Acta Veterinaria-Beograd 2024, 74 (1), 30-43
UDK: 636.7.09:616.728.2-071
DOI: 10.2478/acve-2024-0003

Research article

ASSESSMENT OF NEW RADIOGRAPHIC TRAITS IN CANINE HIP DYSPLASIA (CHD)

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(Received 15 November 2023, Accepted 26 February 2024)

Canine hip dysplasia (CHD) is a polygenic, multifactorial developmental disorder of the hip joint. Hip laxity, an early characteristic of CHD, leads to degeneration within the joint due to mechanical injury. Definitive diagnosis can be achieved by x-ray examination. The aim of our study is to refine CHD assessments using a quantitative planimetry method. The measurement of the Norberg angle (NA) was found subjective and insufficient to measure hip laxity on the standard ventrodorsal projection, because extension of the pelvic limbs stretches the joint capsule and supports joint congruence. Therefore, we have decided to verify other methods of detecting CHD, which include measurement of femoral head coverage (linear and area coverage) and congruence angle (AoC). These parameters could provide us with relevant information about how well the head of the femur fits into the acetabulum and thus might help to assess CHD better, and identify affected individuals better. In our study, we included 122 x-ray images of 3 breeds of dogs of both sexes and at different ages 5.6 ± 1.8 years. The highest correlation was between both femoral head linear and both area overlap for Bavarian hounds. For Bernese mountain dogs it was between right NA and linear and area femoral overlap, between both femoral head linear and both area overlap. For German shepherd dogs it was found between both NA, between right NA and right AoC, between both AoC, between both NA with both femoral overlap and between both AoC and both femoral overlap on the same side.

Keywords: Angle of congruence, dog, femoral overlap, hip joints, Norberg angle

INTRODUCTION

Canine hip dysplasia (CHD) is a polygenic and multifactorial developmental disorder of the hip joint characterized by irreversible changes in the joint socket and on the femoral head. It is a hereditary disease, but the influences of the external environment have a significant effect on the hip joint phenotype [1]. This disease occurs mainly in large breeds of dogs with a fast growth tendency [2-4]. Clinical signs include pain, decreased activity and lameness. This disorder of development and growth manifests

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as the pathological formation of the hip joint. Newborn puppies are usually born with morphologically and functionally normal hip joints, and the formation of the hip joint in the postnatal period depends on the following:

- genetic predisposition of the individual, which determines the anatomical conditions in the joint (shape and size of the joint, musculature, innervation).
- biomechanical loads and forces acting in the joint affect the growth and modelling of the joint structures.
- formation of cartilaginous and bony tissues that influence the circumstances and the places of the joint where the soft cartilaginous tissue will be transformed into hard bony tissue [5].

From the data valid and accepted so far, CHD is a multifactorial disease. The anatomical structure of the joints, the amount of muscles, and innervation of the hip joints are genetically conditioned in dogs. The heritability coefficient was determined to be 0.2 - 0.8. The development of this disease is thus conditioned by multiple factors such as breed size, growth rate, nutrition, body constitution, muscle mass index in the pelvic area, hormonal balance and neuromuscular dysfunction. The formation of the hip joint and the development of CHD therefore depend on the genetics of the dog and the environmental factors [6].

In order to get reliable results on CHD, it is necessary to carry out a thorough examination of the hip joints, which consists of an orthopaedic examination and several x-ray images after the 12th month of the dog's life, performed with deep sedation at an officially approved workplace. A complete orthopaedic examination should consist of observing the dog at rest, walking and running, and some specific tests Ortolani's, Barlow and Bardens test to confirm or suspect the disease. One of the positive signs of the presence of CHD is an Ortolani's sign [7].

The primary goal of any screening program is to exclude genetically positive individuals from breeding. Since CHD is a polygenic inherited trait and all current screening programs rely on the interpretation of radiographs, the effectiveness of reducing its incidence is limited and the prevalence of CHD is still high [8,9]. This is partially due to very subjective assessment protocols used for an official evaluation and the fact, that some of the officially examined images are not of a suitable quality mostly due to poor positioning.

The goal of this study is to refine CHD evaluations using the quantitative method of hip joint planimetry, because the Norberg angle (NA), the fundamental evaluation criterion for official diagnosis is quite a subjective parameter. As the measurement of NA has been found to be insufficient to measure hip joint laxity on the ventrodorsal projection of the pelvis, as extension of the pelvic limbs stretches the joint capsule, the ligament of the femoral head and the associated muscles supporting joint congruence, we decided to verify other methods of detecting laxity and scoring CHD, which include measurement of the femoral head coverage (linear and area overlap), angle of congruence (AoC) and presence of the caudal curvilinear osteophyte and circumferential femoral head osteophyte. These can provide relevant information about how well the femoral head fits in the acetabulum. Insufficient agreement on scoring hip joint quality might be caused by differences in the assessability of a radiograph (exposure, contrast, positioning, and diagnostic quality). Disagreement between different observers in one country or different countries can have a profound impact on the credibility of the screening system because dogs with a comparable hip quality might be excluded or accepted for breeding depending on the scoring committee. The reliability of evaluated planimetric parameters was tested with intra- and interobserver agreement.

MATERIALS AND METHODS

In our randomized blinded study, we included 122 x-ray images from three dog breeds: Bernese Mountain Dog (BMD, n = 32), Bavarian Hound (BH, n = 69), and German Shepherd Dog (GSD, n = 21) of both sexes (60 males and 62 females) at the mean age 5.6 ± 1.8 (2-8) years.

All images were taken using CONTROL-X VAREX IMAGING x-ray machine with direct digitalisation. The dog's chest was placed in a comfortable soft positioning device in the dorsal recumbence with the pelvic legs extended and with fulfilment of the official requirements for the CHD evaluation [8]. Only good quality radiographs were included in the study (Figure 1).

All dogs were examined under deep sedation using a standard protocol of butorphanol (*Butomidor 10mg/ml Richter Pharma*) 0.2 mg/kg i.v., medetomidin (*Cepetor KH 1mg/ml CP Pharma*) 0.015 mg/kg i.v., and propofol (*Propofol MCT/LCT Fresenius 10mg/ml Fresenius KABI*) 1 mg/kg i.v.

Ethical approval

The conducted research is not related to animals use. No ethical approval was obtained because this study did not involve laboratory animals and only involved gaining data and records from non-invasive procedures.

Data of all dogs of selected breeds that came to the clinic for CHD screening were collected. After collecting all radiographs of selected breeds, which are the most commonly evaluated breeds at our workplace, we sent these images to two experienced examiners and one less experienced, who were blinded to the breed and to the officially determined grade of CHD. The examiners evaluated the parameters three times, each radiographs after 5-7 days, and then the average was calculated and used for intraobserver agreement, and the three measurements were used for interobserver agreement.

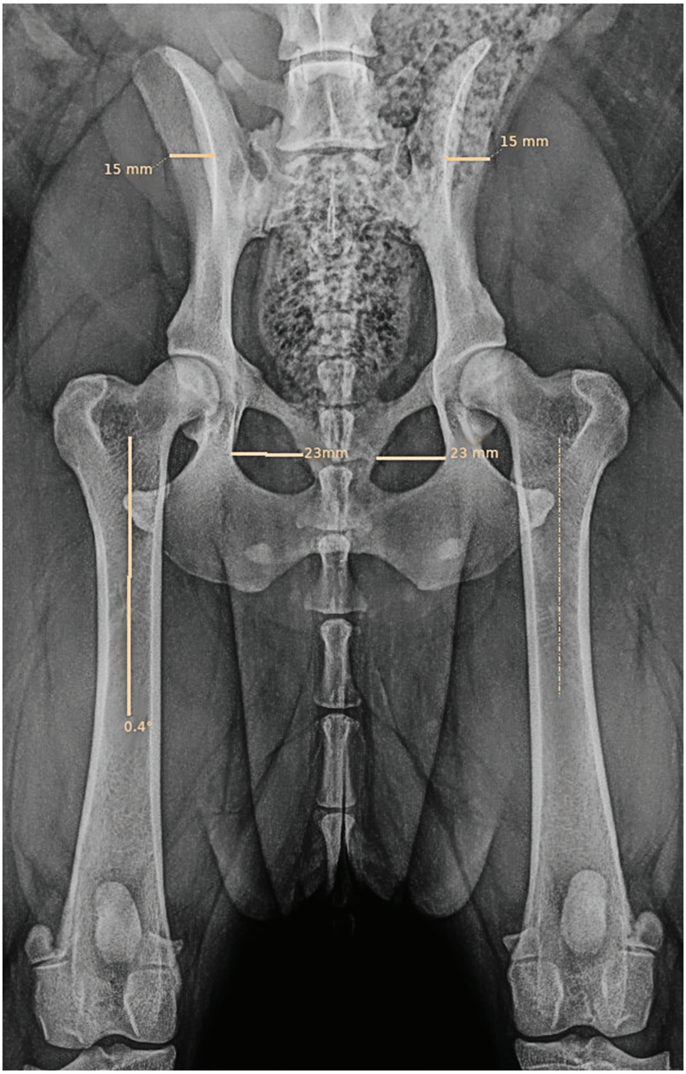

Figure 1. An example of a correct ventro-dorsal positioning of the pelvis for hip dysplasia evaluation - standard extended position.
All the lines highlighted in yellow show the measured length of the individual structures, which should match as much as possible between the right and left side.
From top to bottom: width of the alla ossis illii at the widest point, diameter of the foramen obturatum and the vertical line represents the parallelism of the femurs and parallelism to the long axis of the body. Next, the patella should be in the middle of the join. Processus spinosus should form one connected vertical line parallel to the long axis of the body. Source: own picture

We evaluated the following parameters:

Norberg angle (NA) - an angle between the line drawn between the centres of the femoral heads and the line drawn from the centre of the femoral head to the craniolateral aspect of the dorsal acetabular rim [10]. In a dog free of CHD, this angle should be greater than 105 degrees. A greater NA reflects a deeper acetabulum and a tighter fitting hip joint, while a lower NA reflects varying degrees of subluxation

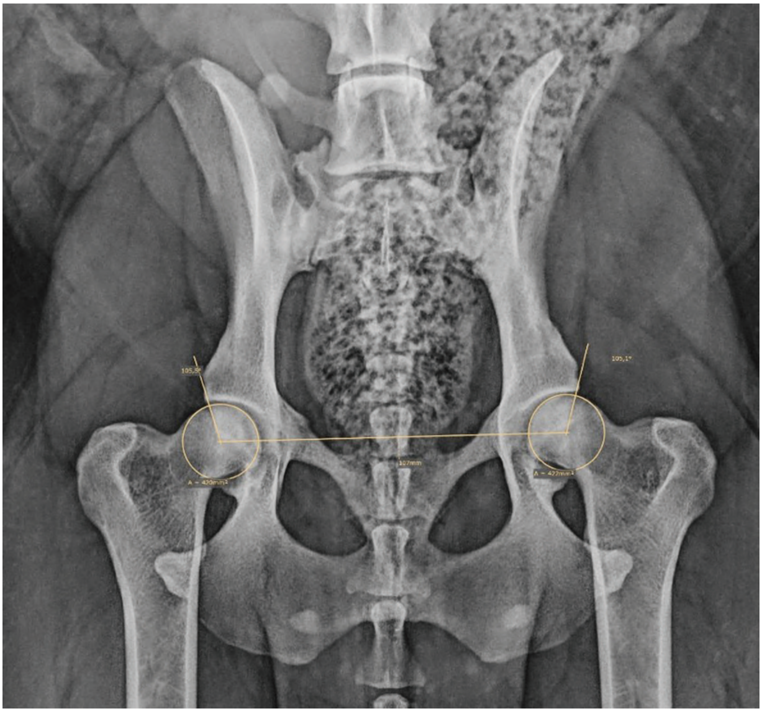

Figure 2. Measurement of Norberg angle
An angle between the line drawn between the centres of the femoral heads and the line drawn from the centre of the femoral head to the craniolateral aspect of the dorsal acetabular rim. Source: own picture

(joint laxity). NA is the gold standard used for phenotypic screening of dogs with hip dysplasia according to the *Orthopedic foundation for animals* (OFA) and the *Fédération Cynologique Internationale* (FCI). An angle of 105 degrees or more is considered as an indicator of a healthy hip joint [3] (Figure 2).

Linear overlap of the femoral head (LFO) - the centre of the femoral head is marked and the diameter of the head is drawn perpendicular to the longitudinal axis of the body running through the centre of the femoral head. The linear overlap of the femoral head is expressed in Fig. 3, it represents the percentage of the line (diameter) that is covered by the acetabulum [11] (Figure 3).

Area of the femoral head overlap (Surface femoral overlap, SFO) - the best possible circle encontouring the contours of the femoral head is drawn, the area within this circle is considered 100%. The dorsal acetabular rim is determined as the most lateral part of the overlapping area, and this defined two-dimensional section of the circle represents the area of overlap, expressed as the percentage [11] (Figure 4).

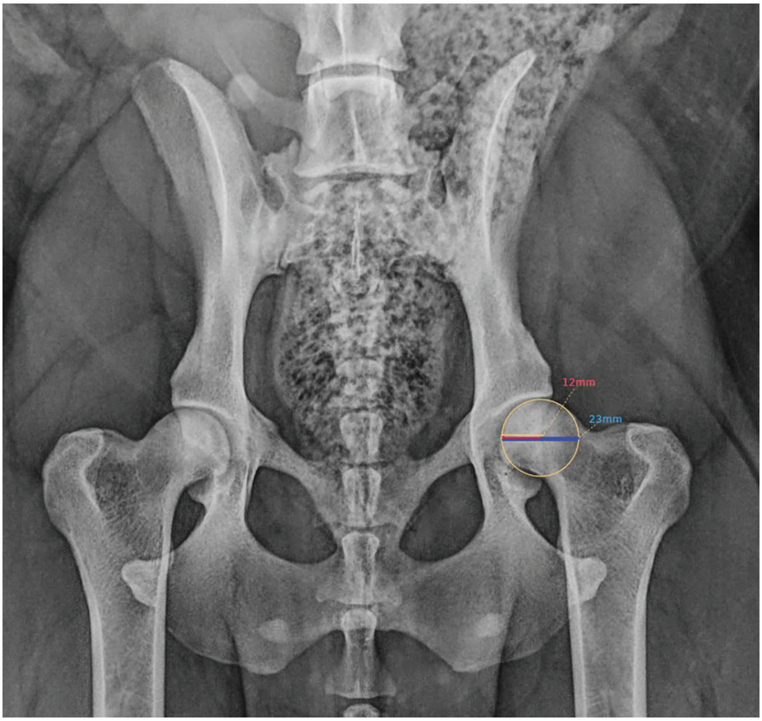

Figure 3. Linear overlap of the femoral head
The diameter of the head is drawn perpendicular to the longitudinal axis of the body running through the centre of the femoral head. The percentage of the length of that part of the diameter that is covered by the acetabulum is calculated like it is mentioned in the text in Materials and methods. Source: own picture

The percentage is calculated by dividing the overlapping part by the diameter and then multiplying by 100.

Angle of congruence (AoC) - is defined with two lines drawn from the centre of the femoral head to the places that border the congruent part of the joint cavity. This means along the curved parallel lines presented by the head of the femur and the acetabulum (Figure 5).

For every parameter we used Digimizer program.

Statistical analysis

Statistical analysis was used to compare and correlate the evaluated radiographic traits and to calculate the intra- and interobserver agreement. Pearson's correlation coefficient (r) was used to determine the association between 4 parameters with each other (NA, SFO, LFO, and AoC). To compare breeds and genders we used a paired t-test, we considered the difference statistically significant when $p < 0.05$. Data are expressed as mean ± SD and min-max values.

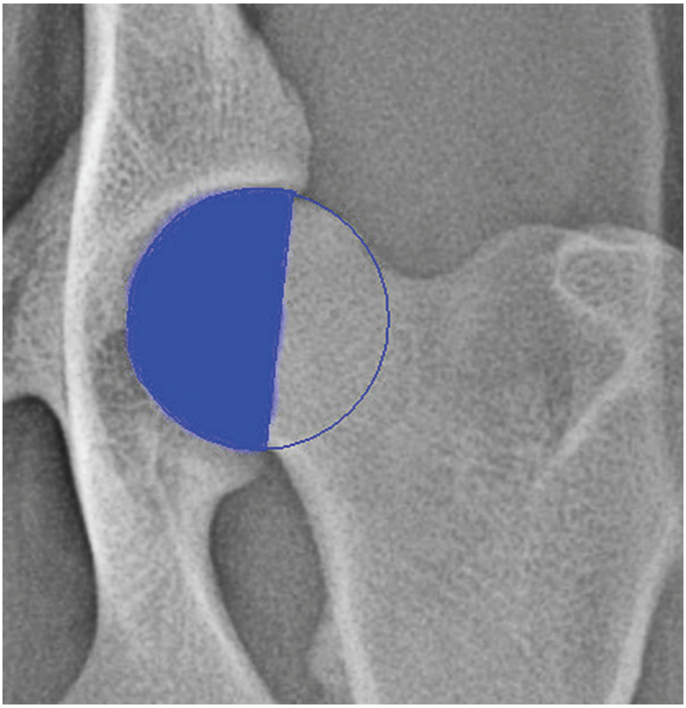

Figure 4. Area of the femoral head
The best possible circle encontouring the contours of the femoral head is drawn, the area within this circle is considered 100%. The dorsal acetabular rim determined the overlapping area. It is expressed as the percentage like it is mentioned in the text in Materials and methods. Source: own picture

RESULTS

The evaluated group of dogs in this study consisted of 60 males and 62 females with the mean age 5.6 ± 1.8 (2-8) years.

In the group of BH the mean body weight was 22.1 kg ± 1.3kg. The weight ranges from 19. 7 to 24. 2 kg. In the group of BMD the mean weight was 52. 1 kg ± 6.8 kg. The weight ranges from 40 to 68 kg. In the group of GSD the mean weight was 34.6 kg ± 2.6 kg. The weight ranges from 30. 3 to 39. 2 kg.

In the group of BH Pearson's correlation coefficient $r > 0.8$ was found between both right and left femoral head linear and area overlap, $r > 0.4$ between NA and both femoral overlaps for the right and also left side, between right and left NA, between AoC and both right area and linear femoral head overlap (Table 1).

Pearson's correlation coefficient $r > 0.8$ in the group of BMD was found between right NA and linear and area femoral overlap, between both right and left femoral head linear and area overlap, $r > 0.4$ were between right and left NA, between right AoC and

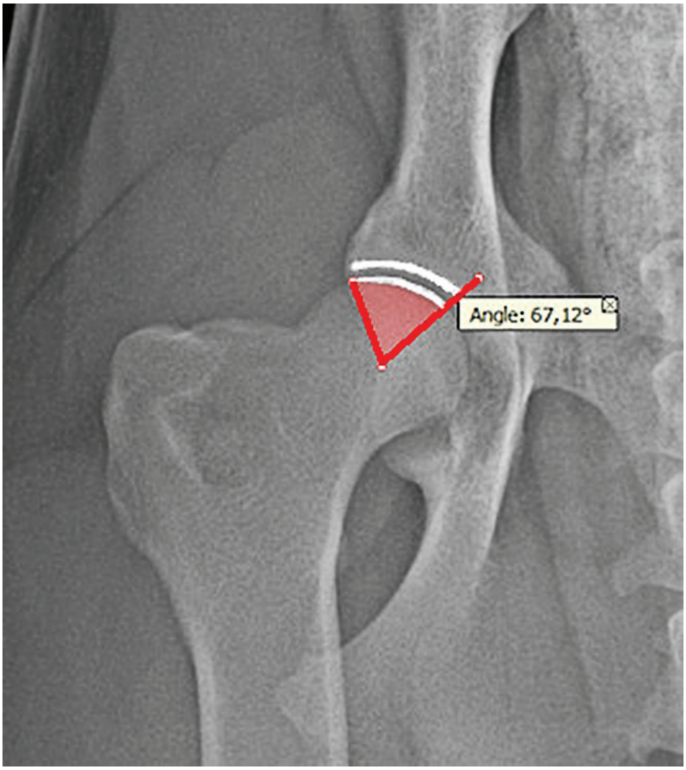

Figure 5. Angle of congruence
AoC is defined with two lines drawn from the centre of the femoral head to the places that border the congruent part of the joint cavity. This means along the parallel lines of the head of the femur and the acetabulum. Source: own picture

NA, between AoC on both sides, between and both femoral overlap on the right with left side, between left NA and left linear and area femoral overlap, between right AoC and both right area and linear femoral head overlap (Table 2).

Table 1. Number of dogs with the corresponding grade of canine hip dysplasia (CHD)

Breed	**CHD grade A**	**CHD grade B**	**CHD grade C**	**CHD grade D**	**CHD grade E**
Bavarian hound	42	19	6	2	0
Bernese mountain dog	18	9	3	2	0
German shepherd dog	10	6	3	2	0

Table 2. Pearson's correlation coefficient calculated for meassured parameters in 69 Bavarian hounds

	NA r	NA l	AoC r	AoC l	LFO r	LFO l	SFO r	SFO l
NA r	1	0.4060	0.4497	0.3228	0.5414	0.1772	0.5896	0.0923
NA l	0.4060	1	0.2011	0.2269	0.1174	0.3971	0.1322	0.3814
AoC r	0.4497	0.2011	1	0.5479	0.4761	0.0714	0.4766	0.0308
AoC l	0.3228	0.2269	0.5479	1	0.2186	0.1672	0.2481	0.1781
LFO r	0.5414	0.1174	0.4761	0.2186	1	0.1838	0.9544	0.0909
LFO l	0.1772	0.3971	0.0714	0.1672	0.1838	1	0.1763	0.9207
SFO r	0.5896	0.1322	0.4766	0.2481	0.9544	0.1763	1	0.1017
SFO l	0.0923	0.3814	0.0308	0.1781	0.0909	0.9207	0.1017	1

The method of measuring individual parameters is mentioned in the text in Materials and methods.
Abbreviations: r- right, l- left, NA- Norber angle, AoC- angle of congruence, LFO- Linear femoral overlap, SFO- surface femoral overlap (Area of the femoral head overlap)

In the group of GSD $r > 0.4$ was found between left NA and left AoC, between right NA and both right linear and area femoral overlap, and between left and right area and also left and right linear femoral overlap with each other. Coefficient $r > 0.8$ were between left and right NA, between right NA and right AoC, between right and left AoC, between both NA with both femoral overlap on the same side, between both AoC and both femoral overlap on the same side (Table 3).

There was no significant difference in all of the measured coxofemoral parameters between male and female dogs in all of the breeds ($p > 0.05$). The group of BMD had significantly higher body weight when compared to BH.

Interobsever and intraobserver agreement was high between the experienced veterinarians (kappa w = + 0.78 and + 0.81 resp.). Lower intraobserver agreement was found in the less experienced veterinarian (kappa w = + 0.48).

Table 3. Pearson's correlation coefficient calculated for meassured parameters in 32 Bernese mountain dogs

	NA r	NA l	AoC r	AoC l	LFO r	LFO l	SFO r	SFO l
NA r	1	0.6887	0.6952	0.4169	0.8422	0.3107	0.8145	0.3501
NA l	0.6887	1	0.3414	0.3692	0.5585	0.6071	0.5257	0.6091
AoC r	0.6952	0.3414	1	0.5814	0.7051	0.1356	0.7291	0.1858
AoC l	0.4169	0.3692	0.5814	1	0.3682	0.0905	0.3556	0.1134
LFO r	0.8422	0.5585	0.7051	0.3682	1	0.4123	0.9836	0.4626
LFO l	0.3107	0.6071	0.1356	0.0905	0.4123	1	0.4028	0.9868
SFO r	0.8145	0.5257	0.7291	0.3556	0.9836	0.4028	1	0.4550
SFO l	0.3501	0.6091	0.1858	0.1134	0.4626	0.9868	0.4550	1

The method of measuring individual parameters is mentioned in the text in Materials and methods.
Abbreviations: r- right, l- left, NA- Norber angle, AoC- angle of congruence, LFO- Linear femoral overlap, SFO- surface femoral overlap (Area of the femoral head overlap)

DISCUSSION

The breeds we selected were due to the inclusion of different groups of dogs. The first representative breed was from the group of large breeds of dogs mostly grown as pet animals, the second one was from the medium-to-large working breeds and the third was medium hunting breed of dog. We choose the breeds for this study according to the accessibility of x-ray images in our clinical database.

BMD belongs to the group of large breeds of dogs and we chose it because of its great activity and a big clinical load, so we were able to access to the x-ray images more easily when compared to other large breeds as they are not so often presented at our clinic. The GSD is the most frequent medium-to-large breed of dogs in our country and we therefore had much easier approach to their x-ray images, as well. From the hunting ones, we chose BH, which is easily available in our country as it is widely used for hunting, which together with its increased activity, tending to faster development and manifestation of clinical symptoms of CHD.

The CHD radiographic diagnosis still plays a determinant role in the selection of breeding stock in the dog. The correct positioning of the dog is essential for an adequate radiographic interpretation and CHD scoring of a ventrodorsal hip extended view. The NA and the femoral head coverage, CHD scoring essential parameters, are influenced by dog positioning on the x-ray table [12]. It is also an important landmark in the diagnosis of osteoarthritis in humans and is used to classify people as either dysplastic or non-dysplastic [13,14].

Guidelines to ensure the technical quality of the ventrodorsal hip extended (VDHE) view were defined in 1961, and inaccurate positioning of the femur and pelvis results in a relationship of abnormal projection between the femoral head and acetabulum [15] and consequently in inadequate canine CHD scores. Despite the existence of precise recommendations on the correct radiographic positioning, the final decision to accept or reject radiographs is always subjective. The agreement between observers on correct positioning varies by up to 70%, and incorrect positioning impairs CHD scoring [16,17].

Radiographs with medial or lateral patellar displacement are not recommended for canine CHD scoring. When animals have more developed muscles, the examiner must expend considerable energy to achieve internal rotation of the hind limbs, and lateralisation of the patella is frequent. Insufficient inward rotation of the femurs in the VDHE view is a common feature [18]. In the internal femoral rotation, the femoral neck axis acts as a fulcrum promoting joint congruence. The external femoral rotation promotes the separation of the femoral head from the acetabulum [19]. The mean NA did not show statistically significant changes with pelvis rotation (2 – 6 degrees), but bigger rotations showed statistically significant changes [17]. Furthermore, animals with moderate or severe CHD are more difficult to position correctly due to a reduced ability to extend their hip joints [20].

There are also some differences in hip joint in some breeds of dogs. For example, in German Shepherd dogs alterations involving the acetabulum are more severe and appeared earlier than in the femoral head and neck. In the Bernese Mountain dogs, the most severe alterations are in the position of the femoral head and joint space while the femoral head and neck showed no significant progression between grades [21].

However, it would be worthwhile to add to these parameters some other ones and thus make the evaluation more objective. It would also help to facilitate the decision-making of the dilemma between two degrees, when the result is not completely clear and indecisive for the evaluator. Some of these criteria are describe in the Brass method, including the evaluation of the acetabulum, the femoral head, the femoral neck, and the joint space [22].

In humans, the Center Edge Angle of Wiberg, Sharp Acetabular Index of weight bearing surface, and recently the Sourcil Sector Angle are used in quantitative measurements of the acetabular coverage area and early identification of hip dysplasia. These measurements were found to have lower inter-observer variability [23].

There was one limitation in this study that FCI grade E was not evaluated due to no number of x-rays according to that properly performed images suitable for evaluation are often performed on healthy or clinically healthy dogs.

The parameters we examined had a high correlation with NA and the degree of CHD, especially the area and linear femoral head overlap, so the evaluation of this parameter should not be forgotten.

Norberg angle generally ranged from 67.4 to 124.4 degrees for Labrador Retrievers, 59.7 to 128.6 degrees for Rottweilers, 70.2 to 119.4 degrees for Golden Retrievers, and 55.3 to 121.3 degrees for German Shepherd Dogs [9]. Considering this wide range of NA across multiple dog breeds, not just these measured in our study, we can say that using the NA $\geq$ 105 degrees and LFO or SFO $\geq$ 50% can correctly predict dogs with dysplastic hip joints [11].

To evaluate the reliability of radiographic measurements, different factors have to be taken into account. An error may derive from differences in the radiograph due to positioning, projection or different forces applied during acquisition. This effect can be assessed by acquiring two identical sets of radiographs and is also referred to as repeatability, also termed intraoperator reliability or agreement, if the radiographs is taken by the same person or reproducibility (also termed interoperator reliability or agreement) if the radiographs are taken by different persons. Furthermore, an error can be derived from the measurement itself. This can be evaluated measuring twice using the same radiograph and is also termed repeatability (intraobserver or interobserver reliability or agreement) or reproducibility (interobserver or intraobserver reliability or agreement) depending if the measurements are made by the same or different persons [24].

CONCLUSION

The CHD grading system around the world is not uniform for all countries, when using different systems, the results are still influenced by subjectivity to some degree. The NA is one of the parameters represented as a quantitative and objective parameter. Our goal was to verify different methods which could be used for CHD evaluation in the effort of a possibly higher objectification of the hip joint evaluation and with the perspective of a future software solution for measuring validated parameters of the hip joint with the aim of eliminating the subjectivity of the evaluator. In our study we studied the relationship between four parameters (NA, LFO, SFO, AoC) and we tried to confirm the hypothesis that their use in the assessment of the degree of dysplasia makes sense and helps to a better, more accurate and more objective result.

We have observed a high positive Pearson's correlation coefficient in both right and left area and linear femoral head overlap, and $r > 0,4$ for NA compared with both right and left area and linear femoral head overlap and other remaining parameters.

These results partially suggest that there could be a more objective way of evaluating CHD. The high correlation coefficients found for some parameters and high interobserver agreement in these breeds indicate that more studies on bigger canine populations could bring an even better view of the various conformation of canine hip joints with an attempt to get rid of dysplasia or to heal predisposed dogs.

Authors' contributions

SM evaluated the X-rays. MK performed the statistical analysis. TL helped to draft the manuscript. All authors participated in the writing and design of the manuscript.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Statement of Informed Consent

The owner understood procedure and agrees that results related to investigation or treatment of their companion animals, could be published in Scientific Journal Acta Veterinaria-Beograd.

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PROCENA NOVIH RADIOGRAFSKIH OSOBINA DISPLAZIJE KUKA (CHD) PASA

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Displazija kuka kod pasa (CHD) je poligeni, multifaktorski razvojni poremećaj zgloba kuka. Labavost kuka, rana karakteristika CHD, dovodi do degeneracije unutar zgloba usled mehaničke povrede. Konačna dijagnoza se može postaviti rendgenskim pregledom. Cilj našeg istraživanja je da preciziramo procenu CHD metodom kvantitativne planimetrije. Utvrđeno je da je merenje Norbergovog ugla (NA) subjektivno i nedovoljno za merenje labavosti kuka na standardnoj ventrodorzalnoj projekciji, jer ekstenzija zadnjih ekstremiteta isteže zglobnu kapsulu i podržava podudarnost zglobnih površina. Zbog toga smo odlučili da verifikujemo druge metode detekcije CHD, koje uključuju merenje pokrivenosti glave femura (linearna i površinska pokrivenost) i ugla kongruencije (AoC). Ovi parametri bi mogli da nam pruže relevantne informacije o tome koliko dobro se glava butne kosti uklapa u acetabulum i na taj način nam mogu pomoći da se bolje proceni CHD i bolje identifikuju pogođene životinje. U studiju smo uključili 122 rendgenske snimke 3 različite rase pasa oba pola i različite starosti 5,6 ± 1,8 godina. Najveća korelacija je bila između linearne glave butne kosti i preklapanja oba područja za Bavarske goniče. Za Bernske planinske pse to je bilo između desnog NA i linearnog i femoralnog preklapanja, između linearnog preklapanja glave butne kosti i preklapanja oba područja. Za Nemačke ovčarske pse pronađeno je između oba NA, između desnog NA i desnog AoC, između oba AoC, između oba NA sa oba butna preklapanja i između oba AoC i oba femoralna preklapanja na istoj strani.