Nutt, A., Shaw, T., Knowles, T., & Burton, N. (2018). Radiological Evaluation of TATE Elbow Cartridge Position in Dogs. *Veterinary and Comparative Orthopaedics and Traumatology*.
<https://doi.org/10.1055/s-0038-1673339>

Peer reviewed version

Link to published version (if available):
[10.1055/s-0038-1673339](https://doi.org/10.1055/s-0038-1673339)

[Link to publication record in Explore Bristol Research](#)
PDF-document

This is the author accepted manuscript (AAM). The final published version (version of record) is available online via Thieme at <https://www.thieme-connect.com/products/ejournals/html/10.1055/s-0038-1673339> . Please refer to any applicable terms of use of the publisher.

University of Bristol - Explore Bristol Research

General rights

This document is made available in accordance with publisher policies. Please cite only the published version using the reference above. Full terms of use are available:
<http://www.bristol.ac.uk/red/research-policy/pure/user-guides/ebr-terms/>

Radiological Evaluation of TATE Elbow Cartridge Positioning in Dogs

Journal:	<i>Veterinary and Comparative Orthopaedics and Traumatology</i>
Manuscript ID	VCOT-17-07-0106.R3
Manuscript Type:	Original Research
Keywords:	canine total elbow replacement, TATE, component positioning, evaluation, radiological
Abstract:	<p>Objective: To evaluate the radiological effect of varying elbow flexion angle and elbow orientation on the measurement of component position for first (1G) and second generation (2G) TATE elbow cartridges, and to test intra/inter-observer variability of measurements.</p> <p>Materials and methods: A cadaveric thoracic limb was implanted with a 1G then 2G cartridge, and mounted in lateral recumbency on an acrylic platform. The platform was tilted by set increments up to 10° in both planes, and radiographs were performed at each angle before repeating with the limb in caudocranial positioning. A deterministic trigonometric model was used to show how component angles should vary with changes in orientation, and these were compared to those measured by two observers. Humeral component angle (HCA), radioulnar component angle (RCA), varus/valgus cartridge alignment angle (VVA), and the cartridge height: isthmus width ratio (CIR) were evaluated. Angles within 5° of the zero degrees inclination angle and ratios within 0.2 of the zero degrees inclination ratio were defined as acceptable.</p> <p>Results: Observer component angles for both cartridges were accurate and precise for inclinations up to 10° except for HCA during adduction/abduction. CIR values were within the acceptable limit for inclinations up to 7.5° in both planes.</p> <p>Clinical significance: Acceptable limits of limb inclination during positioning for TATE elbow replacement cartridge assessment were defined. All component measurements were sufficiently accurate and precise to be considered for evaluation of component position in clinical cases.</p>

SCHOLARONE™
Manuscripts

Figure 1: a) True mediolateral radiograph of the elbow with the medial (blue circle) and lateral (yellow circle) portions of the humeral condyle perfectly superimposed. Three 2mm steel balls were positioned on Play-Doh that was placed on the medial aspect of the elbow (white dots). b) A compass was used to draw arcs (black dotted circles) on the Play-Doh from the centre point of each ball (yellow dots). The intersect of the three arcs (white cross) was the condyle centroid. c) After marking the centroid using a kirschner wire, a drill C-guide was used to advance a 2.5mm drill bit across the humeral condyle. d) Mediolateral radiograph showing the hole in the centre of the humeral condyle.

17x5mm (600 x 600 DPI)

Figure 2: Radiographs were **taken** with the elbow at both 90° of flexion (a) and 135° of flexion (b). Viewing software was used to position the elbow precisely. Purple ellipse = humeral head, red circle = margin of the humeral component of the cartridge, blue circle = centre of the epiphyseal region of the distal radius, yellow lines = mechanical axes of the humerus and radius. The angle between the lines cranial to their intersect defined the elbow flexion angle.

40x20mm (600 x 600 DPI)

Figure 3: Examples of the apparatus for positioning the elbow in various combinations of abduction/adduction/internal rotation/external rotation. a) For the mediolateral projections, the limb was positioned at either 90° of elbow flexion (shown) or 135°, and an Ellis pin was placed in the previously drilled condylar hole to align the elbow joint exactly parallel with the x-ray beam. b,c) Examples of 135° elbow flexion angle with 10° of external rotation. The inclination in the craniocaudal plane measured in b) was 10°, and in the proximodistal plane measured in c) was 0°. d) Elbow positioned for a caudocranial projection with 2.5° flexion.

481x384mm (300 x 300 DPI)

Figure 4: a) mediolateral and b) caudocranial bone model projection of the elbow illustrating the descriptors used to define specific movements of the limb in each plane.

409x204mm (300 x 300 DPI)

Figure 5: a) Measurement of the position of the humeral component relative to the humeral mechanical axis (the humeral component angle). b) Measurement of the position of the radio-ulnar component relative to the humeral mechanical axis (the radio-ulnar component angle). c) Measurement of the cartridge height to ulnar isthmus width ratio. d) Measurement of the varus/valgus cartridge alignment angle. Mediolateral images: Purple ellipse = humeral head, red circle = articular surface of the humeral/radio-ulnar component, yellow line = mechanical axis of the humerus, blue line = component line, θ = component angle, measured between the yellow and blue lines cranial to their intersect (orange), green line = isthmus width, purple line = cartridge height. Caudocranial image: Long yellow line = line passing through the centre of the ellipse and the mid-portion of the most distal aspect of the radio-ulnar component, short yellow line = line from distal aspect of the first line to the mid-portion of the proximal extent of the radio-ulnar component, θ = varus/valgus cartridge alignment angle.

246x95mm (300 x 300 DPI)

Figure 6: Illustration of how the circles were templated for best fit depending on the appearance of components with changing inclination. a) Circular template of the radio-ulnar component. b) Best fit oval template of the radio-ulnar component. c) Three circle template of the radio-ulnar component when the limb was inclined in adduction or abduction. d) Three circle template of the radio-ulnar component when the limb was inclined in external rotation or internal rotation. See text for further details.

24x6mm (600 x 600 DPI)

Component measurement	Intra-observer variability		Inter-observer variability
	Observer 1 LoA	Observer 2 LoA	LoA
Humeral component angle	-4.2° to 4.4°	-2.8° to 2.2°	-7.3° to 3.8°
Radio-ulnar component angle	-1.9° to 1.6°	-1.3° to 0.8°	-1.6° to 1.4°
Varus/valgus cartridge alignment angle	-0.8° to 1.3°	-1.1° to 1°	-1.4° to 1.5°
Cartridge height to ulnar isthmus width ratio	-0.06 to 0.05	-0.03 to 0.04	-0.02 to 0.02

Table 1: Table to show the intra-observer and inter-observer variability limits of agreement for the component measurements. LoA = limits of agreement.

Figure 7: Graphs to show one of the four deterministic HCA data sets (a) and one of the four observer HCA data sets (b). All four of the deterministic and observer graphs showed very similar trends and so are not shown. Note that on the deterministic graph, increasing the inclination up to 10° had almost no effect on the component angle, whereas there was a more obvious deviation from the zero inclination angle up to 10° of inclination on the observer measured graph.

31x33mm (600 x 600 DPI)

	Predicted inclination required to change measured component angle by 5°					
	Humeral component angle		Radio-ulnar component angle		Varus/valgus cartridge alignment angle	
Elbow model	Abduction/ Adduction	External rotation/Internal rotation	Abduction/ Adduction	External rotation/Internal rotation	Flexion/Extension	External rotation/Internal rotation
ML, 1G at 90° elbow flexion angle	52.5	44.6	36.7	34.8		
ML, 1G at 135° elbow flexion angle	53.5	45.4	47.7	42		
ML, 2G at 90° elbow flexion angle	61	49	36.4	34.7		
ML, 2G at 135° elbow flexion angle	58	47.7	47.1	41.5		
CC, 1G					60.8	N/A
CC, 2G					61.8	N/A

Table 2: Table to show the inclination, as predicted by the deterministic model, required to cause the measured component angle to change by 5° from the zero degrees inclination angle. For varus/valgus cartridge alignment angle during internal and external rotation, since the zero degrees inclination angle was less than 5°, the change in inclination did not exceed 5° because the angle gradually reduced to zero. ML = mediolateral, CC = caudocranial, 1G = first generation cartridge, 2G = second generation cartridge.

	Greatest deviation in component measurement from the zero degrees inclination angle/ratio			
Elbow model	Humeral component angle	Radio-ulnar component angle	Varus/valgus cartridge alignment angle	Cartridge height to ulnar isthmus width ratio
ML, 1G at 90° elbow flexion angle	5.8° (10° AB)	1.13° (7.5° ER)		0.3 (10° AB)
ML, 1G at 135° elbow flexion angle	6.83° (10° AB)	1.78 (10° AD)		0.27 (10° AB)
ML, 2G at 90° elbow flexion angle	4.39° (10° AD)	1.22° (10° ER)		0.28 (10° AB)
ML, 2G at 135° elbow flexion angle	7.43° (10° AB), 5.38° (7.5° AB)	2.04° (10° IR)		0.2 (10° AB)
CC, 1G			4.6° (10° IR)	
CC, 2G			3.79° (10° ER)	

Table 3: Table to show the greatest deviations in measurements from the zero degrees inclination angle (for HCA, RCA and VVA) or zero degrees inclination ratio (for CIR) for the various elbow models and component measurements. The angles shown in red indicate those which were greater than 5° from the zero degrees inclination angle. The second greatest deviation is also shown for HCA with the ML, 2G at 135° elbow flexion elbow model for completeness, as this was the only other angle greater than 5° from the zero degrees inclination angle. The values shown in blue relate to cartridge height to ulnar isthmus width ratio, and indicate values that were greater than 0.2 from the zero degrees inclination ratio. ML = mediolateral, CC = caudocranial, 1G = first generation cartridge, 2G = second generation cartridge, AB = abduction, AD = adduction, ER = External rotation, IR = Internal rotation.

Figure 8: Graphs to show one of the four deterministic RCA data sets (a) and one of the four observer RCA data sets (b). All four of the deterministic and observer graphs showed very similar trends and so are not shown. Note that on the deterministic graph, increasing the inclination up to 10° had almost no effect on the component angle, whereas there is a more obvious deviation from the zero degrees inclination angle up to 10° of inclination on the observer measured graph.

30x31mm (600 x 600 DPI)

Figure 9: Graphs to show the 1G deterministic and observer measured VVA data sets. The 2G graphs showed the same trend and so are not shown. Note that on the deterministic graph, increasing the inclination up to 10° had almost no effect on the component angle, whereas there is a more obvious deviation from the zero degrees inclination angle up to 10° of inclination on the observer measured graph.

30x32mm (600 x 600 DPI)

Figure 10: One of the four CIR graphs demonstrating the observer measured change. All four graphs showed a very similar trend and so are not shown.

15x8mm (600 x 600 DPI)

Figure 11: Examples of the effect of positioning on the appearance of the components in mediolateral projection. Key: 2.5, 5, 7.5, 10 = degrees, AD = adduction, AB = abduction, ER = external rotation, IR = internal rotation.

313x307mm (300 x 300 DPI)

Figure 12: Examples of the effect of positioning on the appearance of the components in caudocranial projection. Key: 2.5, 5, 7.5, 10 = degrees, E = extension, F = flexion, ER = external rotation, IR = internal rotation.

122x170mm (300 x 300 DPI)

1 Figure legends

2

3 Figure 1: a) True mediolateral radiograph of the elbow with the medial (blue circle) and lateral
4 (yellow circle) portions of the humeral condyle perfectly superimposed. Three 2 millimetre steel
5 balls were positioned on Play-Doh that was placed on the medial aspect of the elbow (white dots). b)
6 A compass was used to draw arcs (black dotted circles) on the Play-Doh from the centre point of
7 each ball (yellow dots). The intersect of the three arcs (white cross) was the condyle centroid. c)
8 After marking the centroid using a kirschner wire, a drill C-guide was used to advance a 2.5mm drill
9 bit across the humeral condyle. d) Mediolateral radiograph showing the hole in the centre of the
10 humeral condyle.

11

12 Figure 2: Radiographs were taken with the elbow at both 90° of flexion (a) and 135° of flexion (b).
13 Viewing software was used to position the elbow precisely. Purple ellipse = humeral head, red circle
14 = margin of the humeral component of the cartridge, blue circle = centre of the epiphyseal region of
15 the distal radius, yellow lines = mechanical axes of the humerus and radius. The angle between the
16 lines cranial to their intersect defined the elbow flexion angle.

17

18 Figure 3: Examples of the apparatus for positioning the elbow in various combinations of
19 abduction/adduction/external rotation/internal rotation. a) For the mediolateral projections, the
20 limb was positioned at either 90° of elbow flexion (shown) or 135°, and an Ellis pin was placed in the
21 previously drilled condylar hole to align the elbow joint exactly parallel with the x-ray beam. b,c)
22 Examples of 135° elbow flexion angle with 10° of external rotation. The inclination in the
23 craniocaudal plane measured in b) was 10°, and in the proximodistal plane measured in c) was 0°. d)
24 Elbow positioned for a caudocranial projection with a 2.5° flexion.

25

26 Figure 4: a) mediolateral and b) caudocranial bone model projection of the elbow illustrating the
27 descriptors used to define specific movements of the limb in each plane.

28

29 Figure 5: a) Measurement of the position of the humeral component relative to the humeral
30 mechanical axis (the humeral component angle, HCA). b) Measurement of the position of the radio-
31 ulnar component relative to the humeral mechanical axis (the radio-ulnar component angle, RCA). c)
32 Measurement of the cartridge height to ulnar isthmus width ratio (CIR). d) Measurement of the
33 varus/valgus alignment of the cartridge (the varus/valgus angle, VVA). Mediolateral images: Purple
34 ellipse = humeral head, red circle = articular surface of the humeral/radio-ulnar component, yellow
35 line = mechanical axis of the humerus, blue line = component line, θ = component angle, measured
36 between the yellow and blue lines cranial to their intersect (orange), green line = isthmus width,
37 purple line = cartridge height. Caudocranial image: Long yellow line = line passing through the centre
38 of the ellipse and the mid-portion of the most distal aspect of the radio-ulnar component, short
39 yellow line = line from distal aspect of the first line to the mid-portion of the proximal extent of the
40 radio-ulnar component, θ = varus/valgus angle.

41

42 Figure 6: Illustration of how the circles were templated for best fit depending on the appearance of
43 components with changing inclination. a) Circular template of the radio-ulnar component. b) Best fit
44 oval template of the radio-ulnar component. c) Three circle template of the radio-ulnar component
45 when the limb was inclined in adduction or abduction. d) Three circle template of the radio-ulnar
46 component when the limb was inclined in external rotation or internal rotation. See text for further
47 details.

48

49 Figure 7: Graphs to show one of the four deterministic HCA data sets (a) and one of the four
50 observer HCA data sets (b). All four of the deterministic and observer graphs showed very similar
51 trends and so are not shown. Note that on the deterministic graph, increasing the inclination up to
52 10° had almost no effect on the component angle, whereas there was a more obvious deviation
53 from the zero inclination angle up to 10° of inclination on the observer measured graph.

54

55 Figure 8: Graphs to show one of the four deterministic RCA data sets (a) and one of the four
56 observer RCA data sets (b). All four of the deterministic and observer graphs showed very similar
57 trends and so are not shown. Note that on the deterministic graph, increasing the inclination up to
58 10° had almost no effect on the component angle, whereas there is a more obvious deviation from
59 the zero degrees inclination angle up to 10° of inclination on the observer measured graph.

60

61 Figure 9: Graphs to show the 1G deterministic and observer measured VVA data sets. The 2G graphs
62 showed the same trend and so are not shown. Note that on the deterministic graph, increasing the
63 inclination up to 10° had almost no effect on the component angle, whereas there is a more obvious
64 deviation from the zero degrees inclination angle up to 10° of inclination on the observer measured
65 graph.

66

67 Figure 10: One of the four CIR graphs demonstrating the observer measured change. All four graphs
68 showed a very similar trend and so are not shown.

69

70 Figure 11: Examples of the effect of positioning on the appearance of the components in
71 mediolateral projection. Key: 2.5, 5, 7.5, 10 = degrees, AD = adduction, AB = abduction, ER = external
72 rotation, IR = internal rotation.

73

74 Figure 12: Examples of the effect of positioning on the appearance of the components in
75 caudocranial projection. Key: 2.5, 5, 7.5, 10 = degrees, E = extension, F = flexion, ER = external
76 rotation, IR = internal rotation.

77

78 Table 1: Table to show the intra-observer and inter-observer variability limits of agreement for the
79 component measurements. LoA = limits of agreement.

80

81 Table 2: Table to show the inclination, as predicted by the deterministic model, required to cause
82 the measured component angle to change by 5° from the zero degrees inclination angle. For
83 varus/valgus cartridge alignment angle during internal and external rotation, since the zero degrees
84 inclination angle was less than 5°, the change in inclination did not exceed 5° because the angle
85 gradually reduced to zero. ML = mediolateral, CC = caudocranial, 1G = first generation cartridge, 2G =
86 second generation cartridge.

87

88 Table 3: Table to show the greatest deviations in measurements from the zero degrees inclination
89 angle (for HCA, RCA and VVA) or zero degrees inclination ratio (for CIR) for the various elbow models
90 and component measurements. The angles shown in red indicate those which were greater than 5°
91 from the zero degrees inclination angle. The second greatest deviation is also shown for HCA with
92 the ML, 2G at 135° elbow flexion elbow model for completeness, as this was the only other angle

93 greater than 5° from the zero degrees inclination angle. The values shown in blue relate to cartridge
94 height to ulnar isthmus width ratio, and indicate values that were greater than 0.2 from the zero
95 degrees inclination ratio. ML = mediolateral, CC = caudocranial, 1G = first generation cartridge, 2G =
96 second generation cartridge, AB = abduction, AD = adduction, ER = External rotation, IR = Internal
97 rotation.

For Peer Review

1 Introduction

2 Elbow osteoarthritis (OA) is the most frequent cause of forelimb lameness in dogs (1) and may occur
3 as a sequela to developmental conditions including elbow dysplasia (2), incongruity secondary to
4 premature growth plate closure (3,4), and traumatic conditions such as luxation or intra-articular
5 fracture (5). Numerous surgical techniques have been described in an effort to ameliorate the pain
6 associated with developmental elbow disease as well as the OA that may ensue (6-9). However,
7 progression of OA may sometimes render the patient in intractable pain and recalcitrant lameness.
8 In cases where this pain is poorly controlled by conservative measures and poor clinical function is
9 persistent, salvage surgery, such as elbow replacement may be considered in an effort to improve
10 patient comfort and quality of life.

11 The first canine prototype hinged total elbow replacement was implanted by Chancrin (1989) and
12 later Lewis (1996), the latter author reporting pilot data on a small cohort of research dogs (10). High
13 complication rates and poor function with these constrained systems resulted in archiving of these
14 designs with subsequent development of a semi-constrained cemented system. This was released
15 commercially in the late 1990's and evaluated in dogs both without elbow OA and a clinical cohort
16 with naturally occurring OA (11,12). Satisfactory results were observed but with a 20% incidence of
17 complications including infection, luxation and humeral/ulnar fracture. Discontentment with this
18 system clinically has resulted in the development of several new total or partial arthroplasty systems
19 (13-15) one of which is the TATE elbow system, a semi-constrained cementless bi-component
20 resurfacing implant (16); a recent retrospective study evaluating this system showed good clinical
21 results in a majority of cases, but with a high complication rate (17).

22 Protocols for evaluation of component placement following arthroplasty have been shown in both
23 human beings and dogs to be important in predicting the success of surgery as well as the risk of
24 complications occurring (18-24). Preliminary retrospective evaluation of TATE elbow component
25 positioning has been performed by de Sousa et al (17). However, measurements were not
26 standardised in this study, firstly due to radiographs that excluded the long axis of the humerus for

measurement, and secondly, any effect of variable elbow flexion angle or positioning of the elbow on the measurement of component position was not evaluated. Any influence of elbow positioning on the measurement of TATE component position is important in developing a protocol for component position measurement that is accurate and repeatable, thus facilitating the objective correlation of component positioning with clinical outcome.

The aim of this study was to evaluate the radiological effect of varying both elbow flexion angle and elbow orientation on the measurement of component position for first generation (1G) and second generation (2G) TATE elbow cartridges, and to test intra-observer variability and inter-observer variability of the measurements. Our hypothesis was that significant differences in the measured verses actual position of components would occur as a function of varying these parameters.

53 **Materials and Methods**

54 ***Preparation of the model:***

55 A right thoracic limb was harvested from a dog that had been euthanized for reasons unrelated to
56 this study and following owner consent having been given for the dog to be used for research
57 purposes. Ethical approval for the veterinary investigation was given by the XX Animal Welfare and
58 Ethical Review Body. The limb was disarticulated at the scapulohumeral joint and the muscles then
59 removed from the humerus and antebrachium. The collateral ligaments of the elbow and
60 carpus/manus, and the interosseous muscle between radius and ulna, were preserved. The limb was
61 then wrapped in saline soaked gauze swabs, bagged, archived and stored at -20°C. The limb was left
62 to thaw at room temperature for 24 hours prior to experimental use.

63 For accurate placement of the TATE cartridge around the centre of rotation (COR), the following
64 protocol was employed. The limb was radiographed to obtain a true mediolateral radiographic
65 projection of the humerus as published in a previous study (25). Play-Doh (Hasbro, China) was
66 applied over the medial portion of the humeral condyle and three 2mm diameter steel balls (Simply
67 Bearings, UK) were placed on top, each approximately 120° to each other (Figure 1 a)). The
68 radiograph was repeated with a 100mm calibration marker positioned level with the steel balls. The
69 image was imported into viewing software (OsiriX MD, Pixmeo, Switzerland) and two concentric
70 circles were drawn centred over the humeral condyle, the circumferences of which defined the
71 medial and lateral portions of the humeral condyle as described by Wood *et al* (2016) (25). The
72 image was calibrated to 100% magnification, the centre point of the circles defined (X), and then the
73 distance from X to each respective steel ball was measured and recorded. The steel balls were then
74 removed from the Play-Doh, and a compass with a radius corresponding to the measured distance
75 between each steel ball to X was placed in the centre of each ball indentation. Arcs for each ball
76 were then marked corresponding to the measured distance to X. The condyle centroid was then
77 defined as the point where the three arcs intersected (Figure 1 b)). A 1.6mm Kirschner wire
78 (Veterinary Instrumentation, UK) and orthopaedic drill (Colibri II, SynthesVet, UK) were then used to

pierce the Play-Doh at the marked centroid and to create a 5mm deep hole in the medial portion of the condyle at that position. This protocol was repeated by taking a radiograph with the limb in lateromedial projection. A drill C-guide (SynthesVet, UK) was then placed in the medial and lateral condylar holes and a 2.5mm drill bit was advanced across the humeral condyle to mark its COR (Figure 1 c)). A mediolateral radiograph was obtained to confirm that the hole was in the exact centre of the humeral condyle (Figure 1 d)). A BioMedtrix first generation (1G) TATE elbow arthroplasty cartridge was then implanted into the limb as previously described (26). The cartridge was centred around the COR hole, thus making it orthogonal to the mechanical axis of the humerus in the sagittal plane, as described by Wood *et al* (2016) (25). The medial epicondylar osteotomy was reduced and stabilised with two 2.7mm cortical screws (SynthesVet, UK) in the medial epicondylar ridge. In a variant to the previously described surgical technique for TATE elbow replacement, a 3.5mm screw was not placed in the transcondylar hole, rather this hole was left empty in order to be used as a reference for the next part of the experiment.

Limb positioning:

Mediolateral projection

The limb was mounted on a 15mm x 500mm x 500mm acrylic sheet (Trent Plastics Fabrications, UK), with the mechanical axis of the humerus parallel to the lateral edge. This was done by ensuring that the centre of the humeral head and humeral condyle were the same distance to the lateral edge. A goniometer was used to position the elbow by eye at 90° of flexion and a 2.4mm Ellis pin (Veterinary Instrumentation, UK) was placed in the COR hole in the humeral condyle. Modelling clay (Newplast TM, Newclay Products Limited, UK) was used to support the proximal humerus and distal antebrachium, which was then adjusted until the pin was exactly parallel to the centre of the x-ray beam, thus appearing as a circle in the centre of the humeral condyle. Using a technique similar to that previously described to define the mechanical axes of bones (25) and using OsiriX MD software, an ellipse of best fit was superimposed over the humeral head, and two circles, one defining the

circular margin of the humeral condyle centred over the Ellis pin, and the other defining the centre of the epiphyseal region of the distal radius, were applied. Lines were drawn through the centres of the circles and ellipse, thus defining the mechanical axes, and the angle between these lines cranial to their intersect was measured. The elbow was progressively adjusted with repeat exposures until the angle on the cranial aspect of the elbow between the two lines was exactly 90° (Figure 2 a), and later 135° (Figure 2 b). This radiograph was labelled '90° elbow flexion angle and 0° inclination'. The Ellis pin was removed, and the platform was then tilted by set increments (2.5°, 5°, 7.5° and 10°) relative to the x-ray table using modelling clay wedges. A digital inclinometer (Chronos Engineering Supplies, UK) placed on top of the platform was used to confirm the inclination induced in orthogonal planes (Figure 3 a-c). The directions of platform tilt were named according to limb movement relative to the shoulder joint (with a fixed scapula). Tilting the platform up and down was defined as adduction and abduction, and tilting it from side to side was defined as external rotation and internal rotation (Figure 4 a). A radiograph was taken at each angle. The method was performed with the elbow flexion angle at both 90° and 135°.

Caudocranial projection

The Ellis pin was replaced in the COR hole, and the limb was fully extended and placed on the platform with the long axis parallel to the side. The limb was positioned such that the Ellis pin was equidistant from the platform at both of its ends in order to position the humerus in true caudocranial. A radiograph was taken in this position and labelled '0° inclination'. The platform was then tilted by the same set increments (Figure 3 d). The directions of platform tilt were again named according to limb movement relative to the shoulder joint (with a fixed scapula). Tilting the platform up and down was defined as flexion and extension, and tilting it from side to side was called external rotation and internal rotation (Figure 4 b). A radiograph was taken at each angle.

The 1G TATE cartridge was then explanted from the elbow, the 2G cartridge implanted, and the method was repeated.

131

132 ***Radiological assessment:***

133 Radiological examination was performed by two independent observers (XX/XX) on two occasions
134 one week apart. A protocol was followed to objectively measure component position, similar to that
135 described by Wood *et al* (2016) (17) and as illustrated in Figure 5. On mediolateral projections, the
136 humeral and radio-ulnar components were assessed relative to the humeral mechanical axis, and
137 the cartridge height to ulnar isthmus width ratio was calculated. On caudocranial projections the
138 cartridge was assessed for varus/valgus malalignment. Each measurement was repeated for every
139 variation of elbow position.

140

141 *Mediolateral projection measurements*

142 - Humeral component angle (HCA)

143 The humeral mechanical axis was determined using the previously described technique (25). An
144 ellipse of best fit was templated onto the humeral head and a circle defining the articular surface
145 was templated onto the humeral component of the TATE cartridge. A line passing through the centre
146 of the ellipse and the centre of the circle was drawn (humeral mechanical axis), followed by another
147 line drawn along the most proximal extent of the humeral component (humeral component line).
148 The angle between the humeral mechanical axis line and humeral component line cranial to their
149 intersect was defined as the HCA (Figure 5 a)).

150 - Radio-ulnar component angle (RCA)

151 An ellipse of best fit was templated onto the humeral head, and a circle defining the titanium-
152 ultrahigh molecular weight polyethylene interface of the radio-ulnar component was templated
153 onto the radio-ulnar component. The humeral mechanical axis was again marked by drawing a line
154 which passed through the centre of the ellipse and circle, followed by another line drawn along the
155 most proximal extent of the radio-ulnar component (radio-ulnar component line). The angle

between the humeral mechanical axis line and the radio-ulnar component line cranial to their intersect was defined as the RCA (Figure 5 b)).

- Cartridge height to ulnar isthmus width ratio (CIR)

The isthmus of the ulna was measured at the narrowest point of the trochlear notch, perpendicular to the caudal border of the ulna. This measured line was extrapolated to the most proximal aspect of the cartridge at that location, and the cartridge height was calculated by subtracting the isthmus width from the total width. The cartridge height to ulnar isthmus width ratio was calculated using the formula: *Cartridge height to ulnar isthmus width ratio = cartridge height/ulnar isthmus width* (Figure 5 c)).

Caudocranial projection measurements

- Varus/valgus cartridge alignment angle (VVA)

An ellipse was templated onto the humeral head and a line passing through the centre of this ellipse and the mid-portion of the most distal aspect of the radio-ulnar component was added. A second line was placed from the mid-portion of the most distal aspect of the radio-ulnar component to the mid-portion of the proximal extent of the radio-ulnar component. The angle between the two lines was defined as the VVA (Figure 5 d)).

Protocols were devised for templating the circles of best fit to control the measuring technique as the radiographic shape changed with inclination, as shown in Figure 6. Image a) and c) show the limb tilted to cause abduction/adduction, and image b) and d) show the limb tilted to cause internal rotation/external rotation. In a) the limb was tilted by 2.5°, therefore the two sides of the cartridge were radiographically very close to one another and not easily distinguishable. A circle of best fit around the two sides of the (in this case humeral) component was therefore templated. Image b) shows templating of the radio-ulnar component with the limb also tilted by 2.5°. An ellipse of best fit

was templated as it was not possible to accurately position a circle. This method was performed for all radio-ulnar measurements. In c) the limb was tilted by 7.5°, therefore the two sides of the cartridge were radiographically much further away from each other. A circle of best fit was first templated onto one side of the humeral component, and this circle was then copied and pasted and positioned over the other side of the component. A third copy of the circle was then transposed to lie equidistant between these circles, and this third circle was used to measure humeral component angle. Image d) shows the appearance of the three circle technique when the limb was tilted in internal rotation/external rotation.

Determination of true component angles:

A deterministic trigonometric model was used to show how the component angles (HCA, RCA and VVA) should have varied with changes in orientation. The model determined how a visualised angle changes with inclination, not taking into account the shape of the cartridge. A 3D coordinates axes rotation matrix was used to calculate the theoretical angles, using the following formula below, where $R_x(\theta)$ equals the component angle when the model is tilted in external rotation or internal rotation, and $R_y(\theta)$ equals the component angle when the model is tilted in abduction or adduction.

$$R_x(\theta) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \theta & -\sin \theta \\ 0 & \sin \theta & \cos \theta \end{bmatrix}$$

$$R_y(\theta) = \begin{bmatrix} \cos \theta & 0 & \sin \theta \\ 0 & 1 & 0 \\ -\sin \theta & 0 & \cos \theta \end{bmatrix}$$

The component angle when the limb was positioned at zero degrees of inclination, the zero degrees inclination angle, was defined as the average of the four observer measured zero degrees inclination angles (two per observer). The model was then used to calculate theoretical component angles at

2.5°, 5°, 7.5° and 10°. Angles at 20°, 30°, 40°, 50°, 60°, 70°, 80° and 90° were also calculated in order to identify trend lines on scatter graphs. As abduction and adduction, and flexion and extension inclination angles were equal (the difference being only positive or negative) these were recorded as one. This was the same for external rotation and internal rotation angles on both mediolateral and caudocranial projections.

Data interpretation:

Intra-observer and inter-observer variability

Intra-observer and inter-observer variability between measurements was evaluated using Student's t-tests and the Bland-Altman method (27). Student's t-tests were used to identify bias between each observer's first and second measurements (intra-observer) and between both observers (inter-observer) e.g. whether one set of measurements was higher or lower. Significance was defined as a p value ≤ 0.05 . For inter-observer variability, permuted block randomisation was used to select observer values in order to ensure that each set of component angle/ratio values was made up of an even but varying combination of first and second measurements made by observer 1 and 2. All Bland-Altman plots were evaluated for bias between the two sets of data, and the 95% limits of agreement (LoA – the mean difference in measurements ± 1.96 standard deviations) were recorded. The plots were also evaluated for trends, for example if the difference between data sets became larger or smaller as the average measurement changed.

Component angle/ratio measurement

For each set of component measurements (HCA, RCA, VVA, and CIR), permuted block randomisation was used to determine which of the two observers, and which of the observer's two values, would be selected for analysis. Scatter graphs for each set of values were then plotted. This was repeated for each combination of cartridge generation, elbow flexion angle and component measurement,

resulting in the following series of data and graphs: 1G HCA at 90° elbow flexion angle, 1G HCA at 135° elbow flexion angle, 2G HCA at 90° elbow flexion angle, 2G HCA at 135° elbow flexion angle, 1G RCA at 90° elbow flexion angle, 1G RCA at 135° elbow flexion angle, 2G RCA at 90° elbow flexion angle, 2G RCA at 135° elbow flexion angle, 1G CIR at 90° elbow flexion angle, 1G CIR at 135° elbow flexion angle, 2G CIR at 90° elbow flexion angle, 2G CIR at 135° elbow flexion angle, 1G VVA and 2G VVA.

The two sets of data (deterministic and observer measured values) were then compared. An angle $\leq 5^\circ$ from the zero degrees inclination angle, and a cartridge height to ulnar isthmus width ratio ≤ 0.2 from the zero inclination ratio were defined as acceptable.

249 **Results**

250 ***Intra-observer variability:***

251 *Observer 1*

252 First and second measurements for HCA were all within 7° of each other. The LoA were -4.2° to 4.4°.
253 The measurements outside of these were for an adduction inclination of 5°. For RCA they varied by
254 no more than 2.3° (LoA -1.9° to 1.6°), and for VVA the largest difference was 1.7° (LoA -0.8° to 1.3°).
255 The largest difference for CIR was 0.1 (LoA -0.06 to 0.05) (Table 1). Student's t-tests for each set of
256 data showed no significant differences between the first and second measurements (p values >0.05).
257 No trends on the Bland-Altman plots were identified i.e. the scatter was distributed evenly for all
258 averages.

259 *Observer 2*

260 First and second measurements for HCA were all within 4.9° of each other and the LoA were -2.8° to
261 2.2°. The measurements outside of the LoA were for an adduction inclination of 10°. For RCA they
262 varied by no more than 1.8° (LoA -1.3° to 0.8°), and for VVA the largest difference was 1.5° (LoA -1.1°
263 to 1°). The largest difference for CIR was 0.04 (LoA -0.03 to 0.04) (Table 1). Student's t-tests for each
264 set of data showed no significant differences between the first and second measurements (p values
265 >0.05). No trends were identified on the Bland-Altman plots.

267 ***Inter-observer Variability:***

268 First and second measurements for HCA were all within 11.1° of each other (LoA -7.3° to 3.8°).
269 Measurements outside of the LoA were during adduction at 10° inclination. For RCA the
270 measurements varied by no more than 1.9° (LoA -1.6° to 1.4°), and for VVA the largest difference
271 was 1.5° (LoA -1.4° to 1.5°). The largest difference for CIR was 0.03 (LoA -0.02 to 0.02) (Table 1).
272 Student's t-tests for each set of data showed no significant differences between observers (p values
273 >0.05). No trends were identified on the Bland-Altman plots.

274

Humeral component angle:

Graphs depicting one of the four deterministic HCA data sets and one of the four observer HCA data sets are shown in Figure 7. All four of the deterministic and observer graphs showed very similar trends. The deterministic graphs showed that for both abduction and adduction, the HCA only started to change significantly from the zero degrees inclination angle at around 50° inclination. After this inclination, the angles changed by more than 5° (Table 2). For internal and external rotation, the HCA only started to change significantly from the zero degrees inclination angle at around 40° inclination. After this inclination, the angle changed by more than 5° (Table 2). The observer measured HCA graphs showed that during adduction, internal rotation or external rotation of the limb, despite a gradual deviation away from the zero degrees inclination angle with increased limb inclination, the values all remained within 5° (specifically within 4.4°). However, during abduction, an increase in inclination of 10° for the 1G cartridge and 10° and 7.5° for the 2G cartridge resulted in a change in the measured HCA greater than 5° from the zero degrees inclination angle (Table 3).

Radio-ulnar component angle:

Graphs depicting one of the four deterministic RCA data sets and one of the four observer RCA data sets are shown in Figure 8. All four of the deterministic and observer graphs showed very similar trends. The deterministic graphs showed that for both abduction and adduction, the RCA only started to change significantly from the zero degrees inclination angle at around 30° to 40° inclination. After this inclination, the angle changed by more than 5° (Table 2). For internal and external rotation, the RCA also started to change significantly from the zero degrees inclination angle at around 30° to 40° inclination. After this inclination, the angle changed by more than 5° (Table 2). The observer measured RCA graphs showed that during abduction, adduction, internal rotation or external rotation of the limb, despite a gradual deviation away from the zero degrees inclination angle with increased inclination, the values all remained within 5° (specifically within 1.8°) (Table 3).

Varus/valgus cartridge alignment angle:

Graphs depicting the 1G deterministic and observer measured VVA data sets are shown in Figure 9. Both first and second generation graphs showed the same trend. The predicted angles graph showed that during both flexion and extension, the VVA only started to change significantly from the zero degrees inclination angle at around 60° inclination. After this inclination the angle changed by more than 5° (for 1G a change in VVA of 5° occurred at an inclination of 60.8°, for 2G the change was at 66.1°). For internal and external rotation, since the zero degrees inclination angle was less than 5°, the change in inclination did not exceed 5° because the angle gradually reduced to 0° (Table 2). The observer measured VVA graphs showed that during flexion, extension, internal rotation or external rotation of the limb, despite a deviation away from the zero degrees inclination angle with increased inclination, the values all remained within 5° (specifically within 4.4°) (Table 3).

Cartridge height to ulnar isthmus width ratio:

One of the graphs demonstrating the observer measured change in CIR is shown in Figure 10. All four graphs showed a very similar trend. An increase in inclination in all four orientations resulted in a positive linear deviation away from the zero degrees inclination ratio. Up to an inclination of 7.5° the values were all within 0.2 of the zero degrees inclination ratio, but at an inclination of 10° the values during abduction and adduction exceeded this with the exception of the G2 at 135° elbow flexion angle model (Table 3). A ratio of 1.0 occurred when the limb was inclined in adduction at 10° in all models except G2 at 135° elbow flexion angle.

327 Discussion

328 This study defines acceptable limits of limb inclination during positioning for radiological assessment
329 of TATE elbow replacement cartridge, and validates the low variability in measurements of cartridge
330 position. A test should be both accurate and precise to be clinically useful. Accuracy is the closeness
331 of measurements of a quantity to its true value and precision is the consistency or repeatability of
332 those measurements. Measurements within 5° of the zero degrees inclination angle, or within 5° of
333 each other for intra-observer or inter-observer variability, were defined as acceptable. This value
334 was chosen based on the study by De Sousa *et al* (2016) whereby alignment greater than 5° varus or
335 valgus was considered imperfect (17). The results of that study indicated no association between
336 outcome and component position, though the relatively low case numbers may have led to a type II
337 statistical error. It has been reported that implant malalignment after elbow arthroplasty in people
338 may predispose to uneven wear of components and component loosening (28), therefore we felt
339 that the accuracy and precision of component position measurements should be an important
340 consideration. To the author's knowledge there have been no further studies investigating the
341 relationship between cartridge alignment and clinical outcome, therefore further research is
342 required.

343 Evaluation of intra-observer and inter-observer variability showed RCA and VVA to be the most
344 precise, with differences between measurements not exceeding 2.3°. HCA was the least precise,
345 especially when the limb was inclined $\geq 5^\circ$ in adduction, but 99% of measurements were still within
346 the defined acceptable limits of 5°. Evaluation of the predicted component angles showed that
347 there should have been little change in angle when inclining the limb between 2.5-10°. Indeed the
348 angles should have been within a maximum of 0.38° of the zero degrees inclination angle, and
349 should only have changed by more than 5° after a minimum of 30° limb inclination (each prediction
350 value was dependent on the component angle, inclination, elbow flexion angle and cartridge
351 generation). The majority of observer measurements were within 5° of the zero degrees inclination
352 angle during inclinations of 2.5-10° but were not within the predicted 0.38°. RCA and VVA were the

353 most accurate of the angle measurements, with inclinations of 10° in any of the four orientations not
354 altering the zero degrees inclination angle by more than 1.8° . Measurement of HCA was the most
355 inaccurate as some values were greater than 5° from the zero degrees inclination angle during
356 abduction of the limb. Measurements for calculation of the CIR showed that with increased limb
357 inclination the ratio increased, especially during abduction and adduction, and that an inclination of
358 10° would often result in a ratio greater than 1.0 (meaning that the isthmus width measured greater
359 than the cartridge height). This could be a clinically significant error; the recommendation when
360 placing a TATE cartridge is to ensure this ratio is less than 1.0 to reduce the risk of ulna fracture (29),
361 therefore this level of inclination would lead one to incorrectly believe that the isthmus was too
362 narrow. Unfortunately it was not possible to deterministically define the effect of inclination on the
363 CIR due to the complexity of the cartridge dimensions. Accurate 3D computerised models of the
364 cartridges would have been required to predict how the measurements of cartridge height and
365 isthmus width should vary with inclination, and this was beyond the scope of the study.

366 We suspect that the discrepancies between the predicted component angles and the observer
367 measured angles were related to the shape of the cartridge. At the zero degrees inclination angle,
368 the cartridge appearance was two dimensional i.e. the width of the cartridge wasn't visible. As the
369 limb was inclined, the radiographic outline of the cartridge began to vary due to the three
370 dimensions of the cartridge coming into view (Figure 11 and Figure 12); superimposition of the
371 template circle over the cartridge component became less accurate, and when measuring the
372 cartridge height and isthmus width it was not possible to differentiate between the other
373 dimensions. We used specific protocols for templating the circles of best fit according to the
374 radiographic outline of the cartridge in an attempt to control the method of measuring (Figure 6).
375 These techniques enabled good precision of the measurements, but likely still did not allow
376 complete accuracy.

377 There are several limitations to this study. We devised a protocol to determine the centre of rotation
378 of the humeral condyle prior to placement of the TATE cartridge. This was to ensure that the

379 cartridge was placed as accurately as possible so that meaningful conclusions could be drawn
380 regarding the measurements. Despite what we considered to be a robust method, there were some
381 aspects that could have led to error: 1) during placement of the compass into the centre of the
382 modelling clay indentations of the steel balls, and 2) during marking of the condyle centroid through
383 the Play-Doh using a kirschner wire. However, the steel balls were only 2mm in diameter, therefore
384 any error in marking was likely to be less than 1mm which would have had a negligible effect on the
385 condyle measurements. The Play-Doh layer was as thin as possible to minimise inadvertent
386 angulation of the kirschner wire during condyle marking. Another limitation was the inability to
387 know the true zero degrees inclination angles due to subtle variation in observer angle measuring
388 technique. To obtain the most accurate values, we defined the zero degrees inclination angle for
389 each component angle, cartridge generation and elbow flexion angle as the mean average of the
390 four observer measurements. However, in order to establish the true zero degrees inclination angles
391 the mechanical axis of the humerus would have needed to be more precisely defined. Paley (2002)
392 described the mechanical axis as being the straight line connecting points at the centre of the joint
393 surfaces proximal and distal to a long bone (30), and subsequently Wood *et al* (2014) developed a
394 protocol that defined the humeral mechanical axis using radiography (25). Whilst the protocol
395 provided a standardised method of measurement from a radiograph, any technique that relies upon
396 human decision making (for example defining the 'circle or oval of best fit' over the humeral head or
397 condyle) will inherently be susceptible to error. A computer-assisted system may have provided a
398 more reliable method of measurement, but investigation into this was beyond the scope of the
399 study. Finally, use of the radio-ulnar component to define varus/valgus component alignment angle
400 may be susceptible to error in cases where there is medial or lateral joint space opening during
401 positioning of the limb for radiography. This movement is limited by the tightness of the joint and
402 should be minimal since the collateral ligaments are not transected during TATE elbow replacement
403 surgery. However, it should be considered when evaluating cartridge position in cases where there is
404 already a degree of joint laxity, or where it is present post-operatively. Whilst our study validates the

accuracy and repeatability of cartridge assessment in relation to elbow positioning for radiography, further research is required in to the benefit of performing such measurements. 'Normal' TATE component angles are yet to be defined; a preliminary retrospective evaluation of TATE elbow component positioning was carried out by [de Sousa et al \(2016\)](#), but the accuracy of the measurements may have been affected by the inability to measure the humeral mechanical axis, and the fact that it was not possible to determine whether the cartridges had been placed around the exact centre of rotation of the humeral condyle. The component angles in our study at zero degrees of inclination are likely to be more accurate since these limitations were overcome, however they were measured on a single limb; it is possible that breed-specific or individual differences in humeral shape may have an effect on component angles. Future studies are warranted to investigate the effect of conformation on the component angles. In addition, the measurements were performed with precise elbow flexion angles (90° or 135°); without this exact positioning, the radio-ulnar component angle would vary since it is measured relative to the humeral mechanical axis, and in a clinical setting spending time ensuring this may not be practical. It was not possible to define an accurate radio-ulnar mechanical axis to use as a reference for measurement of the radio-ulnar component due to removal of the radial head during the surgical procedure.

In summary, the results of the study suggest that measurement of HCA, RCA, VVA and CIR are accurate and precise and these parameters can be considered for evaluation of component position in clinical cases. Our experience of limb positioning during the experiment lead us to conclude that inadvertent inclination of the limb at 5° or greater in any of the four orientations relation to the table would be unlikely in a clinical setting. However, the effect of an individual animal's conformation and the presence of joint disease that may limit joint range of motion and positioning remain to be quantified; we recommend that every effort is made when positioning for post-operative TATE views to avoid inadvertent abduction or adduction of the limb.

References

1. Johnson JA, Austin C, Breur GJ. Incidence of canine appendicular musculoskeletal disorders in 16 veterinary teaching hospitals from 1980 through 1989. *Vet Comp Orthop Traumatol* 1994; 2: 5-18.
2. Grøndalen J. Arthrosis in the elbow joint of young rapidly growing dogs. III. Ununited medical coronoid process of the ulna and osteochondritis dissecans of the humeral condyle. Surgical procedure for correction and postoperative investigation. *Nord Vet Med* 1979; 31: 520-527.
3. Theyse LF, Voorhout G, Hazewinkel HA. Prognostic factors in treating antebrachial growth deformities with a lengthening procedure using a circular external skeletal fixation system in dogs. *Vet Surg* 2005; 34: 424-435.
4. Macpherson GC, Lewis DD, Johnson KA, et al. Fragmented coronoid process associated with premature distal radial physeal closure in four dogs. *Vet Comp Orthop Traumatol* 1992; 3: 8-14.
5. Gordon WJ, Besancon MF, Conzemius MG, et al. Frequency of post-traumatic osteoarthritis in dogs after repair of a humeral condylar fracture. *Vet Surg* 2003; 16: 1-5.
6. Evans RB, Gordon-Evans WJ, Conzemius MG. Comparison of three methods for the management of fragmented medial coronoid process in the dog. A systematic review and meta-analysis. *Vet Comp Orthop Traumatol* 2008; 21: 106-109.
7. Wendelburg KM, Beale BS. Medium and long term evaluation of sliding humeral osteotomy in dogs. *Vet Surg* 2014; 43: 804-813.
8. McConkey MJ, Valenzano DM, Wei A, et al. Effect of the Proximal Abducting Ulnar Osteotomy on Intra-Articular Pressure Distribution and Contact Mechanics of Congruent and Incongruent Canine Elbows Ex Vivo. *Vet Surg* 2016; 45: 347-355.
9. Caron A, Fitzpatrick N. Bi-Oblique Dynamic Proximal Ulnar Osteotomy: Surgical Technique and Clinical Outcome in 86 Dogs. *Vet Surg* 2016; 45: 356-363.

- 453 10. Lewis RH. Development of elbow arthroplasty (canine) clinical trials. Proceedings from the 6th
454 Annual ACVS Symposium; 1996 October; San Francisco , USA pg. 110.
- 455 11. Conzemius MG, Aper RL, Hill CM. Evaluation of a canine total-elbow arthroplasty system: A
456 preliminary study in normal dogs. Vet Surg 2001; 30: 11-20.
- 457 12. Conzemius MG, Aper RL, Corti LB. Short-term outcome after total elbow arthroplasty in dogs
458 with severe, naturally occurring osteoarthritis. Vet Surg 2003; 32: 545-552.
- 459 13. Wendelburg K, Tepic S. Kyon elbow prosthesis project. Proceedings from the Kyon Symposium;
460 2011 April 15-17; Boston, USA.
- 461 14. Innes JF. Complications with Iowa State TER and how this has informed development of the Sirius
462 Total Elbow Replacement. Proceedings from the British Veterinary Orthopaedic Association Autumn
463 Meeting; 2011 November 18-20; Bristol, UK. pg 67-72.
- 464 15. Schulz KS, Cook JL, Karnes J. Canine unicompartamental elbow arthroplasty system. Proceedings
465 of the 21st Annual ACVS Symposium; 2011 November 3-5; Chicago, USA. pg 123-125.
- 466 16. Acker R, Van Der Meulen G, Sidebotham CA. Preliminary evaluation of the TATE Elbow total
467 arthroplasty system in client owned dogs. Proceedings of the 14th European Society of Veterinary
468 Orthopaedics & Traumatology Congress; 2008 September 10-14; Munich, Germany. pg 13.
- 469 17. De Sousa RJR, Parsons KJ, Owen MR, et al. Radiographic, surgeon and owner assessment of the
470 BioMedtrix TATE(®) elbow arthroplasty. Vet Surg 2016; 45: 726-735.
- 471 18. Lenoir H, Micallef JP, Djerbi I, et al. Total elbow arthroplasty: Influence of implant positioning on
472 functional outcomes. Orthop Traumatol Surg Res 2015; 101: 721-727.
- 473 19. Nelson LL, Dyce J, Shott S. Risk factors for ventral luxation in canine total hip replacement. Vet
474 Surg 2007; 36: 644-653.
- 475 20. Dyce J, Wisner ER, Schrader SC, et al. Radiographic evaluation of acetabular component position
476 in dogs. Vet Surg 2001; 30: 28-39.

- 477 21. Dargel J, Oppermann J, Brüggemann GP, et al. Dislocation following total hip replacement. Dtsch
478 Arztebl Int 2015; 111: 884–890.
- 479 22. Dyce J, Wisner ER, Wang Q, et al. Evaluation of risk factors for luxation after total hip
480 replacement in dogs. Vet Surg 2000; 29: 524-532.
- 481 23. Roe SC, Sidebotham C, Marcellin-Little DJ. Acetabular cup liner and prosthetic head exchange to
482 increase the head diameter for management of recurrent luxation of a prosthetic hip in two dogs.
483 Vet Comp Orthop Traumatol 2015; 28: 60-66.
- 484 24. Renwick A, Gemmill T, Pink J et al. Radiographic evaluation of BFX acetabular component
485 position in dogs. Vet Surg 2011; 40: 610-620.
- 486 25. Wood MC, Fox DB, Tomlinson JL. Determination of the mechanical axis and joint orientation lines
487 in the canine humerus: a radiographic cadaveric study. Vet Surg 2014; 43: 414-417.
- 488 26. Burton NJ, Ellis JR, Burton KJ. An *ex vivo* investigation of the effect of the TATE canine elbow
489 arthroplasty system on kinematics of the elbow. J Small Anim Pract 2013; 54: 240-247.
- 490 27. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of
491 clinical measurement. The lancet 1986; 327: 307-310.
- 492 28. Van der Lugt JCT, Rozing PM. Systematic review of primary total elbow prostheses used for the
493 rheumatoid elbow. Clin Rheumatol 2004; 23: 291-298.
- 494 29. Course Proceedings of BioMedtrix TATE elbow Workshop; 2009 April 25-26; Glasgow, UK.
- 495 30. Paley D: Normal lower limb alignment and joint orientation. *In*: Paley D, Herzenberg JE, *editors*.
496 Principles of Deformity Correction. Berlin: Springer; 2002. pg. 1-18.