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Femoral rotation and relationship between the femoral head and the acetabulum

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ABSTRACT: Canine hip dysplasia is a debilitating hereditary orthopaedic disease with a high prevalence in dogs. The aim of this study was to describe the influence of internal or external rotation of the femur on the projected radiographic position of the patella within the trochlear groove, and on the femoral head in relationship to the acetabulum in the standard ventrodorsal hip extended view, i.e., medial or lateral patella displacement, Norberg angle, femoral head subluxation index and femoral head subluxation category. Eleven adult dog cadavers of large and giant breeds were radiographed in standard ventrodorsal hip extended view and with internal and external femoral rotation. The medial and lateral patella displacement, Norberg angle, subluxation index and subluxation category variables were measured on radiographs, and analysed comparing the normal position with positions of different degrees of internal or external rotation of the femur. In the normal ventrodorsal hip extended view, the patella was centred within the distal femoral metaphysis ($P > 0.05$). A mean ± SD internal femoral rotation of 16.0 ± 5.9° resulted in a medial patella index displacement of 0.23 ± 0.09, and a mean external femoral rotation of 17.9 ± 6.7° resulted in a lateral patella index displacement of 0.24 ± 0.1. The mean Norberg angle was 105.3 ± 4.3°, 107.7 ± 5.5° and 104.2 ± 4.3° ($P < 0.05$); the subluxation index was 0.15 ± 0.06, 0.12 ± 0.05 and 0.18 ± 0.06 ($P < 0.05$); the subluxation category was 1.55 ± 0.6, 1.46 ± 0.7 ($P > 0.05$) and 1.96 ± 0.65 ($P < 0.05$) in normal, internal and external femoral rotation ventrodorsal hip extended views, respectively. In conclusion, as the Norberg angle, subluxation index and subluxation category are parameters used for classification in the main international hip dysplasia scoring systems, adequate femoral position with the patella centred in the distal metaphysis is of uppermost importance to ensure the technical quality of radiographs.

Keywords: Norberg angle; subluxation index; subluxation categories; dog; hip dysplasia

Canine hip dysplasia (HD) is a hereditary and debilitating disease with a high prevalence in medium, large and giant dog breeds (Ginja et al. 2009; Ginja et al. 2010). It is characterised by an abnormal development of the hip joint, femoral head subluxation and joint laxity leading to the development of

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osteoarthritis (Lust et al. 2001; Thompson et al. 2007; Anderson 2011).

Veterinary medical intervention has been directed at improving the welfare of dogs affected with clinical HD, or at the selection of breeding stock in order to prevent the reproduction of affected animals and the genetic transmission to offspring (Anderson 2011; Ginja et al. 2015). Despite intensive worldwide research, HD continues to be a challenging disease and one of the main areas of interest in veterinary orthopaedics. A marker-assisted accurate canine HD diagnostic test is still lacking, and no ideal radiographic technique has been found (Ginja et al. 2015; Martins et al. 2017).

The standard ventrodorsal hip extended (VDHE) radiographic view remains the only technique accepted worldwide for HD screening (Fluckiger et al. 1999; Andronescu et al. 2015; Ginja et al. 2015), and is used by the main international canine HD scoring systems: those of the Federation Cynologique Internationale, the Orthopedic Foundation for Animals and the British Veterinary Association/Kennel Club (Genevois et al. 2007; Verhoeven et al. 2007; Ginja et al. 2010; Dennis 2012; Chalmers et al. 2013).

The Norberg angle (NA), subluxation and/or congruity are used to evaluate the relationship between the femoral head and the acetabulum, and are the determining characteristics in scoring a normal hip in the main international canine HD scoring systems (Ginja et al. 2010; Dennis 2012; Chalmers et al. 2013). Guidelines to ensure the technical quality of the VDHE view were defined as far back as 1961 (Whittington et al. 1961), and inaccurate positioning of the femur and pelvis results in a relationship of abnormal projection between the femoral head and acetabulum (Genevois et al. 2007) and consequently in inadequate canine HD 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 HD scoring (Broeckx et al. 2014).

In the standard VDHE view, the femur should be internally rotated so that the patella of each pelvic limb is centred over the distal femur (Whittington et al. 1961). Although there are reports that investigate the effects of pelvic mispositioning in the VDHE view (Genevois et al. 2007; Bausman and Wendelburg 2010; Martins et al. 2017), we are not aware of studies that objectively quantify the effect of excessive or insufficient femoral internal rotation on the projected radiographic position of the femoral head in relationship to the acetabulum in the VDHE view. The main purpose of this study was to evaluate, in the standard VDHE radiographic view, the relationships between femoral rotation and lateral or medial patella displacement, Norberg angle (NA), femoral head subluxation index (SI) and femoral head subluxation category (SC). We hypothesised that internal or lateral rotation of the femur results in patella displacement and affects the values of measured NA, SI and SC.

MATERIAL AND METHODS

Eleven adult cadaver specimens from large and giant dog breeds weighing from 20 to 45 kg, mean ± SD 32.4 ± 8.6 kg, were evaluated at the Veterinary Teaching Hospital of the University of Tras-os-Montes and Alto Douro. Three radiographic VDHE views were analysed: normal, internal and external femoral rotation. Radiographic studies were performed using a computed radiography FCR Prima reader unit (Fujifilm, Tokyo, Japan), with an exposure of 65 to 70 kVp and 10 mAs, and using the ventrodorsal hip view processing software. Cadavers were frozen at –20 °C for less than one month, and then thawed at room temperature for 2–3 days. The dogs died for medical reasons unrelated to the study. All the animal procedures undertaken as part of this study were carried out in compliance with the regulations of our institutions, and in accordance with Portuguese and European regulations for animal use and care (European Directive 2010/63/EU and National Decree-Law 113/2013). Inclusion criteria included normal knee and hip joints, only slight signs of HD (based on Federation Cynologique Internationale scheme), which still allowed an unequivocal identification of essential radiographic land-marks, and that dogs were aged over 12 months.

The normal VDHE view was obtained by positioning and immobilising the cadaver using a special fixation device and pins applied to each femoral diaphysis and fixed in a transverse strip of wood (Martins et al. 2016; Martins et al. 2017). For accurate positioning, the pelvis should be symmetric, femurs parallel to each other and the patella should be over the midline of the femurs. Internal or exter-

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Figure 1. Modified ventrodorsal hip extended view with internal femoral rotation (right side 16° and left side 10°). Right side (R)

nal femoral rotation was achieved by rotating the femoral pin internally or externally, respectively (Figure 1). The pin orientation on normal and rotated views was registered manually, in a paper worksheet. Subsequently, the registered tilt of each pin in the worksheet was measured in degrees using a goniometer and the level of femoral internal or external rotation in each view was measured (Figure 2).

The measurement of variables was performed using specific computer software (OSIRIS Imaging Software® Version 3.1: University Hospital of Geneva, Geneva, Switzerland) in digital radiographs, at a resolution of 300 dpi. All measurements were taken by the same examiner who is an experienced radiologist (MMDG). The patella displacement was measured comparing its position over the femoral diaphysis in the normal and rotation views. Firstly, in normal VDHE view, a line-a was drawn from the base of the patella to the apex of the patella; then, the horizontal distance between line-a and the lateral (line-b) and medial (line-c) femoral cortical was measured in millimetres; finally, the line-b or line-c patella distance in millimetres was divided by the sum of line-b and line-c (femoral metaphy-

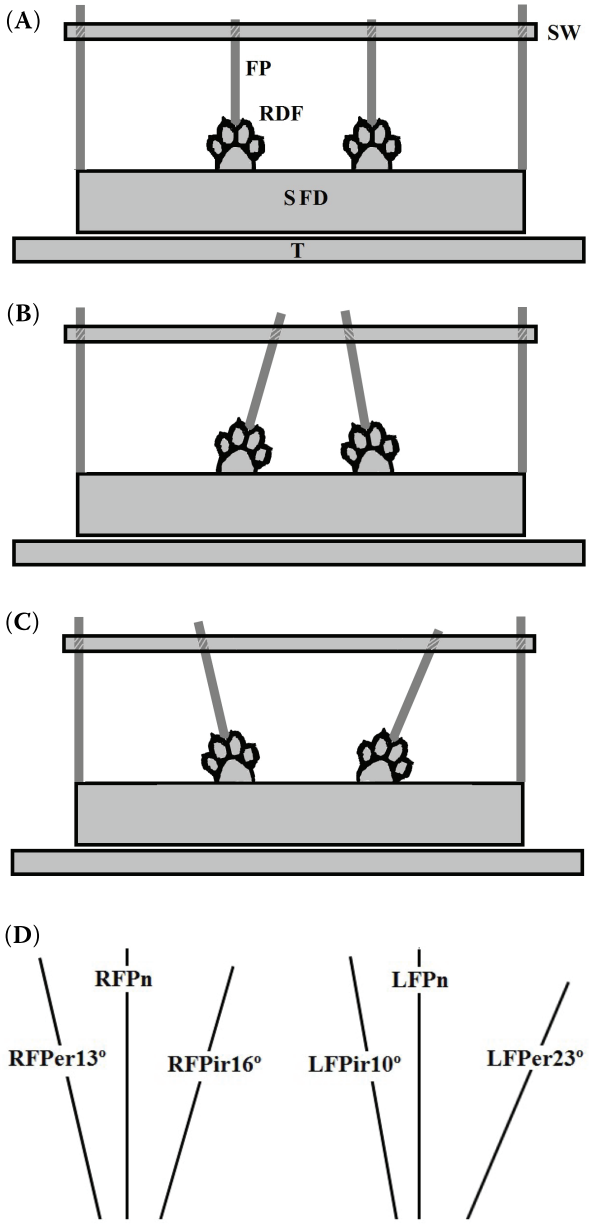

Figure 2. Illustration outlining the rear view of the special fixation device (adapted from Martins et al. 2017, with permission): (**A**) Cadaver positioned in the normal ventrodorsal hip extended view; (**B**) Modified view with femoral internal rotation; (**C**) Modified view with femoral external rotation; (**D**) Worksheet with the tilt of each pin in normal, internal and external femoral rotation radiographic views. Femoral pin (FP); left femoral pin external 23° rotation (LFPer23°); left femoral pin internal 10° rotation (LFPir10°); left femoral pin normal view (LFPn); right dog foot (RDF); right femoral pin external 13° rotation (RFPer13°); right femoral pin internal 16° rotation (RFPir16°); right femoral pin normal view (RFPn); special fixation device (SFD); strip of wood (SW); X-ray table (T)

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sis thickness) and measured as an index. In each external and internal femoral rotation view similar measurements were performed, and the lateral and medial patella displacement index was calculated by subtracting the respective index of the normal VDHE view (Figure 3). The NA was measured in degrees as the angle formed by a line joining the centres of the femoral heads and a line joining the centre of the femoral head and the craniolateral aspect of the ipsilateral acetabular rim, as described previously (Henricson et al. 1966; Vandekerckhove et al. 2003; Gaspar et al. 2016; Martins et al. 2017). The SI was measured in millimetres as the linear distance between the centre of the femoral head and the acetabular centre, divided by the radius of the femoral head, as described previously (Fluckiger et al. 1999). The SC was assessed in 7 categories, from 0 – femoral head centred in acetabulum to 6 – femoral head centre completely dislocated from acetabulum, as described previously (Dennis 2012; Martins et al. 2017).

Statistical analysis was performed using the SPSS Version 19.0 computer software. The data analysis was performed on joints individually, by grouping data in three groups: normal, internal femoral rotation and external femoral rotation. The Pearson product-moment correlation (r) was used to determine the femoral rotation-patella displacement association and a linear regression equation (i.e., $y = ax + b$) was used to predict internal or external femoral rotation (y) in degrees based on values of the medial or lateral patellar displacement index (x). The paired t-test was used to evaluate if the patellar centre distance index to the medial and lateral femoral cortical was similar in the normal VDHE views, and whether mean NA, SI and SC variable values differed significantly between the normal VDHE view and the internal or external femoral rotation view.

RESULTS

In the normal VDHE view the patella was found to be centred within the distal femoral metaphysis as the patellar distance indices to the medial and lateral femoral cortical were similar ($P > 0.05$; the mean of the differences in these indices ± SD was 0.07 ± 0.07). The internal femoral rotation ranged from 6 to 32°, mean ± SD 16 ± 5.9°, and resulted in a medial displacement patella index of 0.23 ± 0.09; $r = 0.85$, $P < 0.001$; $y = 55.7x + 3.2$ (Figure 4). The external femoral rotation ranged from 8 to 32°, mean ± SD 17.9 ± 6.7°, and resulted in a lateral displacement patella index of 0.24 ± 0.1, $r = 0.87$, $P < 0.001$, $y = 61.6x + 2.6$ (Figure 4).

The mean ± SD of NA was 105.3 ± 4.3°, 107.7 ± 5.5° and 104.2 ± 4.3° in normal, internal and external femoral rotation VDHE views, respectively ($P < 0.05$; Figure 5A). The mean ± SD of SI was 0.15 ± 0.06, 0.12 ± 0.05 and 0.18 ± 0.06 in normal, internal and external femoral rotation VDHE views,

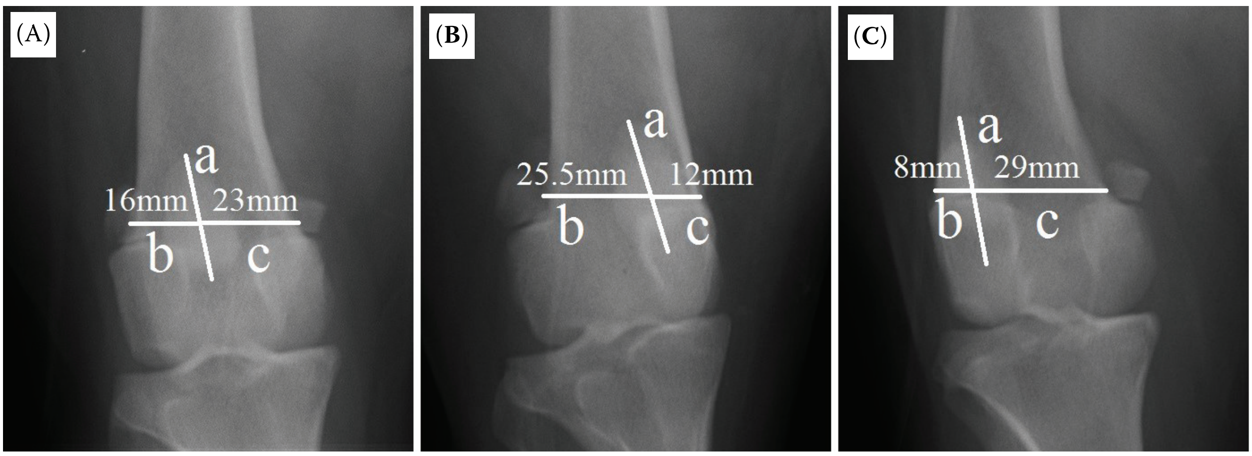

Figure 3. Right patella displacement with femoral rotation (same animal as Figure 1): (**A**) Normal ventrodorsal hip extended view; (**B**) Internal femoral rotation of 16° resulted in a patella displacement index of 0.27 (0.59 medial index in normal view minus 0.32 medial index in internal rotation view); (**C**) External femoral rotation of 13° resulted in a patella displacement index of 0.20 (0.41 lateral index in normal view minus 0.21 lateral index in external rotation view). Line drawn from the base of the patella to the apex of the patella (a); horizontal distance between line-a and the lateral femoral cortical (b); horizontal distance between line-a and the medial femoral cortical (c)

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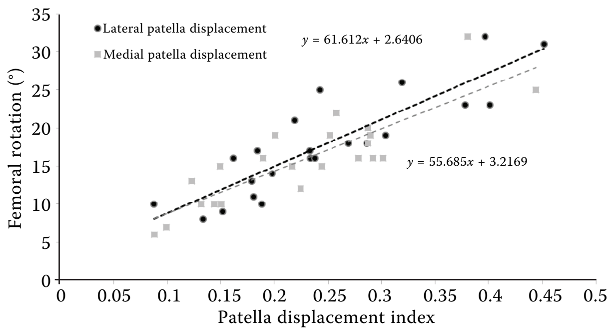


Figure 4. Scatterplot of lateral (black circles) and medial (grey squares) patella displacement indices and regression line versus femoral rotation in degrees

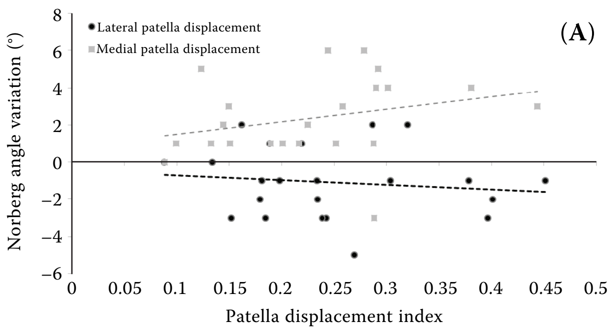
respectively ($P < 0.05$; Figure 5B). The mean ± SD of SC, converted directly into a numerical scale, was 1.55 ± 0.6, 1.46 ± 0.7 ($P > 0.05$) and 1.96 ± 0.65 in normal, internal and external femoral rotation VDHE views, respectively ($P < 0.05$; Figure 5C).

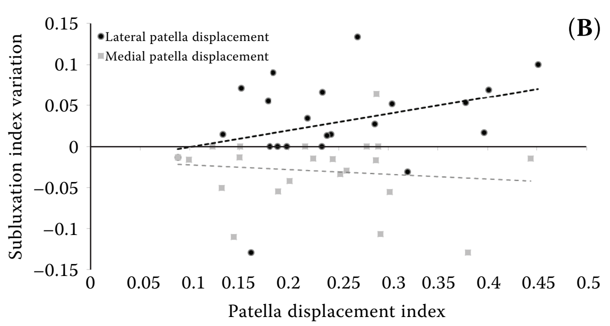
DISCUSSION

Despite the large amount of research that has been carried out, many doubts persist about the diagnosis and treatment of canine HD. Worldwide, the HD screening of dog populations for breeding purposes is based on the standard VDHE view scoring (Fluckiger et al. 1999; Ginja et al. 2015).

Accurate quantification of radiographic phenotypic criteria remains difficult, with the inherent variability associated with examiners, technical quality, different HD scoring criteria, anatomical differences in animals or muscle relaxation level making HD grade comparison and standardisation difficult (Bausman and Wendelburg 2010; Verhoeven et al. 2012; Schachner and Lopez 2015).

In the veterinary literature, there are clear recommendations about the ideal femoral positioning in the VDHE radiographic view (Whittington et al. 1961). However, objective information about acceptable femoral positioning and its implication in HD scoring are scarce (Verhoeven et al. 2010; Dennis 2012; Broeckx et al. 2014). We selected the NA, SI and SC because they are quantifiable radiographic parameters in the VDHE view and one or more of them are used in the main canine HD scoring systems. Although the clinical information provided by these variables may be considered complementary in certain aspects, some redundancy cannot be avoided since they all relate the centre of the femoral head with a component of the acetabulum: in the case of NA, the craniolateral aspect of the acetabular rim; SI, the distance in millimetres from the acetabular centre; SC, relationship with the dorsal acetabular edge. In the VDHE view, the correct positioning of the dog is of uppermost importance for an adequate radiographic interpretation, and has been recommended for more than 50 years (Whittington et al. 1961). However, the very high frequency of inadequate VDHE views makes it almost impossible to reject all of them (Genevois et al. 2007).





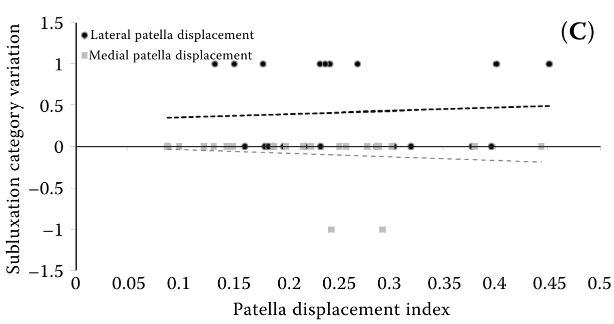


Figure 5. Scatterplot of lateral (black circles) and medial (grey squares) patella displacement indices and regression line versus (**A**) Norberg angle variation in degrees; (**B**) subluxation index variation; (**C**) subluxation category variation

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Our study shows that patella displacement is an accurate variable for estimating femoral rotation, which can impair or enhance the projected radiographic relationship between the femoral head and acetabulum. Internal or external femoral rotation can be identified by the patella displacement within the distal femoral metaphysis. The high correlation between these variables was expected and the presented regression equations can be used for this purpose. In normal VDHE, the patella was centred in the femoral trochlea at a similar distance from both medial and lateral femoral cortices ($P > 0.05$), and the mean of the normal patellar displacement index difference was 0.07 ± 0.07. Therefore, radiographs with medial or lateral patellar displacement indices greater than these values are not recommended for canine HD scoring. Inadequate femur positioning is especially common in large, long-haired breeds. 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 (Fluckiger et al. 1999). In contrast, in sedentary animals the examiner only requires to apply slight internal force to place the patella medially. Furthermore, animals with moderate or severe HD are more difficult to position correctly due to a reduced ability to extend their hip joints (Broeckx et al. 2014).

The internal femoral rotation and its beneficial effects on the relationship between the femoral head and the acetabulum in terms of NA, SI and SC, were unexpected since we are unaware of reference scientific literature that has quantified these radiographic parameters. However, these results make logical sense and are in agreement with previous studies that claim that the VDHE view (with slight internal femoral rotation) promotes hip congruence (Smith et al. 1990; Gaspar et al. 2016). These observations can be understood on the basis of the biomechanical functioning of the hip joint. This joint is supported in part by musculature and surrounding soft tissue with insertion into the femur (greater trochanter) and pelvis, and the long axis of the femoral neck usually has a cranial orientation relative to the frontal plane of the femoral diaphysis (anteversion angle) (Martins et al. 2012). Therefore, in the internal femoral rotation, the femoral neck axis acts as a fulcrum promoting joint congruence. However, when internal femoral torsion exceeds femoral neck anteversion or there is not enough tensioning of hip muscles this effect may not occur and this fact was registered in our study. That external femoral rotation impairs the relationship between the femoral head and the acetabulum as measured by the NA, SI and SC, can be understood by similar biomechanical principles that promote the separation of the femoral head from the acetabulum.

Our work should contribute to a better understanding of the effects that incorrect femoral positioning have on the interpretation and measurements made of the projected femoral head and acetabulum, because until now no objective investigation has been carried out on this topic. Future studies in live animals should be carried out to confirm the true effect of femoral rotation on HD assessment. The adequate selection of breeding stock based on canine HD radiographic diagnosis clearly continues to be an important intervention area in veterinary medicine. However, canine HD control programs have not always met with the desired outcome. The appropriate positioning of the femur on radiographs seems to be essential for correct HD scoring, since it may be lead to the incorrect selection (false negatives) of animals for the breeding stock or the removal (false positives) of animals from this stock.

In conclusion, internal or external femoral rotation is directly associated with patella displacement within the distal femoral metaphysis. Internal femoral rotation enhances hip congruence, and external femoral rotation impairs this effect.

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