.4 (-3.2 – 2.3) [-5.6 – 4.8]	3.2 (1.2 – 5.2) [-0.6 – 7.1]	2.7 (-0.4 – 5.8) [-3.2 – 8.6]
	M1 average	-0.6 (-3.5 – 2.3) [-6.1 – 4.9]	3.0 (0.4 – 5.7) [-2.0 – 8.0]	2.5 (-0.3 – 5.3) [-2.8 – 7.8]
	M2 left	4.4 (-1.9 – 10.8) [-7.7 – 16.5]	4.2 (-0.9 – 9.4) [-5.5 – 14.0]	4.0 (2.1 – 5.9) [0.4 – 7.6]
	M2 right	4.9 (-1.5 – 11.3) [-7.3 – 17.0]	4.7 (-0.7 – 10.0) [-5.5 – 14.8]	4.5 (0.4 – 8.6) [-3.4 – 12.2]
	M2 average	4.7 (-1.4 – 10.7) [-6.8 – 16.1]	4.5 (-0.3 – 9.2) [-4.7 – 13.6]	4.3 (1.8 – 6.7) [-0.4 – 8.9]
	M3	-1.4 (-7.2 – 4.4) [-12.5 – 9.6]	-1.8 (-7.0 – 3.5) [-11.7 – 8.2]	2.7 (-0.2 – 5.5) [-2.8 – 8.1]
	M4	0.4 (-0.7 – 1.6) [-1.8 – 2.6]	0.4 (-1.1 – 1.9) [-2.5 – 3.3]	0.4 (-1.6 – 2.5) [-3.4 – 4.3]
	M5	1.3 (0.1 – 2.4) [-1.0 – 3.4]	0.4 (-0.9 – 1.6) [-2.0 – 2.7]	0.6 (-0.3 – 1.5) [-1.1 – 2.4]

Table 2 Difference between anatomical and radiographic measurements of the length and width articular processes of the APJ of C5/6 of seven horses (For definitions of parameters, see figure 2). Data is presented as mean difference, 95% Confidence Interval (CI) and limits of agreement for three different observers.
T1-LR = L-50°-V to RD; T1-RL = R-50°-V to LD; T2-RL = R-40°-C-45°-D to LCrV; T2-LR = L-40°-C-45°-D to RCrV

Vertebra	Anatomical measurement (mean)	Mean difference (95% CI) [limits of agreement]											
		Observer 1				Observer 2				Observer 3			
		T1-LR	T1-RL	T2-RL	T2-LR	T1-LR	T1-RL	T2-RL	T2-LR	T1-LR	T1-RL	T2-RL	T2-LR
Caudal C5	Left length	3.3 (-0.8 – 7.4) [-5.6 – 12.2]	-2.2 (-5.3 – 0.8) [-8.9 – 4.4]	4.7 (0.45 – 8.9) [-4.5 – 13.8]	2.6 (-1.4 – 6.5) [-6.0 – 11.1]	2.2 (0.78 – 3.6) [-0.9 – 5.3]	5.6 (2.0 – 9.3) [-2.3 – 13.6]	3.4 (-0.5 – 7.3) [-5.1 – 11.9]	1.4 (-1.4 – 4.3) [-4.6 – 7.5]	6.4 (1.6 – 11.1) [-3.9 – 16.6]	1.9 (-0.8 – 4.5) [-3.8 – 7.5]	10.9 (5.3 – 16.5) [-1.2 – 23.0]	2.0 (-2.8 – 6.7) [-8.3 – 12.2]
	Left width	6.1 (4.0 – 8.2) [1.6 – 10.7]	-	4.7 (0.9 – 8.5) [-3.5 – 12.9]	-	5.1 (2.9 – 7.3) [0.2 – 9.9]	-	1.7 (-0.3 – 3.6) [-2.6 – 5.9]	-	7.8 (5.4 – 10.2) [2.7 – 12.9]	-	3.7 (2.2 – 5.2) [0.5 – 7.0]	-
	Right length	1.3 (-2.2 – 4.8) [-6.2 – 8.8]	5.7 (3.4 – 8.1) [0.6 – 10.8]	-0.5 (-2.6 – 1.6) [-5.0 – 4.1]	7.9 (2.0 – 13.9) [-6.0 – 11.1]	3.0 (-0.3 – 6.3) [-4.1 – 10.2]	6.1 (4.5 – 7.7) [2.6 – 9.6]	0.1 (-0.9 – 1.2) [-2.1 – 2.4]	5.5 (0.4 – 10.6) [-5.5 – 16.5]	1.4 (0.3 – 2.5) [-1.1 – 3.8]	8.3 (6.7 – 10.0) [4.8 – 11.9]	1.1 (-1.4 – 3.6) [-4.4 – 6.5]	12.0 (7.5 – 16.5) [2.3 – 21.7]
	Right width	-	3.3 (-0.6 – 7.3) [-5.2 – 11.9]	-	3.4 (-0.8 – 7.5) [-5.6 – 12.3]	-	6.0 (3.5 – 8.5) [0.6 – 11.4]	-	1.4 (-1.8 – 4.6) [-5.6 – 8.4]	-	7.6 (5.1 – 10.1) [2.2 – 13.0]	-	3.5 (1.0 – 5.9) [-1.8 – 8.8]
Cranial C6	Left length	3.1 (-1.0 – 7.2) [-5.8 – 11.9]	-0.6 (-4.6 – 3.5) [-9.3 – 8.1]	4.0 (-2.3 – 10.3) [-9.5 – 17.6]	-1.6 (-6.8 – 3.5) [-12.8 – 9.5]	2.3 (-0.9 – 5.5) [-4.6 – 9.2]	4.3 (-0.4 – 9.0) [-5.9 – 14.4]	4.4 (-0.7 – 9.5) [-6.6 – 15.4]	-0.1 (-3.8 – 3.6) [-8.2 – 7.9]	5.3 (3.2 – 7.4) [0.7 – 9.9]	1.7 (-0.9 – 4.2) [-3.9 – 7.2]	5.7 (0.3 – 11.2) [-6.0 – 17.5]	-0.5 (-6.2 – 5.2) [-12.9 –11.8]
	Left width	8.6 (6.1 – 11.1) [3.1 – 14.1]	-	4.1 (2.7 – 5.5) [1.0 – 7.1]	-	7.5 (4.6 – 10.5) [1.1 – 13.9]	-	5.1 (2.1 – 8.1) [-1.3 – 11.6]	-	9.1 (6.1 – 12.1) [2.5 – 15.7]	-	5.1 (2.7 – 7.6) [-0.2 – 10.4]	-
	Right length	-0.3 (-7.2 – 6.6) [-15.3– 14.7]	4.7 (2.2 – 7.1) [-0.6 – 9.9]	-4.3 (-7.9 – -0.7) [-12.1 – 3.5]	7.3 (1.6 – 13.1) [-5.2 – 19.9]	1.3 (-0.5 – 3.1) [-2.6 – 5.3]	5.5 (2.4 – 8.6) [-1.2 – 12.2]	-2.5 (-5.6 – 0.5) [-9.1 – 4.1]	2.9 (-1.6 – 7.4) [-6.9 – 12.7]	1.6 (-3.9 – 7.1) [-10.3 – 13.5]	7.3 (6.47 – 8.1) [5.4 – 9.1]	-0.9 (-3.0 – 1.2) [-5.5 – 3.6]	7.0 (1.3 – 12.7) [-5.3 – 19.4]
	Right width	-	4.4 (0.5 – 8.2) [-4.0 – 12.7]	-	4.3 (3.2 – 5.4) [1.9 – 6.7]	-	8.4 (6.2 – 10.5) [3.8 – 12.9]	-	2.1 (0.1 – 4.1) [-2.2 – 6.4]	-	8.6 (5.8 – 11.5) [2.4 – 14.8]	-	3.4 (1.6 – 5.3) [-0.5 – 7.4]

que views, are ideally performed with the generator 45-50°ventral from straight lateral, from either side of the neck, as described by *Withers* et al. (2009). Alternatively, the generator can be moved Lateral 45°-50° dorsal to lateral ventral (*Dimock* and *Puchalsky* 2010) or Lateral-40°caudal-45°dorsal to latero-cranio-ventral (*Lautenschläger* 2007). The latter technique would result in geometric distortion of the anatomy of the APJ. However, this was not identified in the analysis of our results, because oblique technique 1 and 2 had similarly high 95% CI and wide LOA.

The selected parameters on the oblique view of the articular processes were easy to identify on the radiographs of the cadaver specimens, because all radiographs were of good quality. On lateral view, this was more difficult, especially for the defined landmarks for M1 and M2 (*Hett* et al. 2006). Even slight obliquity made it almost impossible to select the right points. Furthermore, in a clinical situation image quality may be reduced due to scattered radiation, especially in horses with a large muscle mass. This may further decrease the accuracy of radiographic measurements.

This study suggests, that the radiographic measurements obtained using the described techniques do not accurately represent the anatomical measures. The range of differences used in clinical studies to differentiate between normal and diseased APJ is smaller than the range of differences identified in this study using three observers and different radiographic views. This pilot data demonstrates that there is potentially too much inaccuracy on radiographs compared to anatomical measurements for radiographic measurements to be recommended as reference values for APJ. Certainly it would be unwise to implement decision making solely based upon on radiographic measurements at this stage given these results.

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