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Hands-free radiographic canine hip distraction view with applied force monitoring

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Abstract

Background Canine Hip Dysplasia (CHD) is a prevalent orthopedic disorder in dogs, primarily characterized by hip joint laxity, which may lead to osteoarthritis and mobility impairments. Radiographic assessment, using the distraction view (DV) is considered the gold standard for evaluating hip laxity (HL). Veterinary professionals should take precautions to reduce exposure to ionizing radiation and its harmful effects. This study aims to compare the hip laxity of the DV obtained through manual restraining, with similar views using the positioning holder device PosUTAD, with an incorporated applied force monitoring system.

Results In this prospective study, 59 dogs (118 joints) were x-rayed using the hip DV twice, one using manual restraint and another using the PosUTAD modified (Mod) holder device. The force to maintain the hips under stress ranged from 17.15 to 44.1 N, 21.0 ± 5.0 N. The mean distraction index (DI) in the pairs of radiographs was similar for manual 0.42 ± 0.11 and holder restraining 0.43 ± 0.12 ($P > 0.05$, Paired t-test), with the maximum DI difference of 0.12. The Bland–Altman analysis shows a good scatter of DI differences distribution with limits of the agreement between -0.10 and 0.10. The intraclass correlation coefficient was 0.90, with the inferior limit of the confidence interval of 0.86 ($P < 0.05$).

Conclusions The PosUTAD Mod allows a reliable alternative technique to obtain the hip DV and avoids exposure of personnel to ionizing radiation. However, using the PosUTAD Mod device requires more specialized human resources, as the experience of an assistant to fix the PosUTAD Mod under adequate force is necessary for the success of the technique. It should also be added that it is a slightly more time-consuming technique, so it will only be an option when veterinary professionals' exposure to ionizing radiation is not allowed or is valued.

Keywords Dog, Hip Dysplasia, Hip laxity, PosUTAD, Distraction index, Ionizing Radiation

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Background

Canine Hip dysplasia (CHD) is one of the most common orthopedic disorders affecting dogs, characterized by hip laxity (HL) and malformation of the hip joint, which can lead to osteoarthritis and mobility issues [1, 2]. CHD is a multifactorial disorder influenced by both genetic and environmental factors that primarily manifests as joint laxity, leading to subluxation of the femoral head [3]. Radiographic assessment is considered the gold standard for diagnosing CHD and evaluating the severity of joint laxity [1, 4]. The ventrodorsal hip extended (VDHE) view and the hip distraction view (DV) under stress are two commonly used radiographic techniques for assessing CHD [1, 2, 4, 5]. These techniques provide qualitative evaluation of CHD grade or quantitative measurement of hip laxity using the distraction index (DI) [1, 2, 5]. Worldwilde, there are different CHD screening schemes and databases for the radiographic scoring of HD using the VDHE view, based on degenerative joint signs evaluation of adult animals: Orthopaedic Foundation for Animals (OFA), Fédération Cynologique Internationale (FCI), and The British Veterinary Association/Kennel Club (BVA/KC). The PennHIP CHD screening scheme and database use the hip DV and are more recent, can be applied to young animals (16 weeks old) and are based on quantification of HL [1, 3, 5]. The level of dog HL helps veterinarians to determine the likelihood of dysplasia progression and predict the development of osteoarthritis [6].

The hip DV examination has been recognized as a reliable and minimally invasive diagnostic tool, which involves applying a distractive force to the hip joint and capturing radiographic images to measure how far the femoral head moves away from the acetabulum [5]. The femoral heads are displaced laterally by using a hip distractor placed between the legs that act as a fulcrum on the femur at the level of the ventral aspect of the pelvis [3, 5]. The DI is used to measure HL and is obtained by dividing the lateral femoral head displacement from the acetabulum by the femoral head radius [3, 5]. A DI of 0 represents absolute joint congruity and a DI of 1 represents complete joint luxation [5, 6]. In the reference literature, there are published works in which hip DV is obtained with the use of different hip distractors, with some advantages and limitations: PennHIP [5], FSA—Fondazione Salute Animale Vezzoni [7] and DisUTAD [8].

One of the problems recognized universally in radiographic diagnosis, practically since the discovery of x-rays, is the undesirable side effects for living beings [9, 10]. Therefore, its use must be very judicious and ALARA (As Low As Reasonably Achievable) exposure recommendations should always be implemented. In veterinary medicine, in some countries professional exposure to ionizing radiation is only allowed in exceptional cases [10] and most of the others have legislation based on radiation protection recommendations: select carefully the clinical cases that would benefit from radiographic diagnosis; replace animal physical restraint with chemical restraint using adequate holder devices; for human restrain adequate radioprotection accessories must be used (lead gloves, apron, thyroid protector and eye shields) [9–12]. Aware of these public health problems associated with exposure to ionizing radiation in veterinary medicine, companies and technicians specialized in the area of radioprotection often present innovative solutions, as floor or ceiling moving anti-X glass panels, always to minimize professional exposure as much as possible. A previous study found a greater incidence of cancer among human orthopedic surgeons with routine ionizing radiation exposure, compared to unexposed workers [13, 14]. Therefore, the promotion of safe medical work practices is recommended [13, 14].

The main aims of the present research were to compare the HL of radiographs obtained on hip distraction views using the DisUTAD with the manual restraining and the holder device PosUTAD modified (Mod) [9], and monitor the applied distraction force. The null hypothesis is that DI measurements obtained in radiographs with manual restraining and with the PosUTAD are similar. As far as the authors are concerned, no published works have made this comparison, and there is only a similar holder device able to hold the dog's hindlimbs on hip DV [15].

Material and methods

Study design and subject inclusion

This is a prospective clinical multicentric study that used live animals, in which clinical interest in evaluating hip laxity is present. All examinations were performed with the dog owner's consent, and all the animal procedures undertaken as part of the research described in this work were performed in compliance with the regulations of our institutions (Ref. Doc84-CE-UTAD-2023). These dogs were presented at the Veterinary Teaching Hospitals of University of the Trás-os-Montes and Alto Douro (UTAD), University of Lusófona of Lisbon or University of Lisbon in the years of 2023 and 2024, for screening hip laxity. The minimum sample size was estimated using a t-test table, selecting a statistical significance of 0.05, a small to medium variable effect size of 0.4, and a statistical power of 0.8, which resulted in a sample of 99 observations [16]. Recorded data included breed, age at the time of the radiography, sex, and body weight. The inclusion criteria were dogs older than four months, with normal musculoskeletal development in clinical examination, with pairs of hip DVs (manual restraining and using the holder device PosUTAD Mod), and an adequate technical quality for DI measurement [8]. The main aim of this study design was to achieve adequate statistical power to accept the null hypothesis, that DI measurements obtained in DV radiographs using the DisUTAD with manual restraining and with the PosUTAD are similar, and to reject the false null hypothesis.

Animals

In our study were radiographed 59 dogs (118 hips), 30 males and 29 females, the age ranged from 4 to 48 months with a mean ± standard deviation of 9.8 ± 10.1 months, and body weight ranged from 10 to 50 kg, 21.0 ± 6.9 kg. The dogs used in this research were of seven different breeds: Portuguese Estrela Mountain dog ($n = 32$), Portuguese Pointer dog ($n = 17$), Portuguese Water dog ($n = 6$), and four other breeds.

Radiographic Procedures

The radiographs were performed, with dogs under deep sedation using butorphanol (Torbugesic Injectable; Fort DodgeVeterinaria, Girona, Spain) and medetomidine (Domitor; Orion Corporation, Espoo, Finland) intravenously. The sedation was reversed with atipamezole hydrochloride (Antisedan; Orion Corporation) intramuscularly.

The dogs were placed in an x-ray table in dorsal recumbency and both distraction views were obtained using the hip distractor DisUTAD, placed between the hind limbs to promote passive HL, stabilized with the weight of two sandbags (about 4 kg each), one placed at the cranial end and the other at the caudal end [8]. The femurs in a neutral position were both elevated and adducted by the examiner against the hip distractor [8]. The pairs of distraction radiographs were always obtained in the same sequence: first, the dog was positioned in the x-ray table and the distraction force was exerted and maintained by the examiner, during the execution of the radiographic exam [8]. Then, was performed the second hip DV with the dog placed in the PosUTAD Mod holder device (Fig. 1). The PostUTAD Mod is made of low radiopacity acrylic, and consists of a base, two side components, and a strap coupled to a dynamometer (12 kg; Pocket Balance). The same examiner performed a similar hip distraction technique and an assistant fixed, under the pressure exerced by the examiner, the lateral components, to promote adduction and fix hindlimbs under stress. The dynamometer measures the adduction force that maintains hips under stress. The examiner and the assistant left the x-ray room and performed the hands-free hip DV. There is no previous research about the level of adequate force exerted in the dynamometer to maintain hips under stress, so the strategy followed was based on previous examiner's experience. The dynamometer force should be sufficient for the examiner to stop feeling the lateral pressure of the hind limbs and after the examiner releases the dog's hindlimbs there should be no lateral yielding.

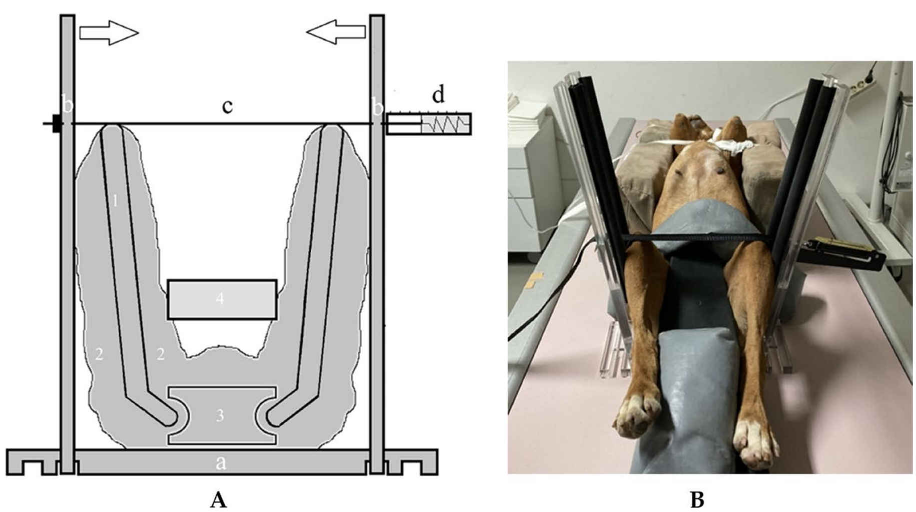

Fig. 1 The PosUTAD modified holder device. **A** Illustration outlining the rear view of the dog's transversal plane at level of hip joints and the PosUTAD: 1- right dog femur, 2- soft tissues, 3- pelvis, 4- DisUTAD; main components of PosUTAD: a- base, b- lateral components, c- a strap joining the two lateral components, d- dynamometer to measure the tension force of the strap. The arrows represent the force exerted by the dynamometer that is transmitted to the dog's hind limbs, to fix them under stress. **B** A Portuguese Pointer dog female, 12 months of age and 20 kg of body weight positioned on the PosUTAD modified to obtain the hip distraction view, with the hip distractor DisUTAD between the hindlimbs, stabilized with the weight of two cylindrical sandbags (about 4.0 kg), one placed at the cranial end and the other at the caudal end

Hip laxity measurement

The hip distraction radiographs of both hip DV techniques were obtained in DICOM format using the Fujifilm Digital Radiography system (Fig. 2). The radiographic measurements were performed randomly on chosen digital images of each set. All DI measurements were performed by the same examiner, MG, using the semiautomatic Dys4Vet version 2.0 software [17]. The DI was determined on both hip joints by measuring the distance between the centers of the acetabulum and the femoral head and dividing this value by the radius of the femoral head [3, 5].

Statistical analysis

Statistical analysis was performed using the computer software SPSS (SPSS Statistics for Windows Version 27.0: IBM Corp., Armonk, NY, USA). The data analysis of hip laxity was performed on joints individually. The paired t-test, the intraclass correlation coefficient (ICC), and Bland–Altman analysis were used for comparing the hip DI of both DVs obtained with and without manual restraint, to evaluate PosUTAD's hip distraction reproducibility [18, 19]. The One-Sample Kolmogorov–Smirnov test was used to assess the normal distribution of DI differences between both radiographic DV examinations. The Pearson correlation was used to evaluate the association between the dog's body weight and the dynamometer force. A value of $P < 0.05$ was considered to be statistically significant. The null hypothesis was that the mean difference between paired observations was zero [16, 19]. A small to medium-sized effect of 0.4 and a statistical power of 0.8 were considered to evaluate the ability of our sample to detect hip DI differences [16].

Results

The dynamometer force was applied to the lateral components of PosUTAD Mod, to promote hindlimbs adduction and maintain the hips under stress in the DV of 59 dogs (118 hips) of seven different breeds, ranging between 17.15–44.1 N, mean ± standard deviation 21.0 ± 5.0 N. A good statistically significant correlation between the dog's body weight, ranging from 10 to 50 kg (21.0 ± 6.9 kg), and dynamometer force was observed ($r = 0.93$; $P < 0.05$). The radiopacity of the PosUTAD acrylic base did not impair adequate visualization of the hips in the radiographic image in any case.

The DI, in the first hip DV of 118 hips with manual dog's hindlimbs positioning ranged from 0.15 to 0.76 (0.42 ± 0.11), and in the second hip DV, of the same 118 hips, with PosUTAD Mod ranged from 0.12 to 0.73 (0.43 ± 0.12). The One-Sample Kolmogorov–Smirnov test showed a normal distribution of DI differences between both radiographic DV examinations ($P > 0.05$). The 118 hips DI differences between both techniques ranged from −0.12 to 0.11, mean of 0.003 ± 0.05. The paired t-test was not significant ($P > 0.05$) when comparing the DI of the manual positioning set with the PosUTAD Mod set. The Bland–Altman analysis shows good scatter DI differences distribution with limits of the agreement for 95% of the differences between −0.10 and 0.10 (Fig. 3). The ICC in this comparison was 0.89, statistically significant ($P < 0.05$), with the limits of 95% of the Confidence Interval between 0.86 and 0.93. The null hypothesis was accepted, the DI measurements obtained in each radiographic set were similar and independent of the stress hip technique, manual or handsfree.

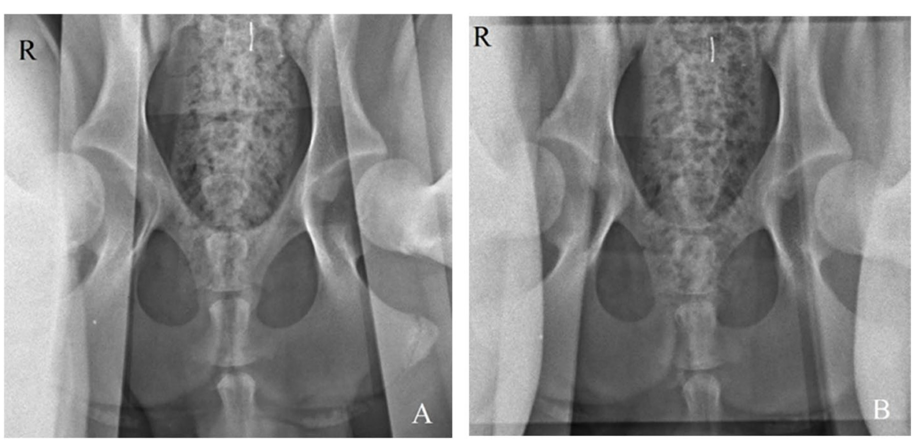

Fig. 2 Hip distraction views of a Transmontano Mastiff dog, male, seven months of age, and 50 kg of body weight. **A** view obtained using manual restraining, with a right and left hip distraction index registered in the database of 0.65. **B** Handsfree view using the PosUTAD modified holder device under an adduction force of 4 kg (39.2 N) with a right and left hip distraction index in the database of 0.63 and 0.61, respectively. R, right side

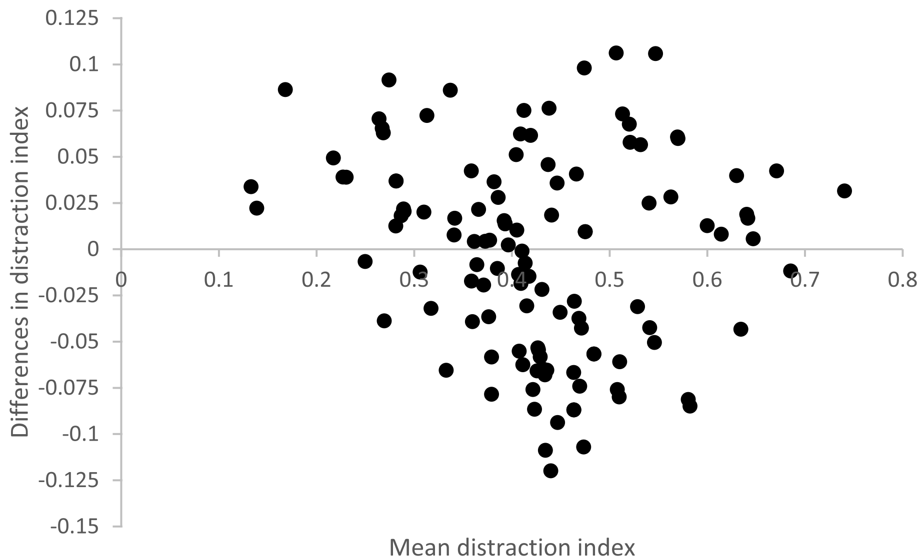

Fig. 3 Differences between the distraction index on examiner restraining hip views and on hands-free holder device views are plotted against the mean distraction index

Discussion

In recent years, veterinary medicine has seen an increase in the use of radiography as an adjunct diagnostic tool. This phenomenon has led to an increase in professional exposure to ionizing radiation [20]. In CHD diagnosis, thousands of radiographs are taken daily, and for technical quality to be achieved, the examiner often stays in the x-ray room to hold the animal [3], being exposed to the hazards of secondary ionizing radiation. The OFA, FCI, BVA/KC, and PennHIP databases have been around for over 50 years and have millions of dog hip x-rays. Distraction hip radiography has been increasingly used worldwide [8, 21–23]. Despite the risks of x-ray human exposure, in most countries using the OFA, FCI, or PennHIP schemes, the legislation about this activity is based on permissive recommendations, and the manual restraining of animals is the most frequent option. The exception is the United Kingdom, which uses the BVA/KC scheme preferentially, where physical animal restraint by humans in the x-ray room is not permitted unless there is a clinical reason, and manual restraint was reduced to 3% [10]. In this country, the hip DV of dogs is carried out only using a hands-free technique, and with the PennHIP distractor, the dog hindlimbs are maintained under adduction pressure with the help of ropes [15]. We, therefore, believe that our research is relevant to implement ALARA recommendations and justified in terms of public health benefits for the veterinary profession [14]. Although there are currently several innovative solutions on the market, such as floor or ceiling moving anti-X glass panels, which, when implemented effectively, minimize professional exposure to ionizing radiation.

Our study shows that hands-free hip DV, obtained with PosUTAD Mod, is reliable. Our results support this idea since there were no significant differences between the mean hip DI obtained under manual stress or the pressure of the PosUTAD holder. Also, a good agreement was observed in the ICC, with the upper limit of the 95% confidence interval >0.75 [18]. The Bland–Altman analysis also shows a good scatter DI differences distribution with limits of the agreement between −0.10 and 0.10, which are similar to other studies performed on DI research [8, 24, 25]. The PosUTAD Mod was also designed to be non-traumatic for the animal; the side components are internally coated with rubber and do not cause radiographic artifacts. The PosUTAD base that overlaps the area of radiographic interest is made of homogeneous acrylic with low radiopacity. Although there are no previous studies, the force applied by the dynamometer to the lateral components of the PosUTAD Mod seemed adequate to maintain the examiner's force and hip distraction, and does not appear to little or too much. The magnitude of the force to be applied should be realistically achievable by the examiner [23]. The force-laxity curve is characterized by two phases, the first is a direct linear response until the maximum laxity is achieved, and the second, a laxity maintenance without response to force [23]. If the hip distraction force is too great, it induces intracapsular negative pressure, which decreases the solubility of gas from the surrounding tissues in the joint space, and cavitation may occur [26–29]. Cavitation is evidenced on radiographs by the appearance of circular joint radiolucency and increased joint laxity [26, 29], and these artifacts were not observed in any joint of our study. Joint gas is reabsorbed into the surrounding joint tissues within 24 h, when the traction force is eliminated [26, 29]. Forces of more than 400 N may be necessary to promote the cavitation phenomenon, however, many other factors can interfere with this occurrence [27–29]. There is no scientific evidence to suggest that plastic deformation of the hip joint occurs when hip DV is performed [23, 26].

Obtaining radiographs of the hip under distraction requires previous training and experience of the examiner to ensure that the distraction force applied is adequate, as well as the positioning of the distractor and the animal on the x-ray table [26]. All examiners who obtained radiographs from this sample were experienced. We would like to point out that when using the PosUTAD Mod, the assistant's previous experience and technical expertise are also essential, as otherwise the distribution of forces over the hips may be inadequate or the positioning of the animal and the distractor may be incorrect. The examination time using the PosUTAD was not included in our study, but it is always a longer procedure because, as described, it requires additional steps compared to manual restraint.

It is clear from the procedures described when using PosUTAD that the hip distraction force is maintained by the force applied to the dynamometer. As a basis for understanding, an interfixed lever model can be used, in which the force measured on the dynamometer is the powerful force, the distractor contact point with the hindlimbs is the fulcrum, and the distraction force transmitted to the hips is the resistant force [30]. Animals with hindlimbs of different lengths and body types are associated with different arms of the powerful and resistant forces (fulcrum distances) and this has a direct interference in their transmission and relationship. It is our conviction that in larger hindlimbs, the powerful arm has a greater relative increase and transmits a greater distraction force to the hip. However, the relationship between the dynamometer and distraction forces is not linear, nor can it be obtained by simply balancing a static mechanical model (levers, arms, and fulcrum). The force of the dynamometer before its transmission to the hips needs to overcome the elastic resistance of the soft tissues of the hindlimb in contact with the PosUTAD (lateral part of the limb) and distractor (medial part of the limb), as well as the weight of the limb itself, which is projected laterally [30]. We believe that the dog's age and body type, or condition, are directly associated with these factors. So, only a complex biomechanical model would allow robust conclusions to be drawn regarding the part of the dynamometer force that will be applied to hip distraction. These biomechanical facts also help to understand why larger animals require greater force on the dynamometer to maintain hip distraction. An adequate biomechanical model could also help to estimate the force that is transmitted by the dynamometer to the distractor (fulcrum), since all these forces are dependent. Recent studies, conducted in dog cadavers using the distractor FSA-Vezzoni, intended to normalize the distraction force by quantifying the force being exerted on the distractor (fulcrum) [23, 31]. The results of these studies concluded that the percentage of maximum hip laxity was dependent on the force applied to the distractor (fulcrum) at the beginning of the distraction, but was not associated with the size of the animal [23]. The fact that the force we apply correlates with the size of the dog, and that a greater force is needed to hold the hips under stress in larger animals, does not contradict this study, since different forces are measured. As already mentioned, the force measured on the dynamometer is also essential to overcome the elasticity of the soft tissues of the hindlimb, which is assumed to be greater in large animals. On the other hand, it is our conviction that DisUTAD promotes distraction forces closer to the femoral heads, compared to other hip distractors [8]. Using the DisUTAD hip distractor, the ratio between the lever arms of the powerful force part (dynamometer side) and the resistant force part (hip side) is about 3 to 1, respectively. So, an adequate hip distraction can be achieved with lower compression forces at the fulcrum level, compared to the distractor used in the study of Vandekerckhove et al. (2024) [23].

These results allow us to recommend the use of PosUTAD to obtain hip DV when screening for hip dysplasia on stress radiographs, since the hip laxity detected on radiographs is equivalent to the examiner hips'stress and thus the examiner's exposure to ionizing radiation can be avoided.

The multicentric nature of the study, three veterinary hospitals, with different examiners and assistants to perform the radiographic examinations, associated with the use of medium and large breeds of dogs and different ages should be seen as strengths of the research, because it allows highlight all these possible potentialities of the hindlimb holder device for different dog types. However, the small number of animals and mainly Portuguese breeds in the sample and the absence of representativeness of some important breeds popular worldwide, should also be mentioned as a limitation of the study. The hands-free procedure described is not traumatic for the animal; the contact of PosUTAD with the dog is made with rubber that covers the lateral components and an acrylic smooth surface on the base. However, the need for prolonged dog sedation and additional specialized personnel to ensure correct force application and more time-consuming procedures could limit its adoption in routine veterinary practice. The described hands-free hip DV technique could benefit from further research aimed at finding the appropriate force to promote hip distraction in animals of different breeds, sizes, and ages.

Conclusion

The results allow us to conclude that the values of DI obtained in the stress radiographs using the PosUTAD Mod are equivalent to the DI values measured in the radiographs obtained by the examiner. The dynamometer monitors the stress force used in the procedure. The hands-free procedure using the PosUTAD Mod is not traumatic for the animal and does not produce any radiographic artifacts. We therefore recommend the use of PosUTAD Mod to obtain radiographs of the dog's pelvis, as human exposure to ionizing radiation is avoided. However, the use of PosUTAD Mod requires more specialized human resources, as the experience of an assistant to fix the PosUTAD Mod with adequate distraction force is essential for the success of the technique. It should also be added that it is also a slightly more time-consuming technique, so it will only be an option where exposure to ionizing radiation is not permitted or valued by the veterinary professionals.

Abbreviations

ALARA	As low as reasonably achievable
CHD	Canine hip dysplasia
CI	Confidence interval
DI	Distraction index
DV	Distraction view
HL	Hip laxity
Mod	Modified
ICC	Intraclass correlation coefficient
UTAD	University of Trás-os-Montes and Alto Douro

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Authors' contributions

Study conception and design: A.F., A.S. and M.G.; data collection: A.F., A.S., I.T., J.Ma., M.G., P.C. and S.AP.; Analysis and interpretation of data: A.F., A.S., B.C., J.Mo. and M.G.; Drafting of manuscript: A.S. and M.G.; Critical revision: A.F., A.S., B.C., J.Mo. and M.G.; All authors read and approved the final manuscript.

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Data availability

Data is provided within the manuscript.

Declarations

Ethics approval and consent to participate

All experimental procedures in this study were approved by the Animal Care and Ethics Committee of the University of Trás-os-Montes and Alto Douro, Vila Real, Portugal—Ref. Doc84-CE-UTAD-2023, and the owners formally agreed, through signing a term of informed consent, to enroll their animals in this study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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References

1. Ginja M, Silvestre A, Gonzalo-Orden J, Ferreira A. Diagnosis, genetic control and preventive management of canine hip dysplasia: a review. Vet J. 2010;184:269–76. https://doi.org/10.1016/j.tvjl.2009.04.009.
2. Reagan JK. Canine hip dysplasia screening within the United States: Pennsylvania Hip Improvement Program and Orthopedic Foundation for Animals Hip/Elbow Database. Vet Clin North Am Small Anim Pract. 2017;47:795–805. https://doi.org/10.1016/j.cvsm.2017.02.003.
3. Ginja M, Ferreira A, Jesus S, Melo-Pinto P, Bulas-Cruz J, Orden M, Gonzalo-Orden J. Comparison of clinical, radiographic, computed tomographic, and magnetic resonance imaging methods for early prediction of canine hip laxity and dysplasia. Vet Radiol Ultrasound. 2009;50:135–43. https://doi.org/10.1111/j.1740-8261.2009.01506.x.
4. Carneiro RK, da Cruz ICK, Gasser B, Lima B, Aires LPN, Ferreira MP, et al. B-mode ultrasonography and ARFI elastography of articular and peri-articular structures of the hip joint in non-dysplastic and dysplastic dogs as confirmed by radiographic examination. BMC Vet Res. 2023;19:181. https://doi.org/10.1186/s12917-023-03753-7.
5. Smith G, Gregor T, Rhodes W. Coxofemoral joint laxity and the development of osteoarthritis in the dog. J Am Vet Med Assoc. 1990;196:59–70.
6. Smith G, Mayhew P, Kapatkin A. Distraction index as a measure of hip joint laxity in growing dogs. J Am Vet Med Assoc. 2016;248:556–67.
7. Broeckx B, Vezzoni A, Bogaerts E, Bertal M, Bosmans T, Stock E, et al. Comparison of three methods to quantify laxity in the canine hip joint. Vet Comp Orthop Traumatol. 2018;31:23–9. https://doi.org/10.3415/VCOT17-05-0064.
8. Santana A, Alves-Pimenta S, Martins J, Colaço B, Ginja M. Comparison of Two Distraction Devices for Assessment of Passive Hip Laxity in Dogs. Front Vet Sci. 2020;7:491. https://doi.org/10.3389/fvets.2020.00491.
9. Santana A, Alves-Pimenta S, Martins J, Colaço B, Ginja M. Imaging diagnosis of canine hip dysplasia with and without human exposure to ionizing radiation. Vet J. 2021;276: 105745. https://doi.org/10.1016/j.tvjl.2021.105745.
10. Booth N, Morley S, Ewers R. Use of radiography in small animal practice in the UK and Republic of Ireland in 2013. Vet Rec. 2013;182:225.
11. Boivin G, Markey S, Bundy K. Radiation safety and the use of ionizing radiation in veterinary practice. Vet Clin North Am Small Anim Pract. 2020;50:135–49.
12. Freitas F, Koehncke N, Waldner C, Belotta A, Lanovaz J, Mayer M. A 7-min video training intervention improves worker short-term radiation safety behavior during small animal diagnostic radiography. Vet Radiol Ultrasound. 2021;62:27–36.
13. Mastrangelo G, Fedeli U, Fadda E, Giovanazzi A, Scoizzato L, Saia B. Increased cancer risk among surgeons in an orthopaedic hospital. Occup Med (Lond). 2005;55(6):498–500. https://doi.org/10.1093/occmed/kqi048.
14. Vernier TH, Hinson WD, Verpaalen VD. Radiation exposure to the orthopedic surgeon-a dosimetric comparison of two mini C-arm fluoroscopy models: a pilot study. J Am Vet Med Assoc. 2023;262:1–6. https://doi.org/10.2460/javma.23.05.0297.

15. Guilliard M. Hands-free distraction radiography. Proceedings of the British Veterinary Orthopaedic Association. 2008:27–29.
16. Cohen J. Statistical power analysis for the behavioral sciences. 2nd ed. Lawrence Erlbaum Associates, Inc. 1988.
17. Franco-Gonçalo P, Pereira A, Loureiro C, Alves-Pimenta S, Filipe V, Gonçalves L, et al. Femoral neck thickness index as an indicator of proximal femur bone modeling. Vet Sci. 2023;10:371. https://doi.org/10.3390/vetsci10060371.
18. Lee J, Koh D, Ong CN. Statistical evaluations of agreement between two methods for measuring a quantitative variable. Comput Biol Med. 1989;19:61–70. https://doi.org/10.1016/0010-4825(89)90036-X.
19. Petrie A, Watson P. Statistics for Veterinary and Animal Science. Oxford: Blackwell Science; 1999.
20. Pentreath R. Radiological protection and the exposure of animals as patients in veterinary medicine. J Rad Prot. 2016;36:42–5.
21. Powers M, Karbe G, Gregor T, McKelvie P, Culp W, et al. Evaluation of the relationship between Orthopedic Foundation for Animals' hip joint scores and PennHIP distraction index values in dogs. J Am Vet Med Assoc. 2010;237:532–41. https://doi.org/10.2460/javma.237.5.532.
22. Aghapour M, Bockstahler B, Kneissl S, Vezzoni A, Gumpenberger M, Hechinger H, et al. Radiographic diagnosis of hip laxity in Rottweilers: Interobserver agreement at eight- and twelve-months of age. Animals. 2023;13:231. https://doi.org/10.3390/ani13020231.
23. Vandekerckhove L, Herregodts S, Saunders J, Broeckx B. Quantifying the stress in stress radiographs to determine sufficient laxity of the coxofemoral joint: A canine hip dysplasia cadaveric study. Vet Comp Orthop Traumatol. 2024;37:23–9. https://doi.org/10.1055/s-0043-1771507.
24. Ginja MM, Ferreira AJ, Silvestre M, Gonzalo-Orden JM, Llorens-Pena MP. Repeatability and reproducibility of distraction indices in PennHIP examinations of the hip joint in dogs. Acta Vet Hung. 2006;54:387–92. https://doi.org/10.1556/AVet.54.2006.3.8.
25. Doğan N. Bland-Altman analysis: A paradigm to understand correlation and agreement. Turk J Emerg Med. 2018;18:139–41. https://doi.org/10.1016/j.tjem.2018.09.001.
26. AIS PennHIP Manual. https://antechimagingservices.com/antechweb/pdf/AIS-PennHIP-Manual.pdf. 2024. Accessed on September.
27. Arvidsson I. The hip joint: forces needed for distraction and appearance of the vacuum phenomenon. Scand J Rehabil Med. 1990;22:157–61.
28. Schröder JH, Marschalek N, Hufeland M, Perka C. The 'Hip Vacuum Sign'-a new radiographic phenomenon in femoro-acetabular impingement. J Hip Preserv Surg. 2016;3:346–51. https://doi.org/10.1093/jhps/hnw018.
29. Kanthavichit K, Klaengkaew A, Srisowanna N, Chaivoravitsakul N, Horoongruang K, Thanaboonnipat C, et al. Evaluation of vacuum phenomenon in dogs with coxofemoral degenerative joint disease using computed tomography. BMC Vet Res. 2020;16:274. https://doi.org/10.1186/s12917-020-02485-2.
30. Ellers O, Ellers KI, Johnson AS, Po T, Heydari S, Kanso E, McHenry MJ. Soft skeletons transmit force with variable gearing. J Exp Biol. 2024;15:227. https://doi.org/10.1242/jeb.246901.
31. Vandekerckhove LMJ, Herregodts S, Saunders JH, Broeckx BJG. Development and validation of a device to measure the force applied to the coxofemoral joint during stress radiography for early diagnosis of canine hip dysplasia. Med Eng Phys. 2023;112: 103953. https://doi.org/10.1016/j.medengphy.2023.103953.

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