Computerized measurements of radiographic anatomical parameters of the elbow joint in Bernese Mountain Dogs

S. Stein; H. G. Schmoekel; H. Waibl; L. Brunnberg

1Animal Health Trust, Lanwades Park, Kentford, Newmarket, Suffolk, UK; 2Department of Small Animal Clinical Sciences, University of Copenhagen, Copenhagen, Denmark; 3Department of Anatomy, School of Veterinary Medicine, University of Hannover, Hannover, Germany; 4Small Animal Hospital of the Free University Berlin, University of Berlin, Berlin, Germany

Keywords
Elbow dysplasia, radiographs, Bernese Mountain Dog, breeding selection

Summary
Objective: Comparison of two methods for evaluation of anatomical parameters of elbow joints in Bernese Mountain Dogs.

Study design: Radiographic analysis.

Animals: Nine hundred and thirty-one radiographs of elbow joints from 305 Bernese Mountain Dogs.

Material and methods: The angles OL, PA and UL were measured according to the Viehmann method and the Radius of the humeral condyle, the Opening angle beta, Quotients Q and Ae as well as the difference and the correlation between the measured parameters of the elbow joint and correlated with the ED score.

Conclusions: In contrast to the method of Mues, the majority of the measured parameters of the method of Viehmann were not influenced by the degree of flexion of the elbow joint and correlated with the ED score.

Clinical relevance: The method of Viehmann warrants consideration for the evaluation of radiographs of elbow joints in the Bernese Mountain Dog for ED.

Introduction
Elbow dysplasia (ED) is a polygenic inherited growth disorder with a high incidence in Bernese Mountain dogs (1–3). Reported causes of ED include a disturbance in endochondral ossification (osteoarthritis), and a temporary joint incongruity during growth (radioulnar or malarticulation of the trochlea notch with the humeral condyle) (4–8). Further influences are genetics, diet, growth rate and hormonal imbalances. Elbow dysplasia includes several conditions of the elbow joint, including fragmented medial coronoid process, osteochondrosis dissecans of the humeral trochlea, and ununited anconeal process. Incomplete ossification of the humeral condyle and fragmented medial epicondyle of the humerus are not taken into account by the International Elbow Working Group ED scoring grid, however they do belong to the ED-complex (9–11).

The International Elbow Working Group screens susceptible breeds of dogs at a minimum age of 12 months (12). Elbow radiographs are evaluated based on the presence of a primary lesion (fragmented medial coronoid process, ununited anconeal process and osteochondrosis dissecans of the humeral trochlea), incongruity of the articular surface, and secondary osteoarthritis, sclerosis, or the combination of these.

Radiological parameters based on joint anatomy, which could be used to predict the potential development of ED before the age of 12 months, would be useful for prophylaxis and treatment. Two methods to evaluate elbow joints radiologically have been developed recently. Mues defined four angles in the elbow joint using anatomical landmarks and an ‘elbow quality’ was calculated from the measured parameters. ‘Elbow quality’ has been used to predict breeding values (13). The method of Viehmann has been used previously for evaluation of Bernese Mountain Dogs and Rhodesian Ridgeback dogs. Correlations have been found by Viehmann between the measured parameters and the degree of osteoarthritis in the elbow joint (14, 15).

The purpose of the present study was to...
comparatively evaluate the methods of Viehmann and Mues (13–15). The two methods are computer-assisted and designed to measure anatomical features of the elbow joint. The methods were investigated with regard to the influence of the angle of flexion of the elbow joint on the measured parameters, the correlation of the measured parameters with the currently used ED score and the potential use of the methods for screening of radiographs for breeding purposes.

Material and methods

Dog population

Nine hundred and thirty-one mediolateral radiographs of elbow joints of 305 Bernese Mountain Dogs at the age of 12 months or older were available through the German ‘Swiss Mountain Dog kennel club’ (Schweizer Sennenhund-Verein für Deutschland e.V. [SSV e.V.]). The elbow joints were scored for ED by a Kennel-club appointed expert, and an ED score of 0 to 3 was allocated based on the guidelines of the International Elbow Working Group. As the radiographs had been taken at various angles of flexion of the elbow joint, they were divided into five groups according to the degree of flexion: 0–30°, 31–60°, 61–90°, 91–120° and >120°.

Computer-assisted measurements

The radiographs were digitized at a resolution of 96 dpi and measured three times using each of the two computer-assisted methods. The software for the measurement according to the method of Viehmann was provided by Innovationstechnik (Gesellschaft für Automation mbG, Bremen, Germany) (14, 15). The method according to Mues was modified and the radiographs were measured with a computer program developed by Dr. Tellhelm, University of Giessen, Germany.

Measurement method according to Mues (modified)

The Mues method was established to characterise the elbow joint using objective measurements of angles for evaluation of genetic parameters in the Rottweiler. The angles were created to describe primary morphologic structures and not secondary osteoarthritic changes (comparable to the Norberg-angle for hip dysplasia). The centre of the humeral condyle was identified as the starting point for all angles. The following angles were measured as previously described (13):

- **Angle OL**
  - The Angle OL (Fig. 2) reflects the inclination of the olecranon towards the axis of the radius. It is measured as the angle between a line drawn through the centre of the humeral condyle and parallel to the axis of the radius (e) and a line drawn from the centre of the humeral condyle to the most caudal point of the cranial contour of the olecranon (b).

- **Angle PA**
  - The Angle PA (Fig. 3) is measured as the angle between line (a), which is drawn from the centre of the humeral condyle to the cranial tip of the anconeal process and line (b), which is drawn from the centre of the humeral condyle to the most caudal point of the cranial contour of the olecranon. It describes the cranial protrusion of the anconal process.

- **Angle UL**
  - The Angle UL (Fig. 4) is the angle created between line (b) and line (c). Line (b) is drawn from the centre of the humeral condyle to the most caudal point of the cranial contour of the olecranon, and line (c) is drawn from the centre of the humeral condyle and the caudal margin of the radial head. This angle describes the section of the joint which is composed of the trochlea notch with exclusion of the apex of the olecranon.

- **Angle RA**
  - The Angle RA (Fig. 5) describes the joint-forming part of the radius (fovea capititis radii) and is measured as the angle created between lines drawn from the centre of the humeral condyle along the cranial cortex of the humerus (h) and the radius.
Measurement method according to Viehmann

The Viehmann method was created to identify abnormal formation of elbow joints in Bernese Mountain Dogs and Rhodesian Ridgebacks (14, 15). The digitized radiographs were evaluated using purpose-made computer-assisted imaging software.

Radius of the humeral condyle

In a mediolateral projection, the humeral condyle is approximately circular. The radius (R) is measured by creating a circle around the condyle and calculating the radius of this circle (Fig. 6). The Radius of the humeral condyle (RC) can be regarded as a simple measurement for the absolute size of the elbow joint.

Opening angle beta

The medial part of the humeral condyle, the trochlea, is encompassed by the trochlear notch. This angle is found by drawing a line from the apex of the anconeal process (PA) and a second line from the apex of the lateral coronoid process (PC) to the deepest point of the trochlear notch (T) (Fig. 7). The size of the angle provides information...
about the moulding of the trochlear notch. The smaller the Opening angle beta (OAB), the more elliptical the trochlear notch is.

**Quotient Q**

To calculate the Quotient Q (QQ; Fig. 8) the following parameters are determined: Length L (the length of a line drawn along the curved trochlea notch from the apex of the anconeal process [PA] to the apex of the lateral coronoid process [PC]) and the length of line a (the distance between the anconeal process [PA] and the lateral coronoid process [PC]). The quotient of L/a results in the QQ. It provides information about the moulding of the trochlear notch. The greater the QQ, the more elliptical the trochlear notch is.

**Quotient Ae**

To calculate the Quotient Ae (QAe; Fig. 9) the following parameters are measured: the length of distance (a) (distance between the anconeal process [PA] and the lateral coronoid process [PC]) and distance (e) (line perpendicular to [a], which connects [a] with the deepest point of the trochlear notch (T)] were measured. The quotient of e/a is quotient Ae. It describes the moulding of the trochlear notch. The greater the QAe, the more elliptical the trochlear notch is.

**Area X**

Area X (AX; Fig. 10) is the percentage of the humeral condyle that is encompassed by the trochlear notch (X). The following parameters are needed for the calculation: length of the trochlear notch (L), area of the humeral condyle (d), and the shortest distance between the anconeal process (PA) and the lateral coronoid process (PC), which is length (a). A cranial displacement of the humeral condyle decreases the percentage of the humeral condyle that is encompassed by the trochlear notch and is therefore a parameter for cranial subluxation of the humeral condyle.

<table>
<thead>
<tr>
<th>Elbow dysplasia score</th>
<th>Number of right elbows</th>
<th>Percent (%)</th>
<th>Number of left elbows</th>
<th>Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>247</td>
<td>81</td>
<td>239</td>
<td>78.4</td>
</tr>
<tr>
<td>1</td>
<td>29</td>
<td>9.5</td>
<td>39</td>
<td>12.8</td>
</tr>
<tr>
<td>2</td>
<td>18</td>
<td>5.9</td>
<td>18</td>
<td>5.9</td>
</tr>
<tr>
<td>3</td>
<td>11</td>
<td>3.6</td>
<td>9</td>
<td>3.0</td>
</tr>
<tr>
<td>Total</td>
<td>305</td>
<td>100</td>
<td>305</td>
<td>100</td>
</tr>
</tbody>
</table>

**Step 1 between the radius and ulna**

The 'Step between the radius and ulna 1’ (S1; Fig. 11) is the distance between two parallel lines drawn along the plateau of the radius (RP) and the apex of the lateral coronoid process (PC), and is measured in mm. It is a parameter for radioulnar incongruence.

**Step 2 between the radius and ulna**

In order to determine the 'Step between the radius and ulna 2’ (S2; Fig. 12), the dorsal articular surface of the radius is marked with six single dots on the screen so that the computer can automatically calculate a circle. This circle is then moved upwards until it meets the lateral coronoid process, and the distance required for this is measured in mm. It is a parameter for radioulnar incongruence.

**Statistical evaluation**

The calculations of the correlations between ED score, the individually measured parameters and the different angles of flexion were carried out using the Pearson chi-squared test. The differences between the mean values of the individual ED scores were calculated with the Student’s t-test. Correlations and differences between the mean values were found to be significant if p <0.05 and highly significant if p <0.01a.
Results

ED score

Nine hundred and thirty-one radiographs of 305 Bernese Mountain Dogs were available. The majority of these dogs (approximately 80%) were assessed with an ED score of 0. Approximately 11% had an ED score of 1, 5.9% an ED score of 2, and 3.3% had an ED score of 3 (Table 1).

Angle of flexion of the elbow

There were at least two radiographs available per dog (left and right side), but in some cases several radiographs which had been taken in varying angles of flexion were available. Table 2 shows the distribution of the radiographs through the different Angles of flexion. Most radiographs were taken with a fully flexed elbow joint, whereas a small number of radiographs were available for an elbow flexion of approximately 90 degrees.

Age of the Bernese Mountain Dogs

The average age of the dogs was 573 days ± 195 and ranged between 363 and 1600 days (Fig. 13). The age of the Bernese Mountain Dogs at the time when the radiographs were taken correlated significantly with the ED score ($p < 0.01$). The mean age of the dogs with a radiographic ED score of 0 was 559 days. The mean ages for dogs with ED scores of 1, 2 and 3 were 567 days, 678 days and 807 days respectively.

Influence of the angle of flexion of the elbow joint on the measured parameters

The Angles OL, PA and RA of the method of Mues correlated with the Angle of flexion of the elbow joint ($r = 0.105$, $p = 0.004$; $r = -0.132$, $p < 0.001$; and $r = -0.111$, $p = 0.001$, respectively). Correlations with the Angle of flexion were also found in the method according to Viehmann for AX, S1 and S2 ($r = -0.203$, $p < 0.001$; $r = -0.930$, $p = 0.024$; and $r = -0.305$, $p < 0.001$, respectively). This means that the above parameters vary in their measurements depending on the positioning of the elbow joint. The Angle UL of the method of Mues and the remaining parameters of the method of Viehmann (RC, OAB, QQ and QAe) were not influenced by the Angle of flexion of the elbow joint.

Correlations of Mues with the ED score

The Angles OL, PA and RA correlated with the ED score ($r = 0.127$, $p < 0.001$; $r = 0.115$, $p < 0.001$; and $r = 0.187$, $p < 0.001$, respectively) (Fig. 14-17). All correlations were positive, which means that the angles in-
creased as the ED score increased. No correlation could be found for angle UL. The measured values of Angle OL for an ED score of 0 were significantly different than those with an ED score of 1 (p = 0.007) and 2 (p < 0.001). The measured values of angle PA for an ED score of 0 were significantly different from those with an ED score of 1 (p < 0.001) and 3 (p = 0.011). The measured values of Angle RA for an ED of 0 were significantly different from those where the ED score was 3 (p < 0.001).

Correlations of Viehmann with the ED score

Correlations were found between the ED score and the values for RC (r = 0.180, p < 0.001), OAB (r = -0.248, p < 0.001), QQ (r = 0.275, p < 0.001) and QAe (r = 0.252, p < 0.001) (Fig. 18-24). Positive correlations were found between S1 and S2 and the ED score (r = 0.290, p < 0.001 and r = 0.188, p < 0.001 respectively). No correlation was found for AX.

For RC, the values for ED scores of 0 were significantly different from the measured values of ED scores of 1 (p = 0.003) and 3 (p < 0.001). For OAB, QQ and QAe, S1 and S2, the values for ED scores of 0 were significantly different from the measured values of ED scores of 1, 2 and 3 (p < 0.001).

Discussion

Canine ED is one of the most common orthopaedic diseases which causes progressive osteoarthritis of the elbow joint. The International Elbow Working Group developed guidelines to screen breeding dogs for ED with radiographs taken of dogs at a minimum age of 12 months (12). The radiographs are evaluated for primary or secondary changes and an ED score is assigned.

Whereas ununited anconeal process and osteochondrosis dissecans are typically diagnosed definitively by comprehensive radiographic assessment, presence and severity of fragmented medial coronoid process and elbow congruity can be difficult to diagnose with certainty using radiography alone (16–18). In contrast, secondary radiographical changes such as osteophytosis and sclerosis of the trochlear notch are good indicators of a fragmented medial coronoid process, but only appear as the disease progresses.

Radiography is clinically useful for diagnosis of elbow pathology; it is widely available, efficient, cost-effective and does not typically require general anaesthesia. Blurring of the cranial edge of the medial coronoid process and ulnar trochlear notch sclerosis are reliable radiographic signs of ED and may be beneficial in screening protocols (17). However other diagnostic modalities including nuclear scintigraphy, computed tomography (CT), magnetic resonance imaging, and arthroscopy may be necessary for definitive diagnosis (17–28). Although CT can provide valuable information in the investigation of dogs with ED, the absence of CT signs or the absence of arthroscopic abnormalities does not rule out the presence of an elbow lesion (24).

The application of CT allows for an earlier and more reliable diagnosis of fragmented medial coronoid process versus radiographs alone as CT alleviates problems of superimposition (17, 18, 22, 23). However, more advanced imaging procedures necessitate general anaesthesia or are invasive (e.g. arthroscopy) and there-
fore are not feasible for assessing dogs with
regards to their suitability for breeding. The
direct visualisation of incongruity between
the radius and ulna remains challenging
and the affect of positioning has been dis-
cussed (4, 5, 29, 30). During pronation the
apex of the medial coronoid process was
elevated, and in supination the opposite ef-
fact occurred. On joint extension, a cranial
translation of the ulna increased the space
between radius and ulna at the ulnar inci-
sure (31). The shape of the trochlear notch
is also affected by positioning, therefore
cautions should be taken when evaluating
this finding (17).

The measurement of ulnar subtrochlear
sclerosis on radiographic images as a way of
increasing the sensitivity of detecting os-
teoarthritis secondary to medial coronoid
disease has been investigated and is valu-
able when CT or arthroscopy are not avail-
able (32, 33).

For breeding stock selection at an early
stage, radiographic anatomy can be ana-
lysed. In this study, the measurement
method according to Mues was compared
with the measurement method of Vieh-
mann to see if either one was superior in
the radiographic detection of ED.

Mues determined four different angles
in the elbow joint (Angle OL, PA, UL and
RA) and derived from this the quality of the
elbow joint to estimate the breeding value.
Viehmann measured the elbow joint as a
two-dimensional geometric figure with
seven different parameters (RC, OAB, QQ
and QAE, AX, S1 and S2) and used this to
evaluate individual anatomical elements.

All measurement parameters of both
methods are determined by computerised
measurements of digitalised radiographs.
The main advantage of the computer-
assisted evaluation is that it facilitates de-
termination of the parameters making the
method more rapid and precise than manual
measurement. As it was difficult to
compare the two methods directly, an indi-
direct comparison was chosen by assessing
the correlation of each parameter of both
methods with the ED score, which was pre-
viously determined by a kennel club ap-
pointed expert. As radiographs had been
taken in varying angles of flexion of the
elbow joint, it was possible to evaluate the
parameters with regards to the potential in-
fluence of the angle of flexion on the
measured values.

Radiographs used for our study were ac-
curately positioned mediolateral projec-
tions with very good contrast and detail.
During digitization of radiographs a small
loss of contrast is inevitable and therefore
only optimally exposed radiographs were
used (14, 15).

A previous study found a similar cor-
relation between the age of the dogs and
their ED score, which was also evident in our
study (34, 35). The older the dogs were at the
time of radiography, the higher the ED score
was. The mean age of dogs assessed with an
ED score of 3 were almost 250 days older
than dogs that were assessed with a score of
0. It has been shown previously that (sec-
ondary) osteoarthritic changes progress
with time and therefore a correlation be-
tween age of the radiographed dogs and the
ED score can be anticipated (36).

Previous studies have shown that the
angle of flexion of the elbow joint can in-
fluence the measured values (14, 15, 23, 34,
35). As shown by Janutta et al. in German
Shepherd dogs, the measured values by the
method of Mues were significantly depend-
ent on positioning (orthograde, pronation,
supination) and the angle of flexion of the elbow joint (4 groups: <20 degrees, 20–28 degrees, 29–39 degrees and >40 degrees) (34). In this study, there was a wider variety of flexion angles ranging from fully flexed to fully extended, divided into five flexion groups. The mean values of the Angle OL became significantly larger as the elbow joint was extended, whereas the Angle PA and RA became significantly smaller as the elbow joint was extended. The Angle UL was not influenced by the angle of flexion of the elbow joint. Therefore a comparison of elbow joints with different angles of flexion is not recommended for the Angles OL, PA and RA. Only radiographs that have been taken in the same angle of flexion should be compared with regards to their correlation with the ED score.

In a population of Rottweilers investigated by Mues, there was a significant correlation between the measured angles (OL, PA, RA, UL) and their heredity of ED. Mues recommended that radiographs of dogs from the age of six months onwards can be used to measure his established angles and evaluate breeding suitability (13). The above correlation of the measured angles and their heredity of ED could not be reproduced for German Shepherd Dogs, and is therefore not believed to be beneficial in reducing the frequency of ED within breeding programmes (34, 35).

In this study, correlations of the ED score with the Angles OL, PA and RA were found, as well as significant differences in the measured values between ED free and affected joints. A study by Schwencke et al. has already shown for Labrador Retrievers that, with the method of Mues, the size of the osteophytes around the elbow joint influenced the result of the measured angle more than the morphology of the elbow joint (37). We were able to confirm this finding in the Bernese Mountain dog breed. Visualising the landmarks for the Angle PA and RA confirmed that osteophytes on the anconeal process and the proximal radius respectively increased the measured Angles PA and RA. Therefore the Angles PA and RA increase with the size of osteophytes, as it becomes obvious in cases of advanced osteoarthritis. We believe that our study adds valuable data to the already existing literature by supporting the conclusion that evaluation of elbow joints in Ber nese Mountain dogs using the method according to Mues cannot replace the OA-grading system of the International Elbow Working Group, and also that radiographic images of elbow joints with different angles of flexion should not be compared.

The RC, as measured in the method of Viehmann, is a parameter for the absolute size of the elbow joint. This value does not change regardless of whether the elbow joint is flexed or extended. There was a correlation between the RC and the ED score, which means that the ED score increased with larger elbow joints. Fast growing, large and giant breed dogs have been previously identified as being predisposed for developing ED. This study shows that even within the Bernese Mountain dog breed, the larger dogs were more likely to develop elbow disease.

As the elbow joint is extended, the AX value becomes significantly smaller. The more the elbow is extended, the smaller the area of the humeral condyle encompassed by the trochlea notch becomes. It appears that extension of the elbow joint causes a cranial subluxation of the humeral condyle. Wind et al. and Brunnberg et al. described cranial subluxation of the humeral condyle as an influencing factor for ED (4, 5, 14, 15). Considering the above results with signifi-
cant differences in the measured values depending on the angles of flexion, it is not advisable to compare AX and potential cranial subluxation of elbow joints if the radiographs have been taken with different angles of flexion. The results of this study showed a significant increase in S1 and S2 for flexed elbow joints compared to extended elbow joints. It is therefore not advisable to compare elbow joints with different angles of flexion. The extent of the radioulnar step of Bernese Mountain dogs in this study was found to become larger, the higher the ED score, which means that dogs with severe ED are more likely to have severe radioulnar incongruency.

However, radiographs are not the first choice for the diagnosis of incongruency (29). With radiography it is not possible to visualise cartilage and the forelimbs are in a non-weight bearing position, which could make the measured incongruency artificial.

Limb rotation in supination or pronation also affects elbow congruity measurements and the use of three-dimensional image processing may allow for improved congruity measurements compared with other two-dimensional measurement techniques (40, 41).

Computed tomography and magnetic resonance imaging have been used as diagnostic modalities to assess incongruity of the humeroradioulnar joint and are also reportedly affected by positioning (26,30,31).

The measured values of the Viehmann method that describe the form of the trochlear notch (OAB, QQ and QAe) have a linear relationship, because all of the parameters contain the measured values (a) (distance between anconeal process and lateral coronoid process) and (e) (depth of the trochlear notch) (14, 15). In our study, the parameters were not influenced by the angle of elbow flexion and remain constant in all flexion groups. The values for OAB, QQ and QAe correlate significantly with the ED score. The results show that the trochlear notch measured on the radiographs becomes increasingly ellipsoid as the ED score increases. In Viehmann’s study there was also a significant correlation of the measured elbow joints of Bernese Mountain dogs with the parameters OAB, QQ and QAe and the ED score.

Fig. 21 Distribution of Quotient Ae (QAe) for each elbow dysplasia (ED) score. A correlation could be found between the QAe and the ED score. Numbers shown are the outliers.

Fig. 22 Distribution of Step 1 (S1) for each elbow dysplasia (ED) score. A correlation could be found between S1 and the ED score. Numbers shown are the outliers.
In another study, the trochlear notch of osteoarthritis-free elbow joints appears almost circular, but with an increasing degree of osteoarthritis, the trochlear notch becomes more ellipsoid (42). Very young (3 months old) Bernese Mountain dogs have a more circular trochlear notch (14, 15). As these dogs grow, the shape of the trochlear notch changes to an ellipse, which is in complete contrast to the Rhodesian Ridgeback as it is a breed that rarely has ED (14, 15). It however was not possible to determine whether it is the result of an alteration in the shape of the trochlear notch to an ellipse as a congenital or developmental underlying cause for the high incidence of ED in the Bernese Mountain dog, or if it indicates a secondary malformation of the elbow joint related to stress of ED.

According to Wind, it is the ellipsoid form of the trochlear notch, which is important for the development of an ununited anconeal process, fragmented medial coronoid process, and osteochondrosis dissecans of the humeral trochlear (4, 5). The ellipse may cause increased pressure on the anconeal process, resulting in a failure of fusion with the olecranon and therefore an ununited anconeal process. In the same way, a high positioned medial coronoid process might disturb the growth of the humeral condylar articular cartilage and lead to development of osteochondrosis dissecans (43).

Thus the assessment of the shape of the trochlear notch appears to be an important factor in the recognition of diseased elbow joints early in life. Following the above results, OAB, QQ, and QAe seem to be suitable for detection of ED because there is a correlation with the ED score and there are no contrary influences caused by variable elbow joint angles of flexion.

To estimate the predictive power of QQ, QAe, and OAB for early selection for breeding, a prospective longitudinal study in a representative population of dogs would be required. Follow-up radiographs from puppy age to adolescence would show whether the formation of an ellipsoid trochlear notch precedes or results from the development of ED with primary and secondary changes on radiographs, and if the measured parameters remain the same during development. Specificity and sensitivity for the occurrence of ED could then be evaluated. Furthermore a study with repeated radiographs at defined regular intervals would help determine the optimal age for radiographs for breeding purposes.

Limitations of this study were its retrospective nature, with all dogs being 12 months or older. As the radiographs were provided as a consecutive series by the German ‘Swiss Mountain dog Kennel Club’, the total number of radiographs for ED scores of 1, 2, and 3 was small. This small number could possibly have led to a type II error when calculating the statistics. For further studies, larger numbers of affected elbow joints would be beneficial. A further limitation is that all measurements were performed in a single breed, i.e. the Bernese Mountain dog, and these results cannot be extrapolated to other breeds.

In summary, the parameters of the method of Mues correlate with the ED score, but they also vary with the degree of flexion of the elbow joint and appear to support only the finding of secondary osteoarthritic change. Almost all parameters of the method of Viehmann correlate with the ED score, but the measurement of the radioulnar step should be performed at a constant angle of flexion of the elbow joint.
In conclusion, prospective longitudinal studies of joint anatomy at a young age are needed to evaluate the potential development of ED.

Acknowledgements
The authors would like to thank Sorrel Langley-Hobbs and Karen Perry for their help in preparing the manuscript.

Conflict of interest
None declared.

This article is a translated and abridged version of Dr. Silke Stein’s doctoral thesis, which was presented on May 8, 2007 at the Freien Universität Berlin, Berlin Germany, and thereafter published in full by Mensch und Buch Verlag. This translated and abridged version is now being published as a peer reviewed article with the kind permission of Mensch und Buch Verlag, Berlin Germany. Original Citation: Stein S. Die computergestützte Ausmessung von Röntgenbildern des Ellbogengelenkes mittels zweier Meßmethoden beim Berner Sennenhund. DMV [dissertation]. Berlin (Germany): Freien Universität Berlin / Mensch und Buch Verlag; 2007.

In addition, this paper was presented as a short communication at the WVC0 2010 in Bologna, Spain on the 17th of September, 2010.

References