Assessment of coxofemoral joint laxity in juvenile boerboel dogs using mobile phone goniometry

by

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DECLARATION OF ORIGINALITY

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DEDICATION

I would like to dedicate this dissertation to my late father, Doempies Triegaardt, who is no longer with us on earth. He has taught me every aspect of dedication and hard work. Everything pertaining to my career is possible because of him. I know that he will be proud.

Furthermore, I wholeheartedly dedicate this work to my beloved wife, Kristie Triegaardt, whose unwavering support and boundless love have been a constant source of strength. Her enduring patience through countless nights spent immersed in my studies has been an invaluable pillar of support, and I am profoundly grateful for her presence in my life.

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SUMMARY

BACKGROUND

Canine hip dysplasia (CHD) is closely associated with hip joint laxity (HJL), which is considered as one of the primary precursors to coxofemoral degenerative joint disease. However, the relationship between HJL and hip joint range of motion remains underexplored.

OBJECTIVES

This study aimed to investigate a correlation between hip joint angles (rotation and abduction) and the laxity index (LI) measured by the Vezzoni Modified Badertscher Distension Device technique (VMBDD) in juvenile boerboels.

METHODS

Hip joint angles were measured in 33 boerboels (aged 4-12 months) using mobile phone goniometer-based measurements by three independent examiners for abduction, internal, and external rotation. Stress view radiography with the VMBDD method assessed HJL, and LI's correlation with measured angles were examined. Inter-and-intra-operator variability of hip joint angles were also evaluated.

RESULTS

No significant correlation was found between abduction or internal rotation angles and laxity. However, external rotation demonstrated a weak correlation with laxity (r=0.207, p=0.095). Weight had a significant negative correlation with laxity (r=-0.265, p=0.031). Intra-operator variability ranged from 2.2 to 5.9, with the highest variability noted with internal rotation (4.0 to 5.9). Inter-operator variability ranged from 4.4 to 11.4, with the greatest variability observed in internal and external rotation (11.4 and 10.9, respectively).

CONCLUSIONS

Mobile phone goniometry appears unreliable for predicting joint laxity due to high inter- and intra-operator variability with poor repeatability.

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LIST OF ABBREVIATIONS

BCS	Body condition score
BVA/KC	British Veterinary Association/ Kennel Club
CHD	Canine hip dysplasia
CI	Compression index
CV	Coefficient of variation
DARA	Dorsal acetabular rim angle
DI	Distraction index
DLS	Dorsolateral subluxation
DPO	Double pelvic osteotomy
DR	Digital radiography
ECVS	European College of Veterinary Surgeons
FCI	Fédération Cynologique Internationale
H0	Null hypothesis
H1	Alternative hypothesis
HAP	Half-axial position
HJL	Hip joint laxity
JPS	Juvenile pubic symphysiodesis
LI	Laxity index
NA	Norberg angle
OA	Osteoarthritis
OFA	Orthopaedic foundation for animals
PACS	Picture archiving and communication system
RA	Reduction angle
SI	Subluxation index
SVDE	Standard ventrodorsal extended
THR	Total hip arthroplasty/replacement
TPO	Triple pelvic osteotomy
UK	United Kingdom

USA	United States of America
VD	Ventrodorsal
VMBDD	Vezzoni modified Badertscher distension device

1. INTRODUCTION

Hip joint laxity (HJL), as found in canine hip dysplasia (CHD), is the main cause of degenerative joint disease (Henrigson et al., 1966, Smith et al., 1995) and progressive osteoarthritis (OA) in the coxofemoral joints of affected patients (Riser, 1973, Runge et al., 2010). Standard ventrodorsal extended (SVDE) radiographs; used in the Fédération Cynologique Internationale (FCI) grading of canine hip dysplasia, has poor sensitivity in detecting HJL and poor overall reliability in the diagnosis of CHD (Heyman et al., 1993, Verhoeven et al., 2012), and may allow affected animals to enter the breeding pool.

Current methodologies for objectively quantifying hip laxity encompass the calculation of the distraction index (DI) of the coxofemoral joint, as outlined by Smith et al. in 1993 and measured through the PennHIP™ method. Alternatively, the laxity index (LI) is determined using the Vezzoni modified Badertscher distension device technique (VMBDD) (Broeckx et al., 2018), amongst other stress view techniques. These approaches entail dynamic ventrodorsal (VD) radiographic views of the pelvis to assess the extent of coxofemoral subluxation. Both methods involve placing the patient in dorsal recumbency and applying a distraction device on the ventral aspect of the pelvis between the femoral diaphyses. With the hips/coxofemoral joints in 100 degrees of extension (neutral position for PennHIP™), the femurs are adducted by applying a medially directed force to the distal aspect of the femurs/stifle joints to displace the femur heads from the acetabulums. The DI or LI is subsequently measured as the distance between the geometric centres of the acetabulums and the femoral heads, divided by the radius of the femoral head (Broeckx et al., 2018). The degree of subluxation has been linked to canine hip dysplasia and OA development, with laxity identified as the earliest pathological change in hip dysplasia (Corley and Hogan, 1985).

The VMBDD technique presents notable advantages, including cost-effectiveness and the requirement for a single operator, in contrast to the PennHIP™ method that necessitates two operators. Importantly, the VMBDD technique does not mandate formal certification for clinicians to use the distractor and determine the LI, offering enhanced accessibility in clinical practice. Additionally, the VMBDD method requires only two radiographs (VD and distension projection), making it less expensive for the clients and decreases radiation exposure to the operators and patients (Broeckx et al., 2018). It can be performed by a single trained person, whereas PennHIP™, being a three-radiograph-based technique (VD, compression, and distraction projection), necessitates two individuals for obtaining distraction and compression views. PennHIP™ use is highly restricted due to legal obligations; only PennHIP™ certified veterinarians are permitted to perform the technique. Furthermore, every radiograph must be submitted and evaluated by the PennHIP™ evaluation centre, with veterinary surgeons awaiting the official PennHIP™ report.

Conversely, the VMBDD aims to allow a complete and correct in-house evaluation of the hip joints by trained clinicians (Bertal et al., 2018).This has created a space for alternative, in-house, complete hip evaluation techniques using HJL as the basis.

One reason why we do not know the level of acceptable laxity is because the currently available stress-radiography techniques measure passive HJL (forced in non-weight bearing) as opposed to functional/dynamic laxity (weight bearing during normal ambulation). The VMBDD technique is a system that can be used in an attempt to answer the question and shed light on the relationship of passive HJL to functional HJL and the development of OA (Corley et al., 1997).

A study has shown that the LI obtained using the VMBDD technique consistently produced results comparable to the PennHIP™-based DI, as measured by the PennHIP™ evaluation centre. All radiographs taken for joint laxity were taken by the same PennHIP™-certified veterinarian, and the resulting PennHIP™ radiographs were submitted to the PennHIP™ evaluation centre. In that study, two independent operators, including a European College of Veterinary Surgeons (ECVS) diplomate and an experienced PennHIP™-certified veterinarian, measured the DI on the PennHIP™ views and the LI on the VMBDD views. The observed inter-operator agreements for both PennHIP™ DI and VMBDD LI were similar (Broeckx et al., 2018; Ginja et al., 2006). This compelling agreement formed the foundation for favouring the use of the LI over the DI in our study. The current distraction radiographic techniques (like the PennHIP™ and VMBDD method) (Smith et al., 1990, Farese et al., 1998, Flückiger et al., 1999), for the quantification of HJL in canine patients all involve deep sedation or general anaesthesia and are reliant on good quality x-ray machines and correct positioning, expensive distraction devices (PennHIP™) and accurate mathematical calculations. For these reasons, simpler, clinical, non-radiographic techniques with good correlation to the LI as well as good inter- and intra- operator variability are preferred.

Despite years of implementing CHD screening and breeding programs relying on phenotypic selection, the prevalence CHD remains high, primarily attributed to the aetiology being multifactorial and hereditary in nature. The manifestation of genes associated with CHD is intricately influenced by a multitude of environmental factors, contributing to the complexity of this condition (Lust et al., 1985). In individuals with a genetic predisposition to CHD, the occurrence or absence of OA in CHD during later stages of life is variable (Smith et al., 1995). This variability hinges on the cumulative impact of environmental factors, as highlighted by Smith et al. Clinical methods to determine HJL can allow for early screening for breeding selection. For nonbreeding stock, preventative surgical techniques like juvenile pubic symphysiodesis (JPS) and double/triple pelvic osteotomy (DPO/TPO) can be considered in patients with HJL and predisposition for the development of CHD. These surgical techniques should only be performed in young dogs before OA changes are detected, which makes the early detection of HJL mandatory. This would allow practitioners to identify these patients at an age before 12 months, the point at which standard radiographs for CHD certification are taken.

Passive hip laxity after 16 weeks of age has been associated with development of hip dysplasia (Smith et al., 1990). The DI at 2 months of age does not significantly correlate with the DI at 4 and 12 months of age but the DI at 4 months correlated well with the DI at 12 months of age (Smith et al., 1998). More than half (59%) of the German shepherd dogs with a DI greater than 0.3 at 12 months of age had CHD whereas only 11% of dogs with a DI of < 0.3 had CHD at 12 months (Smith, 1998, Smith et al., 1998). Based on these results the earliest reliable measurement for DI is made at 16 weeks.

A crucial question emerged regarding the influence of an elongated or lax ligament of the femoral head, as observed in dogs with hip dysplasia, on external rotation angles. In clinical cases where femur head and neck excision arthroplasty were performed, the author noted anecdotally that resection of the ligament of the head of the femur allowed for larger external rotation angles. However, to the best of the author's knowledge, this clinical query regarding whether larger external rotation angles are correlated to HJL remains undefined in live dogs. Additionally, no published studies comparing LI values of large breed dogs with the rotation and abduction angles of the coxofemoral joint could be found. There is limited data on the prevalence of CHD and DI in boerboel dogs, which is a popular breed in South Africa. In the PennHIP™ database, the median DI for the South African boerboel breed is 0.50, derived from a cross-section of 1752 dogs using the PennHIP™ method (2024). Based on clinical experience, the Orthopaedic foundation for animals (OFA) database that evaluated 595 boerboels, and findings from a recent study in Nigeria that evaluated 64 dogs (Ajadi et al., 2023), the prevalence of CHD is high (41.3% and 58% respectively) in this breed, making it a breed of particular interest for this study. The utilisation of a single breed allowed for a standard body conformation for the study to reduce confounding variables.

The results of this study are potentially valuable for providing an early suspicion of CHD in boerboels. This may offer the owners an early screening test allowing for an earlier diagnosis and consideration of treatment options for CHD. Early, dependable, and cost-effective screening could raise awareness among clients/owners regarding a predisposition to CHD, improved quality of life for dogs, reduced treatment costs over time, and minimized radiation exposure for both patients and personnel. The findings may provide valuable insights for breeding programs by assisting in the selection or exclusion of individuals (Vidoni et al., 2021).

This study postulated that the ligament of the femoral head, amongst other factors, restricts the external rotation of the femur, and suggests that laxity in the coxofemoral joint leads to increased range of motion due to laxity in supporting structures, including the ligament of the head of the femur and the joint capsule. The primary objective was to investigate the potential correlation between rotation-and-abduction angles of coxofemoral joints and joint laxity, offering a potential non-radiographic diagnostic measure for hip laxity that is well correlated to the later development of CHD.

2. LITERATURE REVIEW

2.1 Introduction

Canine hip dysplasia was first diagnosed in dogs by Schnelle and was defined as hip laxity of genetic origin (Schnelle, 1935, Henrigson et al., 1966, Adams et al., 1998, Mäki et al., 2000). It is an inherited polygenic disorder characterized by abnormal development of the femoral head and acetabulum, leading to incongruity (Henrigson et al., 1966). Laxity's heritability estimates vary, ranging from 0.46 in German shepherd dogs and Labrador retrievers to 0.64 in golden retrievers, and up to 0.85 in Estrela mountain dogs (Pascual-Garrido et al., 2018; Smith et al., 2001;).This condition is particularly prevalent in large and giant breeds although any breed can be affected (Ginja et al., 2009a).

Dogs have normal hips at birth (Riser and Shirer, 1966), but as they age, it's common for them to develop radiographic signs of HJL at around 2 months of age and show signs of OA at 4 to 6 months (Smith, 1998). The canine hip joint is a ball-and-socket joint formed by the femoral head and the acetabulum of the pelvis (Figure 1). Proper functioning of the joint relies on a delicate balance between the growth of the supporting soft tissues and the skeleton (Alexander, 1992). If there is an imbalance between growth rates of these structures or musculature is not of sufficient strength to support and maintain the congruency between the femoral head and the acetabulum to keep the head in the socket HJL will occur (Alexander, 1992). The consequence of this abnormal conformation and HJL is subluxation with resultant micro trauma of the joint. In this condition the laxity and consequent instability of the hips in the young dog leads to forces being focused on developing areas of the hip joint and in turn leading to abnormal development and secondary changes as they mature. Continuous (low grade) inflammatory stimuli due to the instability eventually leads to OA of the coxofemoral joint (Riser, 1973).

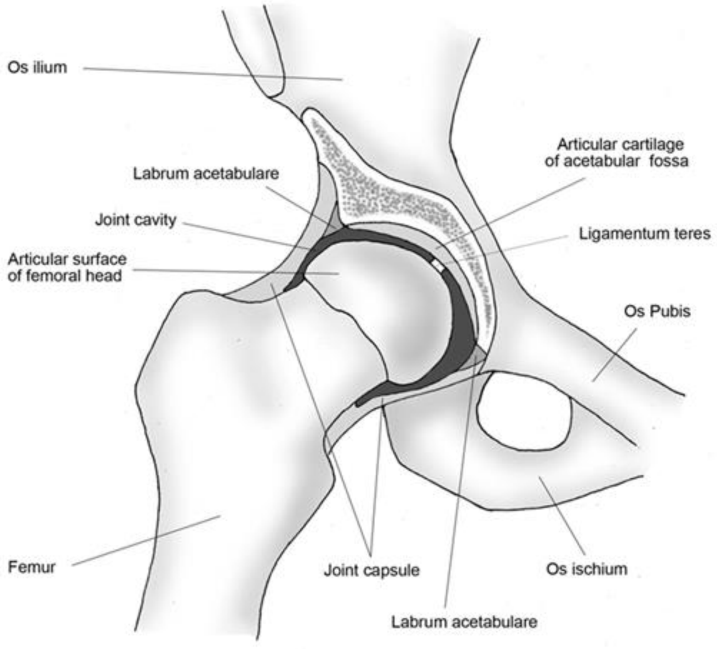

Figure 1. Basic anatomy of the canine hip joint (Grundström, 2014).

Hip joint laxity and weight are major risk factors for developing OA later in life and the probability of having OA increased with the age of these patients (Smith et al., 2001, Runge et al., 2010). The association between increased HJL, measured by the DI, and the probability of having OA is breed specific (German shepherd dogs with HJL (DI > 0.3) had a 4.95 times increased risk of having OA when compared to three other breeds like golden retrievers, Labrador retrievers and rottweilers) and this should be considered in breeding programmes (Smith et al., 2001).

Canine hip dysplasia is a very common disease (Bouw, 1982) , but can easily go undiagnosed and 76% of cases show no or minimal gait abnormalities, of which the most common sign is a swaying pelvic limb action. Additionally 63% of affected dogs show no clinical signs of pain (Barr et al., 1987). This can result in patients going undiagnosed if early screening is not employed.

In a paper published by Smith et al. (2001), it was mentioned that despite the absence of available epidemiological data, clinical experience suggested that fewer than 5% of pet dogs with radiographic evidence of OA would exhibit clinically significant CHD. The authors suggested that there was considerable uncertainty surrounding the manifestation of OA and the clinical signs of CHD. This uncertainty prompted exploration of alternative phenotypes associated with CHD that had a more direct connection to the genotype of the disease. At this point HJL gained recognition as a potential phenotype. Notably, the stated prevalence of CHD does not reflect a true prevalence because a significant number of radiographs from dysplastic dogs are omitted or withheld by breeders (Pascual-Garrido et al., 2018).

The selection to reduce the incidence of CHD will only improve if the confounding variables (e.g. weight, diet, etc) and the genetic predisposition of CHD are all incorporated into the estimation of the breeding values of the stock (Distl et al., 1991).

Despite many decades of dedicated efforts by breeders and veterinarians to manage CHD, its global prevalence persists at significant levels both inter- and intra-breed. Prevalence ranges from 1% (whippet) to 71% (bulldog) between different breeds and from 9% to 73% within specific breeds such as the golden retriever (King, 2017). Unfortunately, progress in mitigating CHD through radiographic screening applications has so far been unsuccessful (Kaneene et al., 1997; Corley, 1992; Leppänen et al., 2000). The efficacy of grading schemes to significantly reduce the prevalence of CHD appears to be limited, raising questions about the effectiveness of this approach in addressing the complexity of this condition. Although there are some breeding programmes that have shown some improvement in the radiographic grading, joint conformation, degree of laxity and the presence of OA (Leppänen et al., 2000). Despite these efforts, the incidence of CHD remains high (King, 2017). This suggests that while there have been strides in enhancing specific components CHD, challenges persist in effectively mitigating the occurrence and impact of CHD (Corley, 1992). The limited published data over the past few decades highlights that the current screening systems may have deficiencies. For example, HJL may be masked by the conventional VD hip-extended radiographs, as maximum hip laxity cannot be assessed on these views (Smith et al., 1990). This may result in impaired capacity to identify the dogs predisposed to CHD. Radiographic signs of CHD might also appear later on in life after the screening was performed and additionally the variability between radiologists' interpretations of these radiographs add to the limitations (Smith et al., 2006, Heyman et al., 1993, Kaneene et al., 2009, Flückiger et al., 1999, Kealy et al., 1997).

Heritability estimates of CHD have been shown to account for about 50% of the disease, suggesting that the remaining portion is attributable to various environmental factors (Henrigson et al., 1966). The OFA phenotype, utilized as a selection test for breeding desirability, is influenced by environmental factors such as age and diet. The influence of these environmental factors poses a challenge to selecting a reliable selection test (Ginja et al., 2010; Kealy et al., 1992). Tests heavily influenced by non-genetic (environmental) factors are considered to have lower value and utility as phenotypic tests in the context of making breeding selections (Ginja et al., 2010). The environment's profound impact on the phenotype of a dog under evaluation may lead them to appear phenotypically normal while, in reality, they are genetically inferior and carry genes that predispose them to CHD (Leighton, 1997).

A good phenotypic test should be strongly associated with CHD genes but not influenced by environmental factors. This will contribute to more rapid progress in the field of CHD management and reduction in the prevalence of the disease (Ginja et al., 2015). Smith et al. conducted a study in 2012 where they showed that the DI was unaffected by non-genetic (environmental) factors including diet and weight and that the DI did not change with age (Smith et al., 1993, Smith et al., 2012).

Another limitation of the OFA data is the selection bias linked to the voluntary submission of radiographs impeded accurate estimation of CHD incidence and OA changes (Kaneene et al., 2009).

An optimal screening test for a condition that can potentially change throughout life should be reliable and conducted early in life and should be based on indicators that are well defined for the disease of interest. The higher the heritability (H^2) of the identified phenotype, a measure estimating the proportion of phenotypic variation attributable to genetic factors, the truer the measure of the genotype (that is less affected by non-genetic factors) will be. Heritability values range from 0 to 1, with higher values indicating a stronger genetic influence on the observed variation (Bennett et al., 2014). A higher heritability suggests that the identified phenotype is a more accurate reflection of the underlying genetic factors. The results of a study by Smith et al. in 2012 and those of earlier studies showed that the DI (and thus also the LI) is a screening indicator that meets all the factors described above (Smith et al., 1993, Smith et al., 2012, Leighton, 1997).

Literature demonstrates spontaneously clinical improvement in CHD patients as they reach maturity (Riser, 1973). There is currently no explanation for the number of dogs that have hip laxity as adults but do not develop OA (Vidoni et al., 2021). It was found that at around 5-6 months of age, these patients suddenly became painful in the pelvic limbs. This is the age where micro fractures start to occur in the acetabular rim. By the time these patients are around 8-11 months of age, they tend to improve clinically as this relates to healing of these fractures and thickening of the joint capsule. By this time the dorsal acetabular rim has undergone sclerosis preventing re-fracture and allows this area to withstand more forces and trauma (Riser, 1973).

Applying preventative medicine for animals predisposed to this condition is difficult, as CHD manifests unpredictably, is multifactorial in origin and is highly variable with an unpredictable progression (King, 2017). No long-term data that evaluated the outcome of surgical versus non-surgical interventions could be found in the literature. Further studies are thus needed to evaluate this (Farrell et al., 2007). Based on a questionnaire and assessment of different variables, between 42% and 66% of patients remained clinically affected after non-surgical management (Farrell et al., 2007).

Available and appropriate treatment options for CHD depends on the patients age at diagnosis, severity of the condition (including severity of any arthritic changes), results of diagnostic tests, other orthopaedic problems, or illnesses, expected performance level and finances (Farrell et al., 2007).

It is evident that there is a need for well-designed long-term evaluations of some treatment options with appropriate controls. Only then will we be able to initiate the optimum management for many individual patients (Anderson, 2011).

An important unanswered question regarding HJL is the degree of acceptable laxity for a given age. Currently, no compelling research explains why some hips with HJL do not develop OA, whereas others that have less laxity, do develop this condition.

It is our experience that such a paucity of information makes it exceedingly difficult to recommend breeding programs or treatments based on HJL alone. A grey zone (>0.3 LI <0.7) exists between "tight" (low LI) and "loose" (high LI) hips and currently there is not enough evidence to determine what happens to patients that fall within, or in-between these categories (Gatineau et al., 2012).

2.2 Development of CHD

Puppies predisposed to CHD are typically born with radiographically normal hips (Riser and Shirer, 1966). They tend to develop normally provided congruity is maintained between the femoral head and the acetabulum (Riser and Shirer, 1966).

At 2 weeks of age, for reasons unknown (whether primary or secondary), the joint capsule and *ligamentum teres* stretch (Riser and Shirer, 1966, Riser, 1973, Alexander, 1992). By 4 weeks, mild synovitis, oedema, joint effusion, and fibroplasia of the *ligamentum teres* occurs. The *ligamentum teres* is mainly responsible for holding the femur head in position for the first 4 weeks after birth (Riser, 1973, Lust and Summers, 1981). At three months these patients start developing changes in the articular cartilage (Lust and Summers, 1981, Morgan, 1992). At cellular level there is loss of chondrocytes and changes in the proteoglycan content and collagen fibril network (Lust and Summers, 1981).

In the intricate cascade leading to OA, joint effusion and *ligamentum teres* stretching induce laxity (Lust et al., 1985). The exact pathogenesis remains unclear, but laxity results in subluxation of the femoral head, concentrating abnormal forces on developing skeletal areas. Subluxation leads to traumatic reduction as soon as the dog is not weight bearing. Histologically, compression forces during weight-bearing delay ossification in localized regions, particularly the dorsal acetabular rim and medial aspect of the femoral head resulting in less femoral head coverage (Riser, 1973).

Chronic subluxation and traumatic reduction of the joint leads to decreased joint stability due to the abnormally shaped acetabular rim and shallow acetabulum, causing uneven weight distribution, microfractures in the subchondral bone, and femoral head (Fries and Remedios, 1995). Microfracture healing makes the bone more sclerotic, impairing the ability of the joint to absorb shock during walking or exercise. Excessive stress forces on the overlying cartilage leads to cartilage degeneration and this is worn away, exposing the subchondral bone (Alexander, 1992). This triggers secondary degenerative changes, including thickening of the joint capsule (Riser, 1973), which, under normal conditions, is pale and 1-2mm thick. In dogs with dysplastic hips, the capsule thickens to 5-7mm (Fries and Remedios, 1995). This stress and traction can lead to stretching or rupture of the ligament of the femoral head, thickening/rounding of the dorsal acetabular rim and femoral neck and atrophy of musculature (Lust et al., 1985).

With age, the joint stability may improve or the joint luxates or subluxates. Secondary changes appear and leads to less laxity and a false interpretation of grading based only on radiographic evaluation (Fries and Remedios, 1995).

2.3 Diagnosis

Diagnosis of CHD is made using a combination of history, clinical examination, orthopaedic examination and radiographic studies. In most of the available scoring systems the diagnosis of CHD is made if there is radiographic evidence of either HJL, OA or both (Smith, 1998).

Clinical signs in dogs with CHD are highly variable and secondary degenerative radiographic changes do not consistently correlate with clinical signs (Barr et al., 1987). As the disease progresses, and secondary changes are seen, the joint can stabilise due to periarticular fibrosis, thickening of the joint capsule and in some instances the formation of bony buttresses on the dorsal acetabular rim. These permanent physiological/anatomical adaptations lead to improved joint congruity and leads to a profound improvement in clinical signs (Barr et al., 1987). As the dog matures, they typically develop OA which leads to chronic pain. However, there are cases where patients exhibit characteristic signs of CHD and laxity at a young age, and remarkably never develop clinical signs as they reach adulthood (Fry and Clark, 1992). Clinical signs can include gait abnormalities, reduced stride length, stiffness, reduced height of step, “bunny hopping”, struggling to rise and climb stairs (Fry and Clark, 1992).

Numerous tests have been developed to evaluate hip joint function and pathological changes, which fall into one of two categories: HJL tests, mainly performed in young animals, or evaluation of arthritic changes, which are usually performed in older animals and utilised in grading schemes. These tests normally require sedation, however, there is a need for a CHD screening test in fully conscious young animals as the Ortolani test can have false negatives. The definitive diagnosis of CHD is established solely upon the presence of characteristic evidence on a standard extended VD radiograph of the pelvis, with the earliest scoring system (FCI) requiring radiographs at only 12 months of age. Signs of OA typically manifest later than laxity, becoming visible only after 6 months of age or frequently much later (Smith, 1998).

Radiographic signs of OA can be a combination of the following: subchondral sclerosis of the craniodorsal acetabular rim, periarticular osteophytes, and joint remodelling from chronic wear with reduction in acetabular depth and flattening or ”mushrooming” of the femoral head (Smith, 1998).

2.3.1 Clinical hip joint laxity (HJL) tests

These tests all measure laxity, but in different ways. They are all used as to gain additional information to alert the examiner to the potential presence of HJL.

The normal range of motion (in degrees) of the canine (German shepherd dog) coxofemoral joint measured with universal plastic goniometer is as follows: (Petazzoni and Jaeger, 2008).

- Flexion	55
- Extension	160-165
- Internal rotation	55
- External rotation	50
- Abduction with flexed hip	120 (stifle 90)
- Abduction with extended hip	85
- Adduction with flexed hip	65 (stifle 90)
- Adduction with extended hip	63 .
- ROM	112

2.3.1.1 Ortolani test

The Ortolani test (Ortolani, 1936) is a physical manoeuvre to test for HJL by applying proximally directed force thought the shaft of the femur to the acetabulum, with the dog in lateral recumbency, which forces the head of the femur out of the acetabulum (in effect dorsolateral subluxation). As this force is maintained, the hip is abducted to the point of an audible sound or palpable “clunk” of reduction of the head back into the acetabulum. Such a palpable or audible ‘jump’ is indicative of a positive Ortolani test (Figure 2). The angle of the long axis of the femur at the point at which the reduction of the hip joint occurs, and horizontal plane of the table is recorded as the angle of reduction. This data can be used to quantify the degree of hip laxity and candidacy for a surgical intervention like for example a TPO (Johnson et al., 1998).

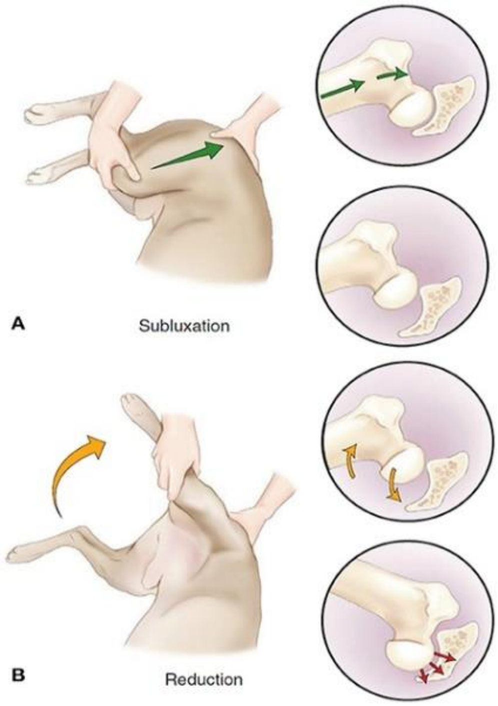

Figure 2. (**A**) Ortolani test, applying proximally directed force to the femur with the dog in lateral recumbency, which causes subluxation of the femur head. (**B**) Hip is abducted and audible sound or palpable “clunk” of reduction of the head back into the acetabulum is noted (Kyriazis and Prassinos, 2016).

The Ortolani test is a good screening test for dogs with HJL, but it is only moderately correlated with the radiographic measurements of HJL (Puerto et al., 1999). The Ortolani sign is best used as a diagnostic test in young dogs before secondary changes due to OA, as dogs with CHD are five times more likely to demonstrate a negative Ortolani sign if they have radiographically evident OA, due to blunting off of the dorsal acetabular rim and changes to the anatomical appearance of the femoral head (Puerto et al., 1999). A positive test result is theoretically a risk factor for CHD development, but no long-term studies have been performed to evaluate the correlation between the two (Farese et al., 1998). The earliest age at which this technique can be used is 7-8 weeks with the patient positioned in dorsal or lateral recumbency. It’s reported sensitivity to detect CHD is 92% (Ginja et al., 2008). The reduction angle (RA) correlates well with the degree of HJL. Mild HJL has an RA of 10-25 degrees whereas more severe forms of HJL has a RA of > 25 degrees (Vezzoni and Schramme, 2004). The likelihood of CHD or OA increases with RA (Gatineau et al., 2012). An RA > 15 degrees has an 85% chance of developing OA (Gatineau et al., 2012). There was a significant positive linear relationship between RA and DI ($P = .015$, $r^2 = 0.32$) (Gatineau et al., 2012). A negative Ortolani always correlated very well with the absence of OA at 2 years (Gatineau et al., 2012). In this study, the RA was a particularly good predictor of OA for a DI in the range (grey zone) of > 0.3 and < 0.7. The RA proved to be the best overall predictor of coxofemoral OA comparing the RA of the Ortolani test and the dorsal acetabular slope from the dorsal acetabular rim radiograph (Gatineau et al., 2012, Vidoni et al., 2021).

2.3.1.2 Barlow's test

Barlow's test is seldom used in animals, but it is another hip laxity test described by TG Barlow (Barlow, 1963). It is a modification of the Ortolani test and was developed because in new-born babies the Ortolani test proved not sensitive enough (Barlow, 1963). In new-borns the femur head slides over the acetabulum in a smooth manner and the "click" is not present or is missed by the examiner. For this test the patient is positioned in dorsal recumbency. By only using your thumb and middle finger; your thumb on the medial aspect of the proximal femur/minor trochanter and your middle finger on the greater trochanter, you move the hip cranially and caudally (Schachner and Lopez, 2015). If there is any movement, it is considered positive for HJL (Von Rosen, 1956, Barlow, 1963).

2.3.1.3 Barden's test

Barden's test can also be used in puppies early in life (6 – 8 weeks of age) (Ginja et al., 2010). The patient is positioned in lateral recumbency. The proximal part of the femoral diaphysis is grasped by using one hand whilst the other hands' index finger is on the greater trochanter. There is a lateral pressure applied to the femur to elevate the femoral head out of the acetabulum. The distance that your index finger travels is measured as the amount of HJL (Bardens and Hardwick, 1968). This test is very subjective in nature and grading the amount of HJL by this means can be unreliable (Ginja et al., 2009b).

2.3.2 Radiography

Radiographic diagnosis of hip dysplasia in dogs is based on evidence of OA, HJL, or both. The first notable signs of CHD are at 7 weeks of age where there is femur head subluxation and a delay in the dorsal acetabular rim development (Riser, 1973). Radiographic signs of OA usually only become evident from four to six months of age or even much later (Smith, 1998). Using standard radiographic views it is not possible to diagnose CHD in dogs less than 4 months of age and only has an accuracy of 16% to positively predict it at six months of age (Smith, 1998).

Stress radiography is another radiographic technique that can be used to diagnose HJL. Examples of these techniques include the PennHIP™ method (Smith et al., 1990), dorsolateral subluxation (DLS) test (Farese et al., 1998), Fluckiger method (Flückiger et al., 1999), the Vezzoni's Half-axial position (HAP) (Badertscher, 1977) or rather the improved version called the VMBDD (Broeckx et al., 2018).

2.3.2.1 Standard radiographic views to evaluate hip joint congruity and OA

2.3.2.1.1 Standard ventrodorsal hip extended view (SVDE)

The SVDE view is a universal view with the patient positioned in dorsal recumbency, hips extended, pelvic limbs parallel to each other and stifles slightly internally rotated (Ginja et al., 2009a) . It is especially important to have proper positioning of the dog to interpret the radiographs accurately (Riser, 1962). There are many different schemes to score radiographs for CHD.

The United States of America (USA) commonly uses the OFA guidelines with seven grades (Appendix D) (Riser, 1962, Flückiger, 2007, Powers et al., 2010). Most European countries use the Fédération Cynologique Internationale’s (FCI) system, with five grades (Appendix D) (Riser, 1962, Flückiger, 2007, Ginja et al., 2008). In the United Kingdom (UK), most commonly the British Veterinary Association/Kennel Club (BVA/KC) scoring scheme is used (Gibbs, 1997). With this system nine parameters for each joint are evaluated and each parameter is given a score between 0 and 6 (except for one parameter which is scored 0–5) (Appendix D). The total score thus ranges from 0 to 106 (Sampson, 2011). The SVDE view has been shown to be too insensitive for detecting HJL because the with the patient in this position it causes tightening of the joint capsule resulting in a false negative result (Smith et al., 1990).

The Norberg angle (NA), also known as the Norberg hip extension angle, is a radiographic measurement used to assess the congruity and coverage of the hip joint in dogs. It provides a quantitative measure of the relationship between the femoral head and the acetabulum (Olsson, 1961). The NA, assessed on a SVDE view, is calculated by measuring the angle between a line connecting the centres of the femur heads and a line intersecting this line from the centre of the respective femur heads to the craniolateral dorsal acetabular rim. The angle formed between these two lines is the NA (Olsson, 1961). A higher NA signifies improved hip joint coverage and congruity, while lower angles, commonly seen in dogs with hip dysplasia, indicate reduced joint coverage and congruity (Puerto et al., 1999).

Currently the CHD screening system in greatest international use is the SVDE view (like the OFA) together with the NA and OA changes. The problem encountered with these evaluation schemes is that laxity is under-diagnosed (due to the hip-extended wind up of joint capsule) and OA has not yet developed by the time assessments are made (Smith et al., 1998). The OFA does screening at 24 months, FCI at 12-18 months, and the BVA/KC at 12 months. It was shown that in patients that developed OA by the end of their lives, 78% developed it only after 2 years and 63% only after 5 years (Smith et al., 2006). None of the laxity based diagnostic screening techniques are implemented in any FCI’s screening programs. This could stem from factors as previously discussed, compounded by breeders' reluctance to grasp the concept, unfamiliarity among veterinarians with certain techniques and in the UK, regulations prohibiting individuals from accompanying patients into the radiology room during radiographic procedures (Broeckx et al., 2018).

2.3.2.2 Stress radiographic views to assess HJL

2.3.2.2.1 PennHIP™ method

This method was developed in 1983 by Smith to assess the relationship between passive hip laxity and the development of OA later in life (Smith et al., 1990). It was also developed because there was a significant variation among radiologists when hip scores were assigned to radiographs based on subjective measuring methods (Smith, 1998). This method involves three radiographs.

The one is the SVDE view to evaluate degenerative changes and asses the standard structures of the coxofemoral joint whereas the other two are with the hip in neutral position. The second radiograph is a compression view (Smith et al., 1990). A compression index (CI) can be used to measure joint congruity. The CI involves measuring the contact area between the femoral head and the acetabulum. Dividing the measured contact area by the total surface area of the femoral head gives a ratio and provides a quantitative measure of how well the femoral head fits into the acetabulum (Smith et al., 1990). In one study they proved that the CI increased with OA, and this may be a valid marker for early hip joint OA, but this has not yet been applied clinically (Gold et al., 2009), with the femur head fully seated in the acetabulum to evaluate congruity of the joint and identify landmarks for measurements, and the third view is a distraction view, with the PennHIP™ distractor (Figure 3), to evaluate and quantify HJL (Smith et al., 1993). With the data obtained from the distraction view, a DI is determined. The DI is a scale between 0 and 1 (Smith, 1998). The DI value is the distance between the geometric centres of the acetabulum and the femoral head, divided by the radius of the femoral head. A zero score means there is full congruity and no laxity of the hip, whereas the closer the value is to 1, the more laxity it represents with one being full luxation (Smith et al., 1990).

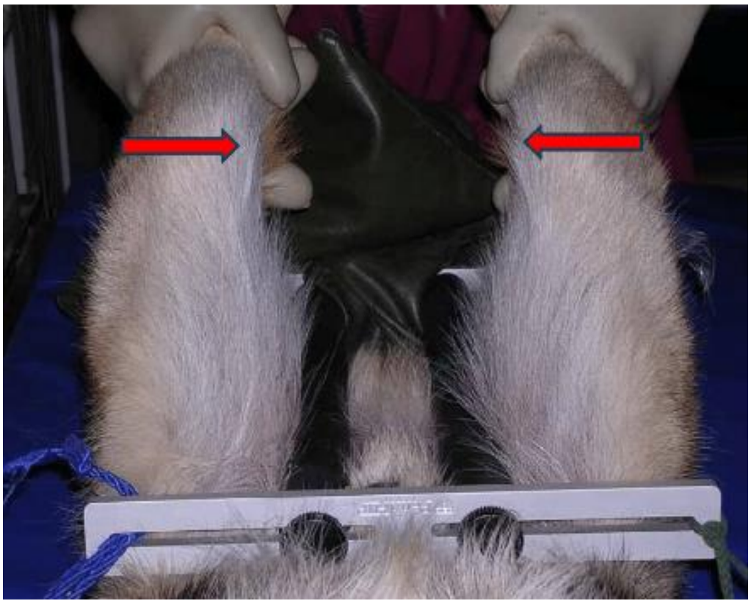

Figure 3. Cranial perspective of a dog in dorsal recumbency with the PennHIP™ distractor placed between the pelvic limbs. The arrows indicate the medially directed force at the level of the stifles to force the femur heads out of the acetabulums, similar to the VMBDD (Soo and Worth, 2015).

Initial research was performed ex vivo on cadaveric specimens and demonstrated that with SVDE views, the passive laxity of the hip was minimal (Heyman et al., 1993), that the laxity was maximal in a neutral position (hip joints in 100 degrees of extension) (Heyman et al., 1993); and it indicated that there was a high repeatability between examiners without the need to standardise the adduction force applied (Bertal et al., 2018).

The DI remained constant within breeds from the age of 16 weeks, and this was taken as the earliest age at which HJL can be examined and quantified, and the DI was 2.5-11 times higher than measured on SVDE view (Smith, 1998).This technique is commonly used in the USA but has not grown in popularity to any extent internationally.

2.3.2.2.2 Dorsolateral subluxation test (DLS)

This method was described by Farese in 1998 (Farese et al., 1998). The stress methods all measure passive HJL. A distinction should be made between passive and functional HJL (Smith et al., 1993). Functional laxity is femur head subluxation during ambulation and activation of the hip muscles versus passive joint laxity that refers to laxity when no muscular forces are applied (Smith et al., 1990). With this method the hip joints are positioned at a standing position and therefore provides an objective measurement of femur head subluxation under near neutral weight-bearing (Farese et al., 1998). The patient is placed in sternal recumbency with stifles flexed and adducted. Hocks are also adducted but extended. The patient is placed on a foam pad with a cut-out hole wherein the stifles are placed so that they make direct contact with the x-ray table. This puts the hips in a weight bearing position. The hips are slightly extended so that the femurs are perpendicular to the table but not superimposing the acetabulums. Radiographs are taken and the DLS score is calculated by measuring the percentage of femur head medial to the most lateral point of the cranial acetabular rim. It was reported that a DLS score greater than 60% suggests that a dog had a low susceptibility, less than 50% suggested a moderate susceptibility and less than 40% suggested a high probability for OA formation, respectively (Farese et al., 1998).

2.3.2.2.3 Fluckiger method

This radiographic technique was developed because all the stress radiography techniques currently only measure lateral subluxation. When the hip is in motion there are cranio-dorsal forces acting on the head of the femur. It is assumed that an unstable femur head subluxates in a lateral and craniodorsal direction and therefore this method employs all those forces when radiographs are obtained. The patient is placed in dorsal recumbency and the femurs are positioned at a 60-degree angle to the table. The stifles are adducted whilst applying proximally directed force through the coxofemoral joint to try and subluxate the femur heads from the acetabulum. This results in cranial, dorsal, and lateral displacement of the unstable femur head. The amount of displacement is calculated in the same manner as the DI, but it is termed the subluxation index (SI). There is a clear association between HJL and OA that has formed the basis for all the HJL scoring systems all over the world (Flückiger et al., 1999).

2.3.2.2.4 Vezzoni modified Badertscher distension device technique (VMBDD)

This technique is remarkably similar to the PennHIP™, but the index is termed the laxity index (LI). This test utilises a different device (Figure 4) and the femurs are adducted against the distension device in slight extension (10° extension, similar to the neutral position of PennHIP™) to expose the acetabulum (Broeckx et al., 2018). An assistant supports the patient while placing a distraction device (VMBDD) between the dog's pelvic limbs (Vezzoni et al., 2008). The assistant then adducts the limbs, aiming to exert force on the femur heads and encourage them to move subluxate from the acetabulums (Broeckx et al., 2018). The PennHIP™ device has padding on the bars that is between the femurs. The amount of compression, visualised on radiographs, of this padding shows that there was enough force generated to try and subluxate the femur heads. The VMBDD does not have padding and theoretically therefore there is no objective way of evaluating whether enough force was applied. This can potentially lead to underestimation of laxity.

A recent study was performed to compare three methods of quantifying HJL (DI, LI, and NA) (Broeckx et al., 2018). A limiting factor of the study was that no relation between the LI and later severity of OA was established and it was concluded that further investigation was needed (Broeckx et al., 2018). The decision to employ the VMBDD over PennHIP™ for assessing HJL is substantiated by its notable advantages. The VMBDD offers cost-effectiveness and requires only a single operator, in contrast to the PennHIP™ method, which requires two operators for its three-radiograph-based procedure. Notably, VMBDD does not impose formal certification requirements, enhancing its accessibility in clinical practice, and its two-radiograph requirement, compared to PennHIP™'s three, contributes to reduced costs and decreased radiographic exposure to patients and operators (Bertal et al., 2018). Furthermore, VMBDD's promising results, similar to PennHIP™-based measurements, underscore its efficacy and efficiency, aligning with the goal of enabling in-house hip joint evaluations by trained clinicians (Ginja et al., 2006; Bertal et al., 2018; Broeckx et al., 2018).

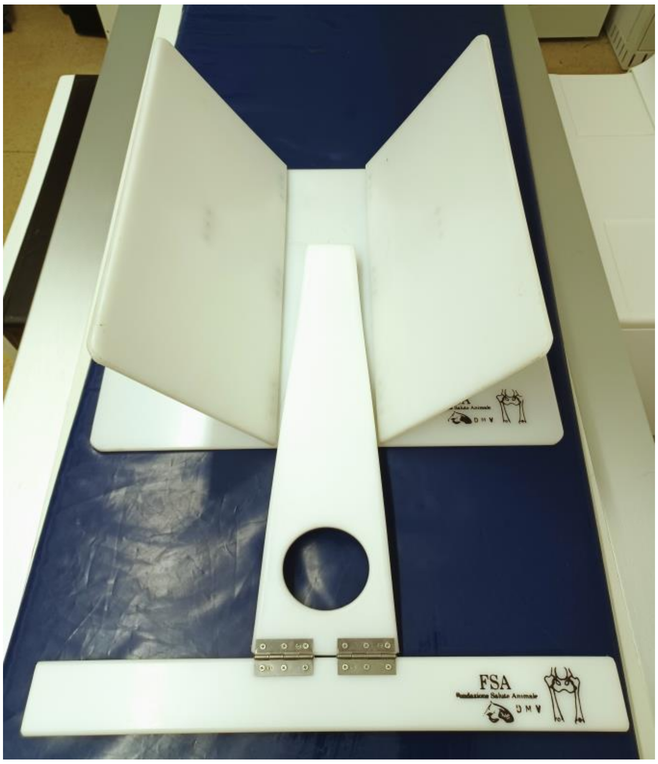

Figure 4. The Vezzoni modified Badertscher distension device (VMBDD).

2.4 Studies similar to the current research

In 1993, Heyman et al. conducted a study where they examined the effects of coxofemoral positioning on hip laxity in canine cadavers by means. The standard and most commonly used view to assess patients' hips and conformation is the SVDE view. The results of this study confirmed that joint laxity was a function of coxofemoral positioning and that the laxity decreased when the hips were in extreme positions. Laxity was maximal with the hips in a position approximating the neutral position (15 degrees extension, 10 degrees abduction and with no internal or external rotation of the femur). The amount of lateral displacement of the head of the femur at different points of flexion, extension, adduction, abduction, and rotation of the femur were all recorded (Heyman et al., 1993).

Another study was also conducted to compare two iPhone-based goniometer applications and the universal goniometer for assessing hip and knee joint angles in humans. The findings indicated that the smartphone-based goniometers provided accurate measurements with moderate correlation (Waddell et al., 2017). There was also a study performed to assess novel digital and smartphone-based goniometers for the measurement of canine stifle joint angles. This study reported a poor correlation with radiographically measured stifle joint angles and suggested additional studies were needed (Freund et al., 2016). This study had limitations as the sample size was very small and differed from our study in that it was mixed breeds, it was cadaver limbs, and the limbs were fixed to a jig. Although there is no research on smartphone-based goniometer measurements for hip joint angles in dogs, existing evidence from human literature suggests high reliability and inter-operator repeatability in the obtained measurements (Werner et al., 2014, Yoon et al., 2014, Quentin et al., 2015) Our study was similar but our joint of interest was the hip joint in dogs.

2.5 Genetic control

Selective breeding remains the primary avenue to manage polygenic diseases like CHD (Leighton, 1997). The fundamental goal of selective breeding is to pair favourable genes, yielding offspring with desired traits. Research estimates the heritability of CHD to be approximately 0.4-0.5, based on a comprehensive study involving 2404 German shepherd dogs from a kennel in Sweden. Examining 401 litters born between 1965 and 1973, researchers observed a gradual reduction in the frequency of CHD, from 50% prior to 1970 to 28% in 1975, following strict adjustments in breeding practices (Hedhammar et al., 1979).

Currently, genotype estimation relies on hip phenotype, yet this approach has limitations, evidenced by persistently high rates of dysplastic hips in offspring from selected breeding stock (Smith et al., 1998). Selection pressure based on the DI, with a heritability of 0.50 or greater in studied breeds, promises more significant and swifter genetic change compared to CHD scores based on the SVDE view. The rate of genetic change in offspring is proportional to the heritability of the trait (h2) multiplied by the selection pressure, emphasizing the importance of informed selection practices (Smith, 1998).

The phenotypic expression of CHD is influenced by environmental factors such as nutrition, exercise, body weight, litter size, maternal age, flooring, pre-weaning mortality, birth season, and neutering (Mäki et al., 2000; van Hagen et al., 2005; Ginja et al., 2008). Despite limited studies on the heritability of subjective hip scores, the presence of recessive major genes complicates phenotypic selection against CHD, hindering substantial genetic progress (Mäki et al., 2004).

Breeders wield control over selection pressure, but not over heritability. Breeding with dogs exhibiting the lowest DI within the breed accelerates genetic change, yet entails a heightened risk of inbreeding and loss of genetic diversity. To preserve diversity while applying meaningful selection pressure, breeding from the tightest half of the breed is recommended, though this approach necessitates more time (Smith, 1998). Minimizing false-negative diagnoses of CHD is crucial for genetic control, as these can perpetuate deleterious genes in the population (Powers et al., 2010).

Numerous recommendations advocate for comprehensive breeding programs to mitigate CHD (Ginja et al., 2010). Laxity-based radiographs are recommended for screening, with standardized acquisition and interpretation by experienced personnel. Careful selection, considering genetic traits, and a thorough understanding of phenotypical distribution are essential (Ginja et al., 2010). Avoiding bias during radiograph submission is imperative, and breeding programs should ideally be devised collaboratively by centralized committees and geneticists (Broeckx et al., 2018).

2.6 Preventative management

The challenge we confront lies in the delayed diagnosis of CHD, often occurring only when clinical signs manifest, shifting the focus from prevention to management and alleviation of clinical signs (Schachner and Lopez, 2015). Conservative and preventative surgical interventions exist for dogs predisposed to CHD, typically characterized by HJL (King, 2017). Early diagnosis during skeletal immaturity presents an opportune window for influencing joint congruity and development (Henrigson et al., 1966).

Dogs affected by CHD may exhibit clinical signs as early as 5-6 months of age, followed by apparent spontaneous resolution of clinical signs at 9-11 months (Riser, 1973). Exercise restriction during this period can reduce secondary OA changes. Studies have shown that reducing food intake by 25% at eight weeks of age resulted in a 67% decrease in CHD prevalence by two years (Smith et al., 2006). The correlation between rapid growth and weight gain with CHD was first reported in 1964 (Riser et al., 1964).

Research indicates that puppies from litters, whose parents have CHD experience higher prevalence, quicker onset, and severity of CHD when subjected to rapid weight gain due to calorie intake compared to those with caloric restrictions (Kealy et al., 1992). Therefore, addressing obesity in canines can alleviate stress on joints and peri-articular structures (Kealy et al., 1997). Low-impact, non-weight-bearing exercise can aid in cartilage nutrition (Kealy et al., 1992).

Non-surgical CHD management encompasses nutrition and weight management, rehabilitation, and appropriate analgesia and disease-modifying drugs.

Long-term outcomes of non-surgical CHD management vary, with some studies reporting favourable results (Barr et al., 1987), while others are less encouraging (Farrell et al., 2007). Although conservative management can alleviate discomfort associated with CHD and OA, it is unlikely to prevent the condition altogether (Manley et al., 2007).

2.7 Surgical treatment

In young, skeletally immature animals you have the opportunity to do corrective osteotomies (TPO and JPS) with the aim to improve joint congruity as these dogs develop and minimizing the secondary changes and development of OA (Johnson et al., 1998). In older, mature dogs you have the option of a total hip replacement (Olmstead et al., 1981), or a femur head and neck excisional arthroplasty as a salvage procedure (Duff and Campbell, 1977). The selection criteria for the surgical procedures differ as well as the financial implications.

2.7.1 Juvenile pubic symphysiodesis (JPS)

Juvenile pubic symphysiodesis (JPS) is a prophylactic surgical procedure performed in predisposed puppies between 14-22 weeks to prevent the development of CHD. The technique involves monopolar electro-coagulation of the pubic symphysis, halting growth and promoting acetabular rim rotation for increased femoral head coverage. While effective in altering hip phenotype, ethical concerns arise as it may mislead breeding decisions, potentially allowing dogs with altered phenotypes to be included in breeding programs without reflecting the true genotype. The technique can also predispose female dogs to dystocia due to narrowed pelvic canals (Vezzoni et al., 2008).

2.7.2 Triple pelvic osteotomy/ Double pelvic osteotomy (TPO/DPO)

This procedure is a very popular preventative surgical intervention in dogs with CHD. This procedure entails isolating the acetabulum by performing osteotomies of the ileum, pubis when a DPO is performed or the ileum, pubis and ischium when a TPO is performed. Rotating the acetabulum results in a reduction in the dorsal acetabular rim angle (DARA) and manually causing more femoral head coverage by the acetabulum. The osteotomised segment is stabilised over the ilial osteotomy with a prebent plate and screws (Slocum, 1986).

2.7.3 Total hip arthroplasty/replacement (THR)

The most common indication for a THR is to improve function and alleviate pain associated with secondary degenerative changes attributed to CHD in end stage joints. Clinical signs of pain or impaired function should be present in these patients before a THR is really justified (Massat and Vasseur, 1994).

2.7.4 Femoral head and neck excision arthroplasty/ostectomy

This is a salvage procedure to eliminate pain associated with degenerative changes of the hip joint causing crepitus and bone-on-bone contact between the femur head and the acetabulum. The femur head together with the neck is removed in an oblique fashion and soft tissue/joint capsule is interposed and sutured in place between the two segments (Harper, 2017). The body forms a pseudoarthrosis and pain is eliminated/reduced. It is indicated for a range of conditions including pelvic/acetabular fractures, neoplasia, coxofemoral luxation, femur head/neck fractures, etc., but in this context, it is limited to its use for the management of CHD. An old study showed that patients with more advanced OA and a more chronic condition have good outcomes, regardless of weight of the patient (Girdlestone, 1943, Lewis et al., 1988).

3. RESEARCH QUESTIONS

3.1 Problem statement

To the author's knowledge no study has been published comparing the LI values of large breed dogs with the rotation and abduction angles of the coxofemoral joint.

This data can be used as an easy and readily accessible predictor of predisposition to future OA and certain preventative measures can be set in place.

3.2. Objective

The objective of this study was to measure and determine the correlation between the rotation-and-abduction angles of the canine coxofemoral joint and the VMBDD laxity indexes in large breed (boerboel) dogs between 4 -12 months of age.

Secondly, the inter- and intra- operator variability, respectively of the method for measuring the internal rotation, external rotation and abduction angles was studied.

3.3. Hypothesis

Null hypothesis (H0)- Rotation-and-abduction angles are not correlated to LI in canine coxofemoral joints.

Alternative hypothesis (H1)- Rotation-and-abduction angles are correlated to LI in canine coxofemoral joints.

H0- Mobile phone-based measurement of internal rotation, external rotation and abduction angles have poor inter- and intra- operator variability.

H1- Mobile phone-based measurement of internal rotation, external rotation and abduction angles have excellent inter- and intra- operator variability.

3.4. Benefits arising from the experiment

A non-radiographic approach not only presents a cost-effective alternative but also minimizes patient and operator exposure to radiation. This enables veterinarians to assess patients' susceptibility to CHD, determine the need for additional diagnostic examinations, plan for ongoing monitoring, and potentially initiate early breeding decisions before definitive diagnostic tests. The widespread implementation of this screening method during routine procedures holds the promise of a transformative impact on the genetic pool. The outcomes of this study would contribute to increased understanding of hip dysplasia.

The data have the potential to significantly decrease patient morbidity associated with OA and provide owners with a more financially viable surgical option early in their dogs' lives, in contrast to more invasive procedures in adulthood. Early screening creates awareness among clients/owners regarding potential predisposition to CHD, enhancing the quality of life for dogs, and additionally translates into substantial reductions in treatment costs over time. Importantly, these findings have the potential to shape breeding programs by facilitating the selection or exclusion of individuals (Vidoni et al., 2021).

4. MATERIALS AND METHODS

4.1 Ethics statement

The author confirms that legal and ethical requirements were met regarding the humane treatment of animals described in the study. Ethical approval was granted by the University of Pretoria Faculty of Veterinary Science animal ethics committee (REC003-22). (Appendix A)

4.2 Declaration of conflict of interest

The author declared that they had no financial or personal relationship with the breeder or organisations that could have inappropriately influenced or biased the content of this study.

4.3 Informed consent

Informed written consent was obtained from the owner before the study commenced (Appendix B). Consent forms are stored in paper format for 5 years by the author, and copies were handed to the administrative personnel of the Department of Companion Animal Clinical Studies at the University of Pretoria.

4.4 Experimental design

This was a quantitative correlational design study conducted in vivo. The purpose of the study was to determine if there was a correlation between the measured variables (rotation and abduction angles) and LI as determined radiographically using the VMBDD.

Independent variable: Joint laxity, position of mobile phone on the leg, sedative used, breed of dog, positioning of the patient.

Dependant variables: Internal rotation, external rotation, and abduction angles.

4.5 Animals used

The study population consisted of thirty-three large breed boerboel males (n = 14) and females (n = 19) from a single breeder (Bostu boerboels), between the ages of 4-10 months. All of the data was collected over three consecutive days, all dogs underwent a thorough clinical evaluation and review of their history to ensure that they did not meet any exclusion criteria, were clinically healthy, and could be safely sedated. The clinical history was used to determine the eligibility of dogs for the study.

Dogs with a history and/or clinical signs that met the exclusion criteria were excluded from the study. The exclusion criteria included:

1. Dogs that were not purebred boerboels.
2. Dogs with cardiac and/or pulmonary disease (to ensure safety during routine sedation).

3. Dogs younger than four months.
4. Dogs older than 12 months.
5. Dogs with a history of pelvic or hind limb trauma.
6. Dogs with clinical signs consistent with immune-mediated OA or any other forms of OA.
7. Dogs with any skeletal abnormalities on SVDE views (Transitional vertebrae etc.)
8. Dogs displaying aggression.
9. Dogs that don't have a body condition score (BCS) of at least 4-5/9 (Laflamme, 1997).

4.6 Sedation protocol for examination

All patients that were examined were sedated by the author with an intravenous combination of 5-10 ug/kg of medetomidine hydrochloride (Domitor®, Zoetis Animal Health, Sandton, South Africa) and 0.1 mg/kg of butorphanol tartrate (Dolorex, MSD Animal Health, Midrand, South Africa). The dogs were left undisturbed for 5-10 minutes to allow the sedation to take effect. If dogs did not achieve an appropriate level of sedation, they were administered propofol 1% (Fresenius Propoven1%, Fresenius Kabi, South Africa) to reach the desired plane of sedation. Once the radiographs were taken and angles (mentioned later) have been measured, the sedation was reversed with atipamezole hydrochloride (Antisedan®, Zoetis Animal Health, Sandton, South Africa) administered IM at the same volume as the medetomidine. The dogs were monitored by the author until they became fully responsive and mobile. At that point, the animal was returned to its owner.

4.7 Method for non-radiographic measurement of hip joint angles (Goniometer)

The measurement of rotation and abduction angles was conducted first using a mobile phone goniometer, specifically the “Measure” application on an iPhone (Apple). This process involved three independent operators (ECVS small animal surgeon, MMedVet small animal surgeon and small animal surgical resident), each blinded to the others' results, who performed measurements on both hips in a randomized order. Each operator repeated every measurement three times and recording of the readings was done by an independent person (surgical resident). This was performed over three consecutive days with an average of 11 dogs per day. The primary objectives were to establish correlations between the measured angles and LI and to assess inter- and intra-operator variability.

The standardized procedure began with dogs placed in lateral recumbency. The non-dependent pelvic limb was positioned parallel to the table with the femur at 90 degrees to the pelvic floor and stifle at normal standing angle (135 degrees), and a line was drawn between the trochanter major and the lateral fabella of the non-dependent limb. The long axis of the phone, mounted on a custom wooden jig crafted by the author, overlapped this line, with the base of the jig resting on the fabella. This jig consisted of a straight wooden plank (40cm x 3cm) with a flat surface for secure phone mounting with double-sided tape and a concave side for a snug fit onto the major trochanter.

The mobile phone application was zeroed by manipulating the leg, so the two circles superimpose (Figure 5A). This was done to ensure the femur is also perfectly parallel to the table. Alignment of the two circles coincided with a 0-degree reading and the screen turned green (Figure 5B).

For external rotation measurements, the operator externally rotated the coxofemoral joint in the transverse plane by externally rotating the stifle and internally rotating the hock until maximal resistance was encountered. The measurement was captured by one of the and independent person with the operator blinded to the result. Internal rotation angles followed the same principles but involved internal rotation of the stifle and outward rotation of the hock. Abduction angles were measured in a similar manner, with the phone placed in the same position. However, the hip was abducted to the point of maximal resistance, and the measurement was taken. Throughout these manoeuvres, one hand was used to stabilise the stifle, preventing rotational forces that could affect accuracy.

The mean of these measurements was calculated and recorded. Each patient served as its own control, with values compared to their official LI score. The order in which operators took measurements was randomized, contributing to the dataset's integrity and allowing for the determination of inter- and intra-operator variability in the measuring method.

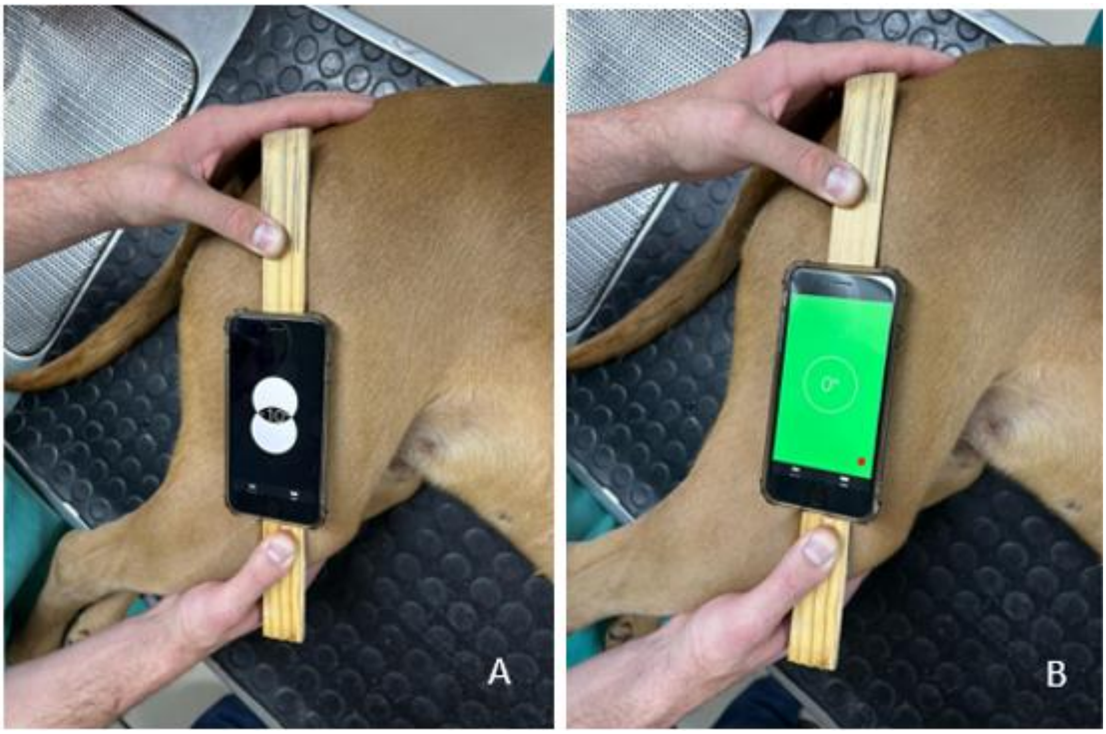

Figure 5. (**A**) Example of the wooden jig and the phone, with measure app, whilst trying to superimpose the two circles, to make sure the leg is parallel to the table; (**B**) Application is zeroed and turns green when circles are superimposed. From this point the measurements commenced.

4.8 Method for radiographic evaluation of HJL and OA (SVDE-and-stress views)

Two radiographs were taken by the author and one other operator. The first radiograph was the SVDE view (stifles slightly inward rotated, femurs parallel to each other and the table, and hips maximally extended) to evaluate degenerative changes and assess the standard structures of the coxofemoral joint.

The second radiograph was a distraction view, using the VMBDD, to evaluate HJL with the hip in 10 degrees of extension (100 degrees in relation to the table) and the device placed between the dog's pelvic limbs and medially directed force pushing the stifles towards each other (Figure 6). The criteria used to determine if the stress view was adequate were symmetry of the obturator foramina and iliac wings, symmetrical position of the femurs, and the lateral displacement of the heads of the femurs from the acetabulums in comparison with the non-distracted SVDE view. With the data obtained from the distraction view, a LI was determined as previously described in the introduction (Bertal et al., 2018) (Figure 7). The results were presented on a scale from 0-1 (Smith et al., 1990), with values given separately for the right and left coxofemoral joints. The quality of the radiographs was screened by the author and an additional two operators, and a LI and NA were determined by the author.

Figure 6. (**A**) Example of patient positioning for the distraction view. An assistant is supporting the patient while placing a distraction device between the dog's pelvic limbs. (**B**) Left-lateral photographic view where the assistant applies an adducting force through the femoral diaphysis.

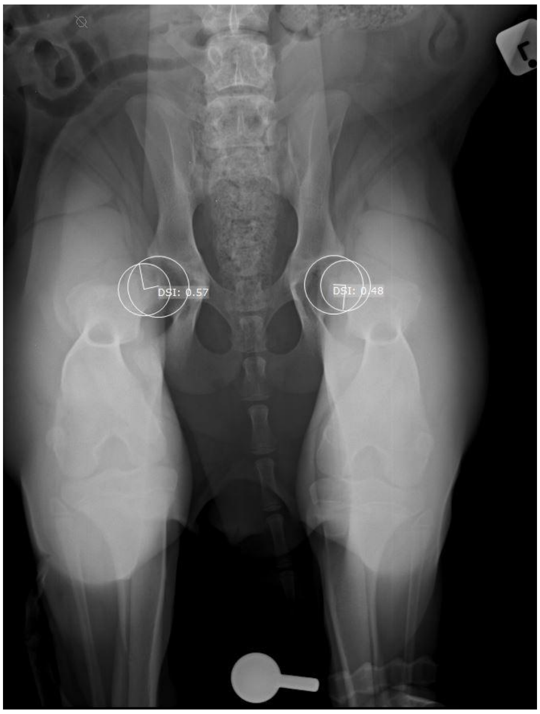

Figure 7. Distraction view radiograph for calculating the of LI. The LI value is the distance between the geometric centres of the acetabulum and the femoral head, divided by the radius of the femoral head. In this patient the left LI was 0.48 and the right LI was 0.57.

The radiographs were obtained using a digital radiographic (DR) system (Vivex, Lomaen Medical, Johannesburg, South Africa) and radiographs were taken in a designated, well-marked, and access-controlled area. Staff involved with taking radiographs followed all the recommendations for radiation safety as stipulated by the Department of Health. The radiographs were marked according to the standardized nomenclature system for radiographic projections used in veterinary medicine developed by Smallwood et al. (Smallwood et al., 1985).

Standard radiographic views for hip dysplasia assessment were employed, avoiding additional radiation beyond routine screening requirements. Since the radiographs were part of routine clinical practice and experimental animals were volunteered by the breeder, no ethical concerns were encountered.

After acquisition of all the radiographs from the study population, the radiographic images were evaluated by the author and one of the operators (ECVS diplomate) for radiographic quality and determination of the LI. Data capture sheets were used during measurements (Appendix C) and they were finalised, transferred and subsequently completed on Excel (Appendix E).

Data captured was stored on the author’s cloud-based server for 5 years. Hard copies will be handed to administration at the Department of Companion Animal Clinical Studies, University of Pretoria. Data and DR images were also backed up in cloud storage (Google Drive®). The radiographic images were stored on the Picture archiving and communication system (PACS) at Onderstepoort Veterinary Academic Hospital, Onderstepoort, Veterinary Faculty.

5. DATA ANALYSIS

5.1 Study population

The sample size was estimated for a correlation of 0.5 or greater between the LI and one of the measured angles to be statistically significant. This sample size was estimated to be 29 dogs, which was increased by four dogs to account for potential exclusions after data collection. This study population consisted of 33 purebred boerboel dogs between the ages of 5-10 months (average 8.36 months) from one breeder, Bostu boerboels. It was a population of 14 (42%) intact males and 19 (58%) intact females.

All the 33 sample dogs (66 hips) met the inclusion criteria, and the radiographs were of good diagnostic quality. The angles measured were all performed in the exact same manner.

5.2 Statistical analysis

Intra-operator repeatability of the goniometer-based rotation and abduction angles of the coxofemoral joints was assessed by calculating the coefficient of variation (CV) for repeated measurements within the same operator. Inter-operator repeatability was evaluated by calculating the CV based on the individual operator means (of the three replicates) for each of the measured angles. The normality assumption for all quantitative data was assessed by calculating descriptive statistics, plotting histograms, and performing the Anderson-Darling test in commercial software (MINITAB Statistical Software, Release 13.32, Minitab Inc, State College, Pennsylvania, USA). Data were descriptively presented using box plots in the ggplot2 package (Wickham, 2009) within R (R Development Core Team, 2017). Pearson's correlation and non-parametric Spearman's correlation coefficients and their corresponding 95% confidence intervals (CI) were estimated between the LI and quantitative data including the goniometer-based angles of the coxofemoral joints for normally distributed and non-normally distributed data, respectively. Correlations were estimated within commercial software (IBM SPSS Statistics Version 28, International Business Machines Corp., Armonk, NY, USA) with significance set as $P < 0.05$.

The degree of correlation was classified as follows:

Table 1. Scale used to indicate the agreement as it related to the correlation coefficients for inter- and intra-operator variability.

AGREEMENT	CORRELATION COEFFICIENT
Poor	<0.5
Moderate	0.51-0.7
Good	0.71-0.9
Very good	>0.91

6. RESULTS

This population consisted of 19 intact females and 14 intact males with BCS of 4-5 out of 9. The median age of the population was 9 months with a range of 5-10 months and an average weight of 49.3kgs (± 8.8kg).

Table 2. The descriptive data for the variables measured in 33 boerboels (66 hips). The data is presented as mean and range of the variables measured (LI with VBMDD and computer software; Norberg angle with computer software; Abduction and rotation angles (mean of 9 measurements) with mobile phone app ("measure app", iPhone, Apple) and wooden jig)

Variable	Mean (SD)	Median (Range)
Laxity index	0.52 (0.09)	0.53 (0.31 – 0.74)
Norberg angle	107.1 (4.9)	106.5 (92.9 – 116.4)
Abduction angle	67.2 (3.7)	67.7 (56.2 – 76.0)
External rotation angle	59.4 (6.2)	60.5 (44.6 – 72.0)
Internal rotation angle	50.2 (5.2)	50.1 (38.3 – 60.6)
Abduction operator C	69.3 (4.2)	70 (56.7 - 76.7)
External rotation operator C	58.0 (6.5)	57.8 (42.3 - 71.7)
Internal rotation operator C	48.8 (6.7)	48 (31.3 - 62.7)
Abduction operator A	67.0 (5.2)	67.2 (53.7 - 80.3)
External rotation operator A	58.5 (9.7)	58.8 (36.0 – 79.3)
Internal rotation operator A	48.9 (7.3)	49.5 (34.7 - 67.3)
Abduction operator R	65.4 (3.9)	65.7 (57.7 - 75.7)
External rotation operator R	61.7 (7.2)	61.8 (44.3 - 78.7)
Internal rotation operator R	52.9 (7.5)	54 (32.7 – 68.0)

Abbreviations: SD, standard deviation.

6.1 Weight

The average body weight of the study population was 49.3 kg (± 8.8 kg) (Table 2). Weight showed a significant negative correlation (-0.265, p = 0.031) with the LI (Table 3; Figure 8), indicating that higher weight was associated with lower laxity.

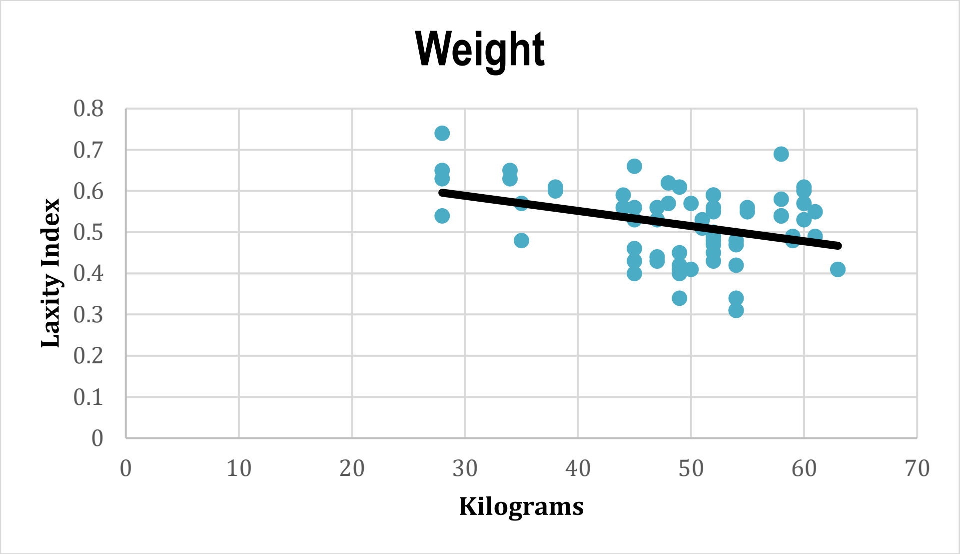

Figure 8. Scatter plot of weight of dogs (n= 33)

6.2 Measured angles and weight and their correlation with LI

Table 3. Correlation of LI with dog characteristics and mean values for the abduction angle, internal rotation angle, external rotation angle and Norberg angle over all replicates and operators.

Variable	Correlation* (95% CI)	P value
Abduction angle$_p$	0.061 (-0.183, 0.299)	0.624
Internal rotation angle$_p$	0.057 (-0.188, 0.295)	0.649
External rotation angle$_p$	0.207 (-0.037, 0.428)	0.095
Norberg angle$_r$	-0.037 (-0.283, 0.214) †	0.769
Age (months)	-0.096 (-0.337, 0.156)	0.441
Weight (kg)	-0.265 (-0.482, -0.017)	0.031

CI, confidence interval
* Pearson’s correlation coefficient unless otherwise noted
† Spearman’s rho correlation
Abduction angle$_p$, measured with the mobile app and wooden jig.
Internal rotation angle$_p$ measured with the mobile app and wooden jig.
External rotation angle$_p$, measured with the mobile app and wooden jig.
Norberg angle$_r$, measured on SVDE 2 radiographs and computer software.

6.2.1 Abduction angles

The mean abduction angle (measured with the mobile app and wooden jig) was 67.2 degrees (± 3.7 degrees). However, there was no significant correlation found between the measured abduction angle and the LI (Table 3; Figure 9).

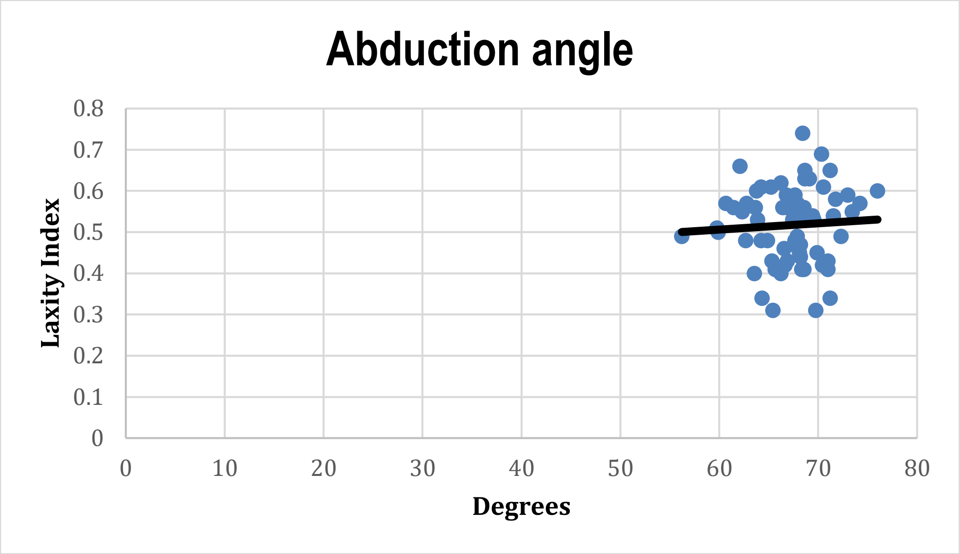

Figure 9. Scatter plot of the abduction angle as measured by 3 operators, using a mobile phone app and wooden jig. (n = 99)

6.2.2 External rotation angles

The mean external rotation angle (measured with the mobile app and wooden jig) was 59.4 degrees (± 6.2 degrees). A weak correlation (r = 0.207) was observed between the external rotation angle and the LI (Figure 10). It's important to note that while the correlation approached conventional levels of significance (p = 0.095), it did not reach statistical significance.

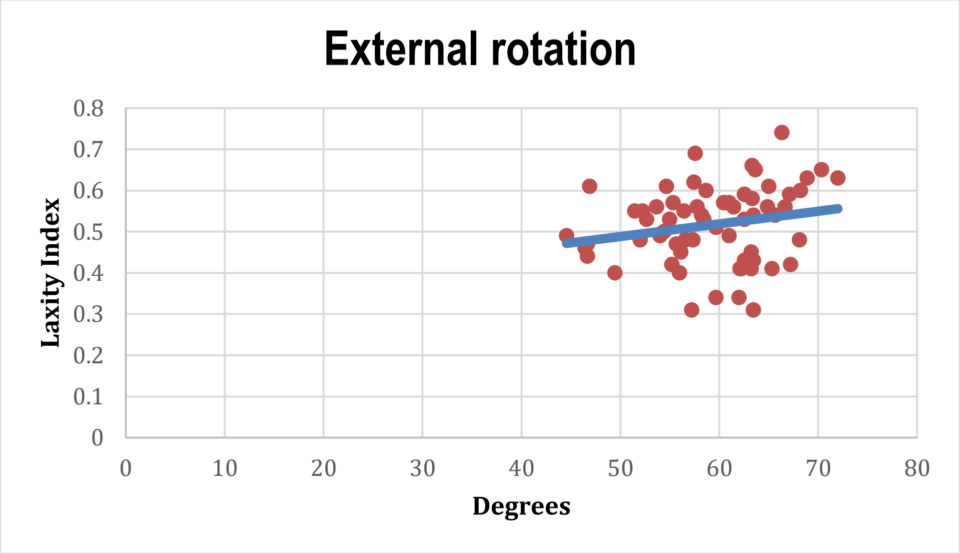

Figure 10. Scatter plot of the external rotation angle as measured by 3 operators, using the mobile phone app and wooden jig. (n = 99)

6.2.3 Internal rotation angles

The mean internal rotation angle (measured with the mobile app and wooden jig) was 50.2 degrees (± 5.2 degrees) (Table 2). No significant correlation was found between the measured internal rotation angle and the LI (Table 3; Figure 11).

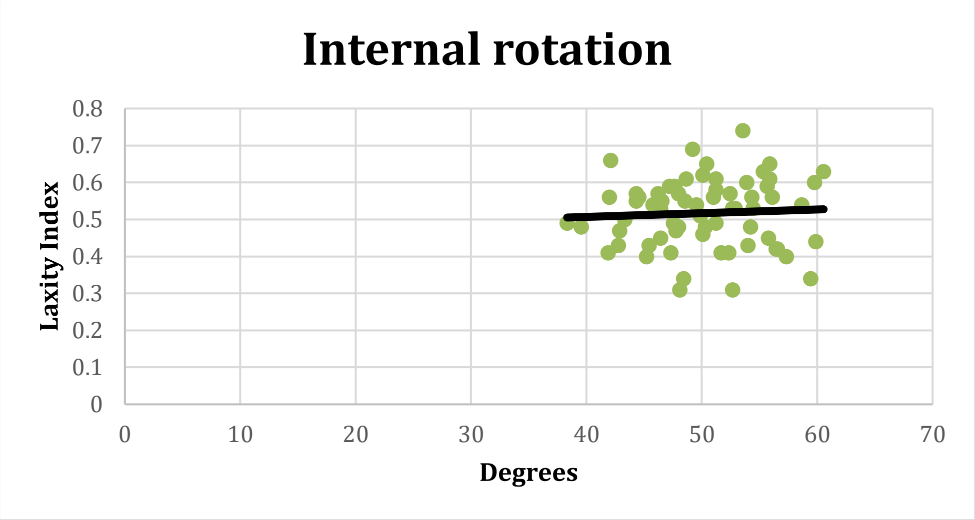

Figure 11. Scatter plot of the internal rotation angle as measured by 3 operators, using the mobile phone app and wooden jig. (n = 99)

6.2.4 Repeatability of measured angles

6.2.4.1 Intra-operator repeatability

The intra-operator variability for the measured angles ranged between 1.5 - 5.9. The largest variation was observed in the internal rotation forces (4.0 - 5.9), followed by external rotation forces (3.1 - 3.8), and abduction forces (1.5 - 2.5) (Table 4; Figure 13).

6.2.4.2 Inter-operator repeatability

The inter-operator variability for the measured angles ranged from 4.4 - 11.4. The highest variation was observed in the internal rotation forces (11.4 (6.7, 16.9) and 11.0 (5.8, 14.9)), followed by external rotation forces (10.9 (7.8, 12.7) and 9.1 (6.0, 12.7)), and abduction forces (4.4 (3.2, 5.6) and 4.4 (3.5, 6.4)) (Table 4; Figure 13).

6.3 Laxity index

LI was calculated on the radiographs, as described in the introduction (Broeckx et al., 2018), for each participant, with a median LI = 0.53 and a range of 0.31 - 0.74 (Table 2). The LI represents the degree of joint laxity in the relevant joint(s) and provides a quantitative measure of joint mobility.

6.4 Norberg angles

The mean NA was 107.1 degrees (± 4.9 degrees) (Table 3). No significant correlation was found between the measured NA and the LI (Table 3; Figure 12).

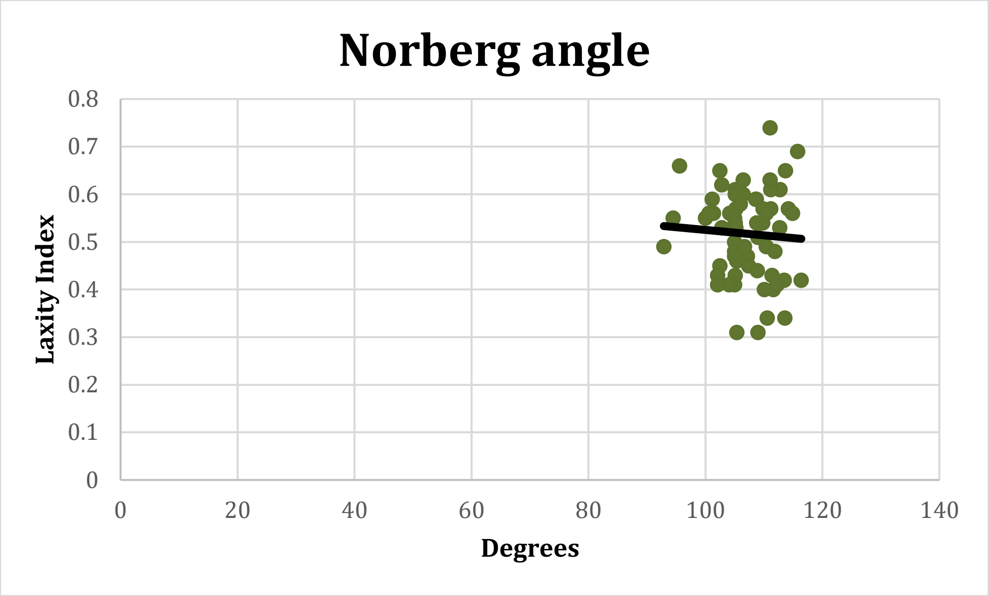

Figure 12. Scatter plot of the Norberg angle measured on SVDE view radiographs. (n = 66)

Table 4. Median (interquartile range) coefficient of variation as a measure of intra- operator and inter-operator repeatability.

Angle	Limb	Operator A	Operator C	Operator R	Inter-operator
Abduction	Left	2.2 (1.4, 2.7)	1.5 (0.9, 3.1)	2.3 (1.5, 3.4)	4.4 (3.2, 5.6)
	Right	2.4 (1.7, 3.2)	2.4 (1.5, 3.4)	2.5 (1.8, 3.5)	4.4 (3.5, 6.4)
External rotation	Left	3.1 (2.0, 4.3)	3.5 (2.8, 4.7)	3.2 (2.0, 4.2)	10.9 (7.8, 12.7)
	Right	3.2 (2.0, 5.9)	3.8 (2.5, 6.2)	3.2 (2.3, 5.2)	9.1 (6.0, 12.7)
Internal rotation	Left	5.1 (3.5,7.7)	4.4 (2.5, 5.8)	5.9 (3.2, 7.1)	11.4 (6.7, 16.9)
	Right	5.0 (2.7, 7.7)	4.9 (3.4, 7.0)	4.0 (2.4, 7.7)	11.0 (5.8, 14.9)

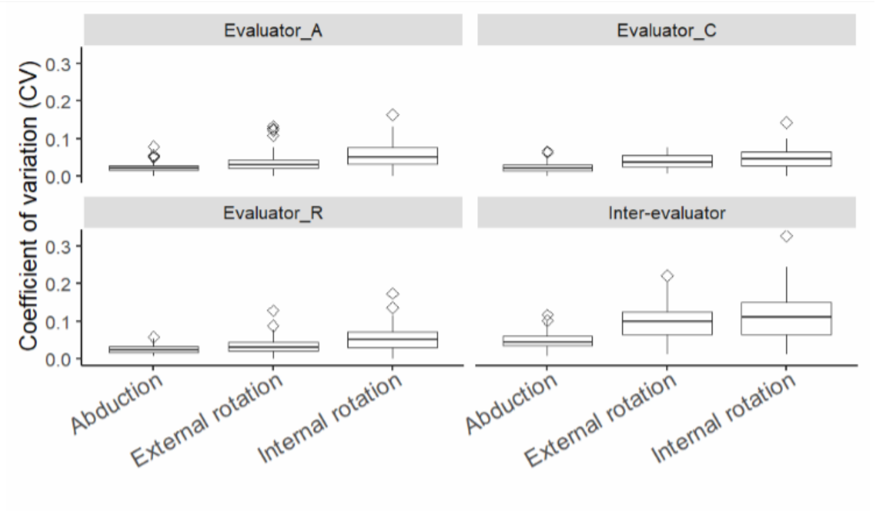

Figure 13. Descriptive presentation of intra-operator and inter-operator repeatability.

7. DISCUSSION

The foundation of this investigation lies in acknowledging that HJL is a fundamental precursor to the development of OA in dogs, as established by Smith et al. (1995). Ginja et al. (2015) found that the heritability of laxity underscores its significant role in canine health. This hereditary trait has prompted efforts, as suggested by Ginja et al. (2010), to integrate the use of joint DI into breeding programs with aim of reducing the incidence of CHD. In this context, the VMBDD emerges as a practical and cost-effective method for assessing hip laxity, chosen over alternatives like PennHIP™ due to its accessibility and simplicity.

The primary objective of this study was to determine if hip laxity could be accurately evaluated using a home-made apparatus based on an iPhone's “Measure” application. A comparison sought between a home-made jig together with a phone-based goniometer application against a more complex, validated radiological method currently in use, namely the VMBDD to measure HJL. The rationale was to investigate the utilisation of a mobile application to provide clinicians with a means to predict a patient's predisposition to OA at an early age when certain surgical interventions might still be an option. By establishing such a correlation, this study aimed to equip practitioners with a practical and accessible tool for identifying dogs at risk of hip dysplasia and through surgery or selecting correct breeding pools, enhancing the quality of life for these animals.

The notable observations in this study included recording a modest correlation between the external rotation angle and the LI. Despite 97% of the population falling into the "grey zone" for LI (> 0.3 and < 0.7), most individuals exhibited a NA exceeding 105 degrees, indicating favourable hip conformation and femur head coverage. Additionally, a noteworthy negative correlation emerged between body weight and LI.

The median age of the study population was 9 months, ranging from 5 to 10 months, notably younger than the average age for hip dysplasia certification, typically occurring between 12 to 24 months according to certification systems like BVA/KC and OFA (Appendix D). A key objective of this study was to assess dogs at a younger age, allowing for timely intervention options, such as a TPO/DPO or JPS. Therefore, selection of this specific age group was deliberate, considering potential external factors that could impact measurements in older dogs, including hip joint fibrosis, increased muscle mass, alterations in acetabulum and femur head conformation, and changes to the *ligamentum teres* with progressive OA. In this study population, LI values were distributed as follows: 0/66 (0%) with LI < 0.3, 65/66 (98.5%) with LI between 0.3 - 0.7, and 1/66 (1.5%) with LI > 0.7. The majority of the population fell into the "grey zone," which, as suggested by Lust et al. (1993), is not a reliable category for predicting individual outcomes regarding dysplastic hip conformation as dogs age.

The mean external rotation was 59.5 (± 6.2 degrees).

Despite a weak correlation with LI (0.207) and a p-value of 0.095, the sample size was insufficient to establish this correlation as statistically significant, potentially leading to a type 2 statistical error (i.e. accepting a false null hypothesis; failing to detect differences). The observed trend line on the scatter plot demonstrated a weak correlation, and a larger sample size might have provided a more robust evaluation. This result aligns with the clinical observation that dogs with high laxity tend to exhibit increased external rotation during femur head and neck ostectomy procedures, based on clinical experience. Further investigation with an adequately sized sample could clarify the potential correlation and its significance for estimating joint laxity and predicting susceptibility to CHD. The largest correlation observed was 0.207 and we would have needed to study 193 dogs in order for this level of correlation to have been statistically significant. The internal rotation angles found in this study (50.2 degrees) were very similar to the normal range (55 degrees) published by Petazzoni and Jaeger (2008). The external rotation angles found in this study (59.4 degrees) differed with less than 10 degrees from the normal range published by Petazzoni and Jaeger (2008), but these angles were measured with a universal plastic goniometer and published for German shepherd dogs and might not represent the true values for a population of dogs from different breeds.

This current study stemmed from observations during femur head and neck excisional arthroplasty, where maximal external rotation of the hip was essential for correct ostectomy and is only achieved after resection of the *ligamentum teres* (Harper, 2017). This highlights importance of the ligament in hip joint mechanics. This observation led to the study's initial design, aiming to establish a correlation between measured external rotation and hip LI.

The *ligamentum teres* is a key structure in maintaining the femur head position during the first 4 weeks of life (Lust and Summers, 1981). Joint effusion and *ligamentum teres* stretching contribute to joint laxity (Lust et al., 1985). The precise pathogenesis of these changes leading to laxity remains unclear. Subsequent degenerative changes involve thickening of the joint capsule, with dysplastic hips exhibiting a 5-7mm thick, stretched and inflamed joint capsule compared to the normal 1-2mm pale joint capsule (Riser, 1973). Additional changes include stretch or rupture of the ligament of the femoral head, thickening of the dorsal acetabular rim and femoral neck, and atrophy of the musculature (Adams et al., 1998).

As patients age, joint stability may improve or deteriorate, potentially resulting in a false interpretation of laxity based solely on radiographs due to secondary changes (Fries and Remedios, 1995).

The average NA was 107.1 (± 4.9 degrees), indicating what is traditionally considered favourable hip conformation, as values >105 suggest good femur head coverage by the acetabulum (Olsson, 1961). A notable 23% (15/66) of the hips in the population had an NA <105, implying that 77% of the population exhibited a configuration suggestive of good hip conformation based on NA alone. Despite a slight negative correlation observed in the scatter plot, there was no significant statistical correlation between the LI and NA.

The NA threshold of 105 degrees, while considered a valuable tool for selecting dogs susceptible to OA, cannot be solely relied upon due to the potential for false positives and false negatives within the population. This conclusion draws from extrapolated data from a study involving seven different dog breeds (Culp et al., 2006). Although boerboels were not part of the studied breeds, it's worth noting that this information might still be pertinent to this breed.

The NA measurement, conducted on SVDE positioned radiographs, may introduce a potential for overestimation of the NA. This could be attributed to tensioning of the joint capsule in this position, resulting in a false perception of congruity of the femur head and the acetabulum (Culp et al., 2006).

The study population, reflecting the conformation of the boerboel breed with an average body weight of 49.3 kg (range 28 – 63kg), demonstrated a notable negative correlation between weight and LI (-0.265, p = 0.031) during their highly active growth phase. The BCS of the animals was relatively similar. This finding suggests that heavier individuals in this breed may have lower laxity indices, potentially attributable to increased muscle mass adding to the stability of the coxofemoral joint. Further investigation into the observed weight-laxity correlation was prompted by the boerboels substantial pelvic muscle mass compared to breeds like the German shepherd dog. This negative relationship between weight and LI raises intriguing questions about the role of muscle mass in influencing hip joint stability. Plausible explanations include the significant muscle surrounding the joints impacting resistance during rotation and abduction angle measurements, potentially limiting the range of motion.

Importantly, the dogs' distal femoral circumference to operators' hand size ratio may have contributed to variations in the angles obtained. Grip strength, though not measured, could have influenced the operator's ability to hold the limb and apply rotational force. Despite these considerations, the negative correlation emphasizes that, within this population, heavier dogs (with similar BCS) tend to have lower laxity indices. All patients had a BCS of 4-5/9, indicating that the weight difference primarily stemmed from muscle and skeletal mass rather than adipose tissue. This finding aligns with a study suggesting that decreased pelvic muscle mass and smaller muscle fibre size in developing dogs are linked to the later development of CHD (Cardinet et al., 1997). Consequently, the results propose a potential avenue for physiotherapeutic interventions in patients with marked hip laxity, aiming to enhance muscle mass around the hips, decrease laxity, and preserve joint congruity.

In terms of intra-operator variability, the median CV ranged from 1.5 - 5.9 over the three operators and three angle measurements (Table 4). Measuring the abduction angle had the best repeatability while the highest CV occurred for measuring internal rotation. The median CV over all operators and limbs ranged from 4.0 - 5.9 for internal rotation forces, followed by external rotation ranging from 3.1 - 3.8 and abduction ranging from 1.5 - 2.5.

Regarding inter-operator variability, the median CV ranged from 4.4 - 11.4 over all angles and limbs. The greatest variation was observed in internal rotation forces, with median (interquartile range) values of 11.4 (6.7 - 16.9) and 11.0 (5.8 - 14.9) for left and right limbs respectively. Similarly, external rotation exhibited high variability, with values of 10.9 (7.8 - 12.7) and 9.1 (6.0 - 12.7) for left and right limbs respectively. The median CV for abduction was 4.4 (3.2 - 5.6) and 4.4 (3.5 - 6.4) for left and right limbs respectively. The inter-operator variability is therefore poor making it an unreliable way of testing hip joint angles. The mean CV in a study in 2016 for two smartphone-based goniometry of stifle angles were 7.37% and 7.57%, respectively. This study's findings were comparable with the study in 2016 in that the variability is too high to be reliable (Freund et al., 2016).

The poor intra and inter operator repeatability might be due to and unfixed position of the jig on the limb, lending itself to movement between measurements with manipulation of the leg. The forces generated by the operators might differ with each measurement as the forces were not standardised i.e. there was no cut-off point. The point used was maximal resistance but different grip strengths etc. could have had an influence on this critical end point as can muscle fatigue after multiple measurements. If there was a strong enough correlation found between laxity and internal rotation and a cut-off value could be determined, it would have been a poor test to use between examiners in a hospital, as the degree difference between examiners could mean the difference between a lax and non-lax hip. It could lend itself to many dogs being classified into either false low, moderate/grey, or in the high laxity groups. Based on a study performed on canine stifles in 2016 the smartphone-based goniometer was not accurate enough to measure the true angles of the stifle joints and that further studies were needed. The gold standard being used globally is the universal plastic goniometer and has a mean CV of 4.88% (Freund et al., 2016).

All patients were sampled from a single breeder with the same environment, exercise patterns, housing and feeding. As a result, the data from this study might not have represented or reflected the values of all boerboels. The variability between LI measurements was not measured. All the LI values were determined by the author and the same accounts for the measurement of the NA. A previous study has shown low inter and intra-observer variability when measuring LI (Bertal et al., 2018). Most of the hips (65/66) had a LI in the grey zone between 0.3 and 0.7, with only one hip having marked laxity (LI = 0.74). This population of dogs might not be representative of dogs in a clinical setup as interbreed variation exists.

Our study population had a mean LI of 0.52, in comparison to a recent study on 215 guide dogs where the mean population DI was 0.48. However, the population age in this study was 4 months, as opposed to our mean study population's age of 9 months. In the mentioned study, it was also discovered that 96% of hips with a DI < 0.58 at 4 months had an FCI score of A, B, or C at 12 months (Taroni et al., 2018). Despite our population being older than the referenced study, these findings were still promising as our population's values correlated well with those of the study.

According to the PennHIP database, the median DI for South African boerboel is 0.50, determined from a cross-section of 1752 dogs. Our study population had an LI of 0.52, which is similar to the breed average documented, indicating that this population is a representative sample of the breed under study.

This large intra and inter operator variation made the goniometer-based angle measurements an unreliable test to use and therefore can’t reliably be used to determine laxity of the canine hip.

From our data in this study the null hypothesis could not be rejected and therefore the measurements of joint angles with a smartphone goniometer were not a reliable or repeatable method of predicting joint laxity.

8. CONCLUSION

There was low correlation with angles measured by the operators and joint laxity except for external rotation which was mildly correlated (0.207) although not statistically significant (Table 4). There was a significant negative correlation between weight and joint laxity (-0.265, p = 0.031). As weight increased the LI decreased.

The data from this study revealed that mobile phone-based goniometry to measure external rotation, internal rotation and abduction angles was not repeatable between examiners as there was a 4.4 - 11.4 variance. Intra-operator measurements also had a variance of 1.5 - 4.4.

At present, considering all the data, we cannot recommend the use of a mobile phone goniometer for predicting joint laxity due to insufficient repeatability and correlation. While there may be some validity to the correlation observed between external rotation and laxity, a larger study population would be necessary to confirm this.

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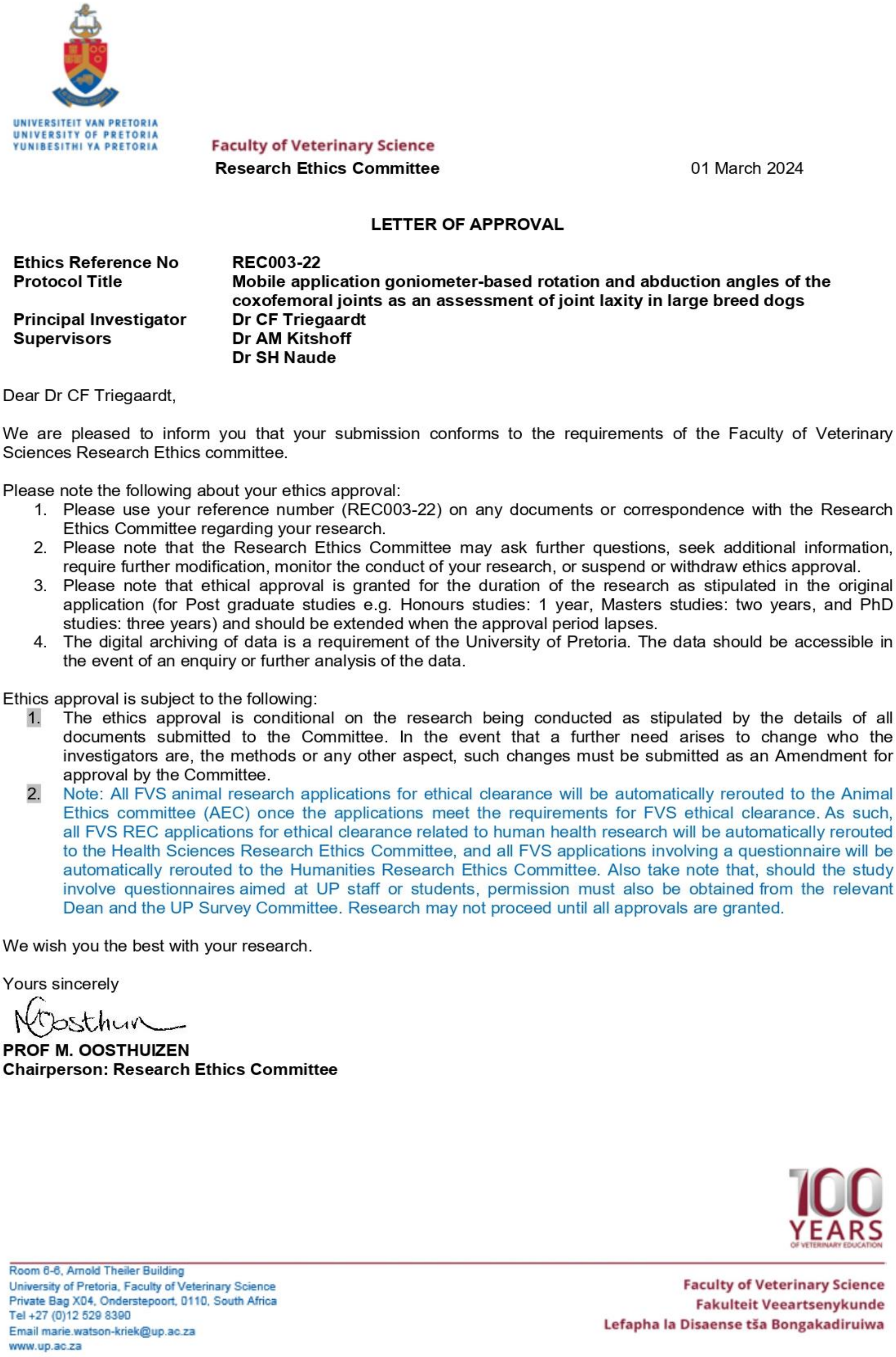
10. APPENDICES

Appendix A: Ethics approval documentation



UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Veterinary Science
Research Ethics Committee

01 March 2024

LETTER OF APPROVAL

Ethics Reference No	**REC003-22**
Protocol Title	**Mobile application goniometer-based rotation and abduction angles of the coxofemoral joints as an assessment of joint laxity in large breed dogs**
Principal Investigator	**Dr CF Triegaardt**
Supervisors	**Dr AM Kitshoff** **Dr SH Naude**

Dear Dr CF Triegaardt,

We are pleased to inform you that your submission conforms to the requirements of the Faculty of Veterinary Sciences Research Ethics committee.

Please note the following about your ethics approval:

1. Please use your reference number (REC003-22) on any documents or correspondence with the Research Ethics Committee regarding your research.
2. Please note that the Research Ethics Committee may ask further questions, seek additional information, require further modification, monitor the conduct of your research, or suspend or withdraw ethics approval.
3. Please note that ethical approval is granted for the duration of the research as stipulated in the original application (for Post graduate studies e.g. Honours studies: 1 year, Masters studies: two years, and PhD studies: three years) and should be extended when the approval period lapses.
4. The digital archiving of data is a requirement of the University of Pretoria. The data should be accessible in the event of an enquiry or further analysis of the data.

Ethics approval is subject to the following:

1. The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.
2. Note: All FVS animal research applications for ethical clearance will be automatically rerouted to the Animal Ethics committee (AEC) once the applications meet the requirements for FVS ethical clearance. As such, all FVS REC applications for ethical clearance related to human health research will be automatically rerouted to the Health Sciences Research Ethics Committee, and all FVS applications involving a questionnaire will be automatically rerouted to the Humanities Research Ethics Committee. Also take note that, should the study involve questionnaires aimed at UP staff or students, permission must also be obtained from the relevant Dean and the UP Survey Committee. Research may not proceed until all approvals are granted.

We wish you the best with your research.

Yours sincerely

PROF M. OOSTHUIZEN
Chairperson: Research Ethics Committee

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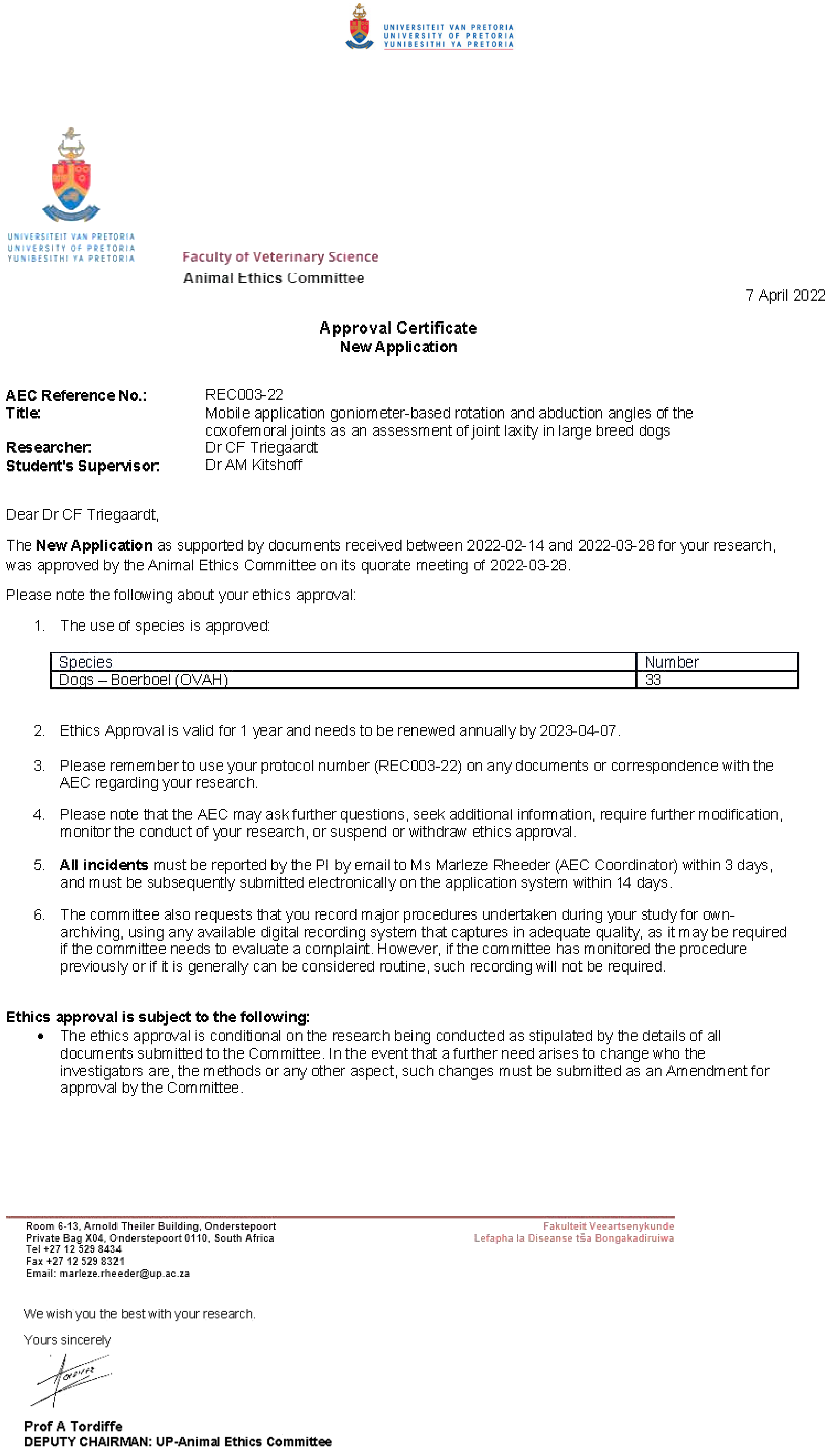UNIVERSITEIT VAN PRETORIA
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Faculty of Veterinary Science
Animal Ethics Committee

7 April 2022

Approval Certificate
New Application

AEC Reference No.: REC003-22
Title: Mobile application goniometer-based rotation and abduction angles of the coxofemoral joints as an assessment of joint laxity in large breed dogs
Researcher: Dr CF Triegaardt
Student's Supervisor: Dr AM Kitshoff

Dear Dr CF Triegaardt,

The **New Application** as supported by documents received between 2022-02-14 and 2022-03-28 for your research, was approved by the Animal Ethics Committee on its quorate meeting of 2022-03-28.

Please note the following about your ethics approval:

1. The use of species is approved:

Species	Number
Dogs – Boerboel (OVAH)	33

2. Ethics Approval is valid for 1 year and needs to be renewed annually by 2023-04-07.
3. Please remember to use your protocol number (REC003-22) on any documents or correspondence with the AEC regarding your research.
4. Please note that the AEC may ask further questions, seek additional information, require further modification, monitor the conduct of your research, or suspend or withdraw ethics approval.
5. **All incidents** must be reported by the PI by email to Ms Marleze Rheeder (AEC Coordinator) within 3 days, and must be subsequently submitted electronically on the application system within 14 days.
6. The committee also requests that you record major procedures undertaken during your study for own-archiving, using any available digital recording system that captures in adequate quality, as it may be required if the committee needs to evaluate a complaint. However, if the committee has monitored the procedure previously or if it is generally can be considered routine, such recording will not be required.

Ethics approval is subject to the following:

- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

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Fakulteit Veeartsenykunde
Lefapha la Disaense tša Bongakadiruiwa

We wish you the best with your research.

Yours sincerely

Prof A Tordiffe
DEPUTY CHAIRMAN: UP-Animal Ethics Committee

agriculture, land reform
& rural development

Department:
Agriculture, Land Reform and Rural Development
REPUBLIC OF SOUTH AFRICA

Directorate Animal Health, Department of Agriculture, Land Reform and Rural Development
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Reference: 12/11/1/12 (2273JD)

Responsible person: Dr Christiaan Triegaardt
Institution: Johannesburg Specialist Veterinary centre, 63 Kayburne Avenue, Randpark Ridge, Johannesburg, 2156
Email: christiaantriegaardt@gmail.com

Dear Dr Triegaardt,

PERMISSION TO DO RESEARCH IN TERMS OF SECTION 20 OF THE ANIMAL DISEASES ACT, 1984 (ACT NO 35 OF 1984)

Title of research project / study: "Mobile application goniometer-based rotation and abduction angles of the coxofemoral joints as an assessment of joint laxity in large breed dogs"

Your application dated 7 January 2022, requesting permission under Section 20 of the Animal Diseases Act, 1984 (Act No 35 of 1984) to perform the research project or study stipulated above, refers.

Based on the information provided in your application, your study does not fall under the scope of Section 20 of the Animal Diseases Act, 1984 (Act no 35 of 1984) provided that statements 1 to 7 hereunder (as applicable) are, and remain, accurate in relation to your research project.

Should the accuracy of any of the statements 1 to 7 hereunder change in any way in relation to your project, you are required to inform the Section 20 Secretariat. You may not proceed with any activities until written permission to do so have been granted by the National Director of Animal Health.

1. No work will be done with any controlled and/or notifiable animal diseases (list of diseases can be obtained from this office), which also includes any animal diseases which do not occur in South Africa;
2. No work will be done with any pathogen, disease, vector, micro-organism, parasite or animal material (including vaccine, serum, test kit, toxin, anti-toxin, antigen, biological product which consists or originates from a micro-organism, animal or parasite);
3. No imported material of animal origin or imported animal pathogens will be utilized in the study;
4. No samples that originate from a biobank will be used in the study;
5. No clinical studies will be performed in the target species, either in a laboratory or in the field;
6. The areas where the samples are to be collected are not under restriction for controlled or notifiable animal diseases to which the species of animal, from which the samples are obtained, is susceptible;
7. No samples or products will be obtained from an abattoir.

Written permission from the Director of Animal Health must be obtained prior to any deviation from the conditions. Application must be sent in writing to MarnaL@dalrrd.gov.za Failure to obtain written permission as above may be considered a contravention of the Animal Diseases Act, 1984 (Act no 35 of 1984).

Kind regards,

Dr Mpho Maja
DIRECTOR: ANIMAL HEALTH
Date: 2022 -01- 11

Appendix B: Owner consent form

Owner detail

Surname		Name	
Company		Tel	
Email address		Send me the radiographs	Y / N

Dog details (all dogs attached to addendum A)

Name		Weight	
Microchip nr		Breed	
Sex	M / F / N	DOB	

I ____ hereby give consent that the above-mentioned dog may be radiographed and sedated as part of the study titled "Rotation and abduction angles of the canine coxofemoral joint as predictors of joint laxity". I am responsible for and able to give informed consent for the above-mentioned dog.

I am aware that the study does produce a hip dysplasia grading report but that the radiographs taken can be submitted for hip dysplasia grading at my expense. The laxity index once available will be provided to the owner if requested. The radiographs are batch processed for the laxity and as such will take time before it becomes available. Outcome data of the patient will be discussed with me.

I am aware that the patient will receive deep sedation to obtain these radiographs.

I have been made aware of the risks of sedation.

I have the right to withdraw the patient at any time.

Signature	________________________ Person responsible	____________ Date	

Appendix C: Data capture sheet example

(kg- kilogram; Dom – domitor; Dol – dolorex; Prop – propofol; Anti – antisedan)

Patient Name				
Microchip				
Age	9M			
Sex	F			
BCS	3			
Weight (kg)	49			
Sedation	Dom Dol Prop Anti			
LAXITY INDEX (LI)	L	0,59		
	R	0,48		
NORBERG ANGLE (NA)	L	107		
	R	109		
Operator 1 C				
Abduction angle	L	74	76	74
	R	70	66	66
External rotation angle	L	52	54	54
	R	60	68	64
Internal rotation angle	L	46	49	47
	R	34	36	36
Operator 2 A				
Abduction angle	L	72	74	68
	R	66	68	68
External rotation angle	L	68	64	64
	R	61	68	68
Internal rotation angle	L	48	37	45
	R	52	51	55
Operator 3 R				
Abduction angle	L	67	67	69
	R	61	62	64
External rotation angle	L	56	61	64
	R	66	65	68
Internal rotation angle	L	53	58	53
	R	57	54	51

Appendix D: Hip scoring systems

CHD scoring systems

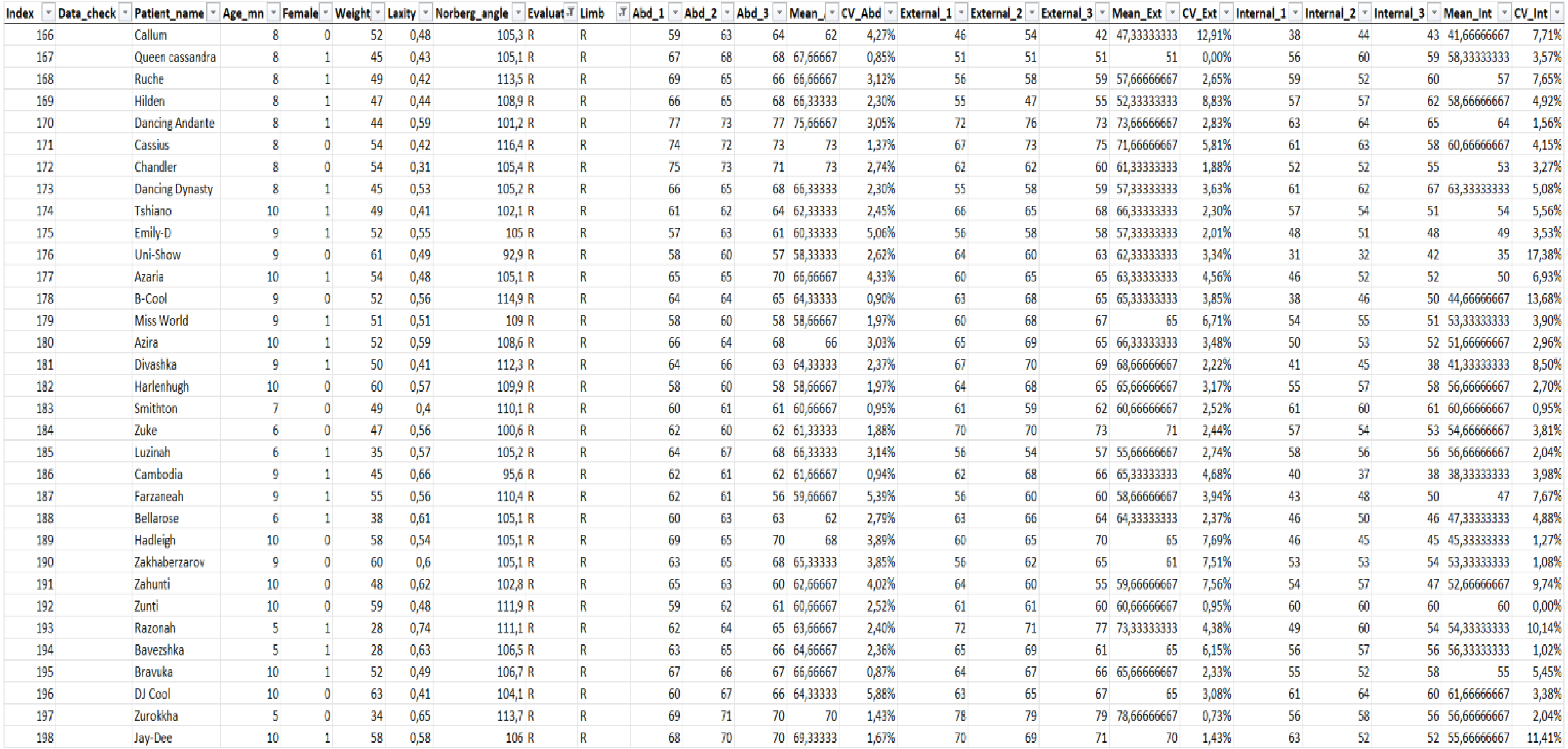
OFA	**FCI** (Europe)	**BVA/KC** (sum of both hips)
Excellent • Superior conformation • Almost complete coverage of femoral head	A-1	0-4
Good • Slightly less than superior conformation • Good coverage of the femoral head	A-2	5-10
Fair • Minor irregularities of the hip • Minor joint incongruency • Slightly shallow acetabulum	B-1	11-18
Borderline • No consensus on dysplastic vs normal • Greater incongruency than a “fair” hip • No OA changes • Anatomic variant that cannot be distinguished from OA	B-2	19-25
Mild • Significant subluxation, partial coverage femoral head • Shallow acetabulum • Usually no arthritic changes	C	26-35
Moderate • More significant subluxation, femoral head barely covered • OA/remodeling/sclerosis along the femoral neck, head and acetabular rim	D	36-50
Severe • Severe subluxation, part or complete loss of coverage of the femoral head • Large amounts of OA	E	51-106

BVA/KC hip grading out of 106

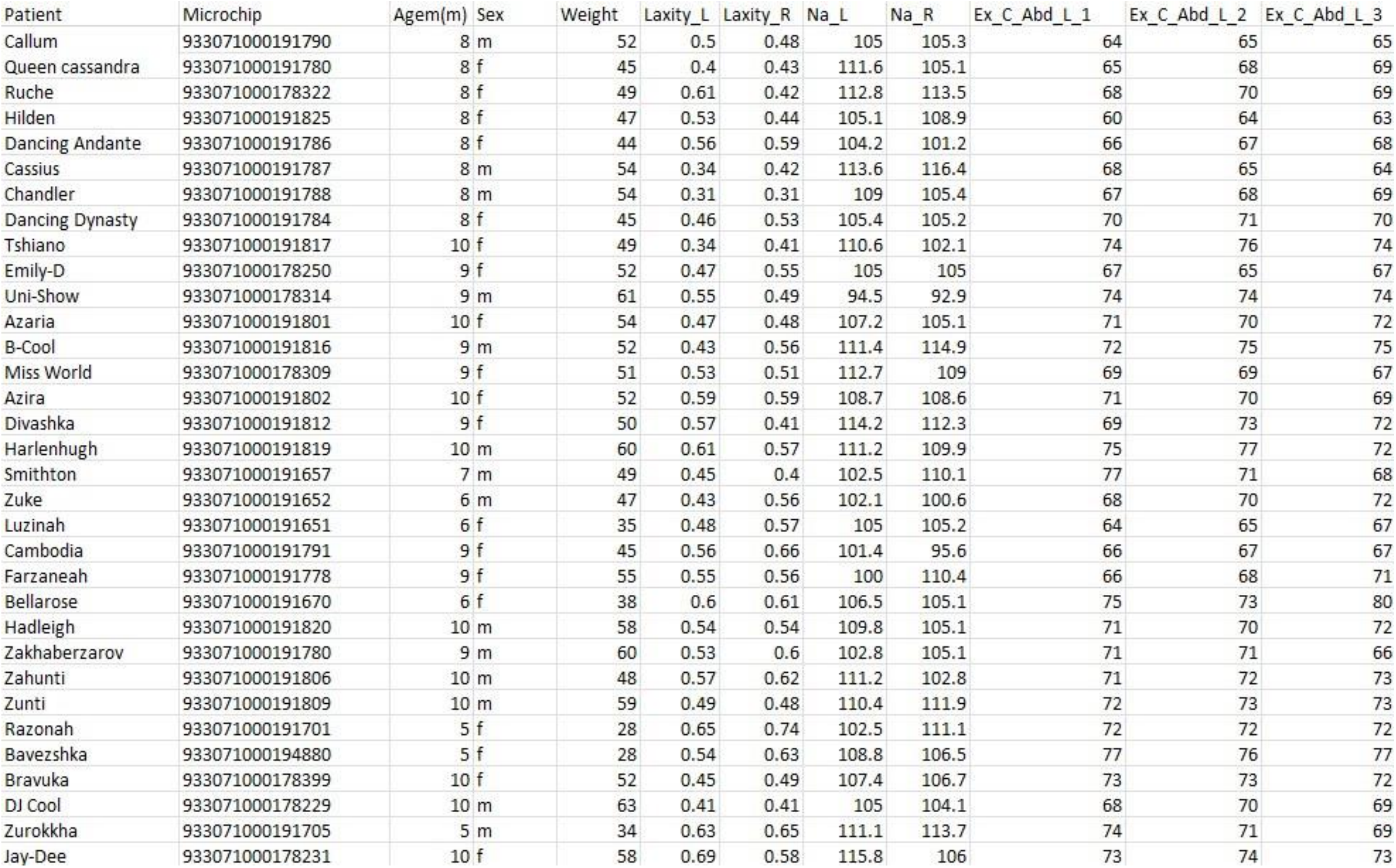
BVA/KC

Hip joint	**Score**
Norberg angle	0-6
Subluxation	0-6
Cranial acetabular edge	0-6
Dorsal acetabular edge	0-6
Cranial effective acetabular rim	0-6
Acetabular fossa	0-6
Caudal acetabular edge	0-5
Femoral head/neck exostosis	0-6
Femoral head recontouring	0-6

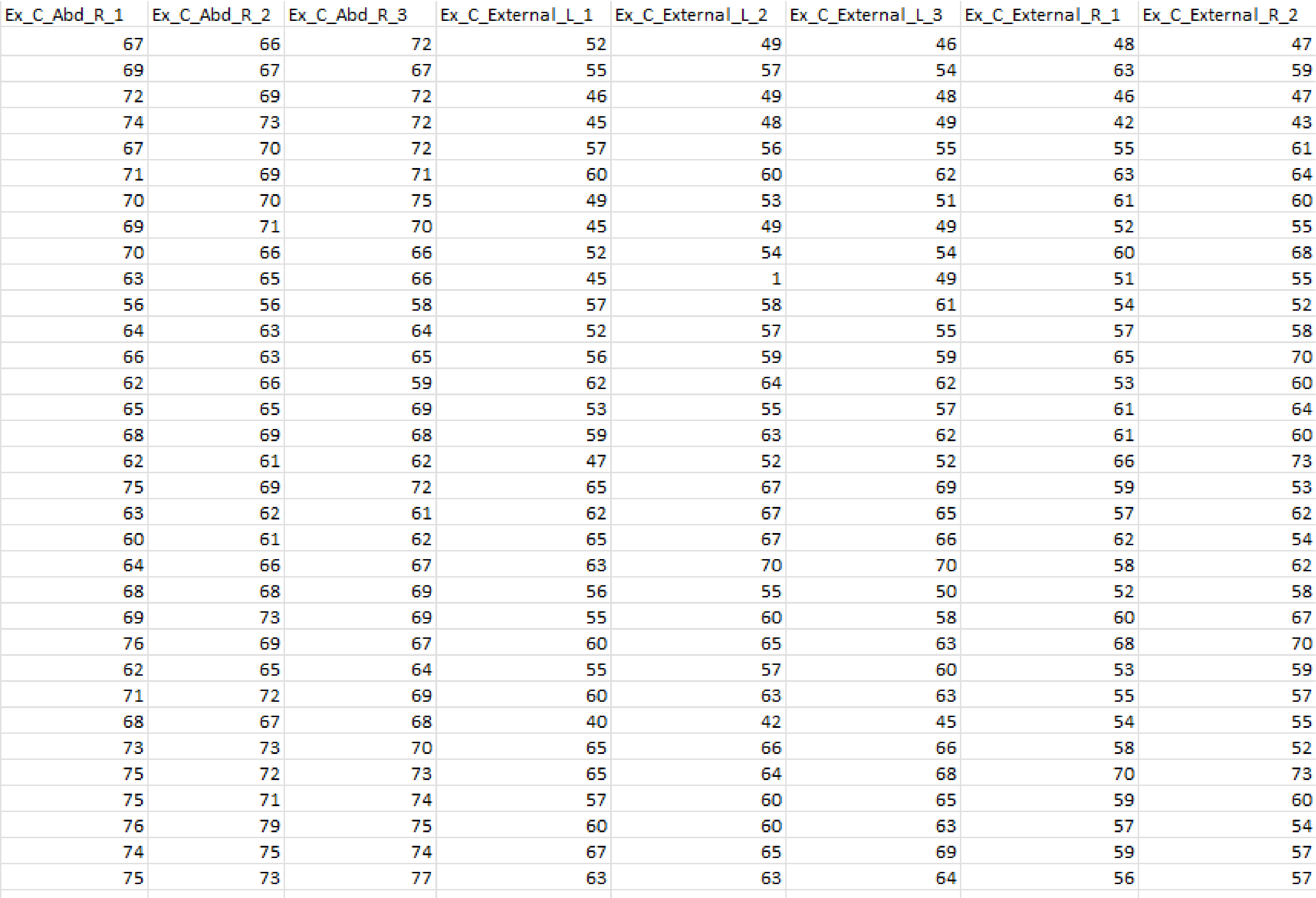
Appendix E: Excel data sheets



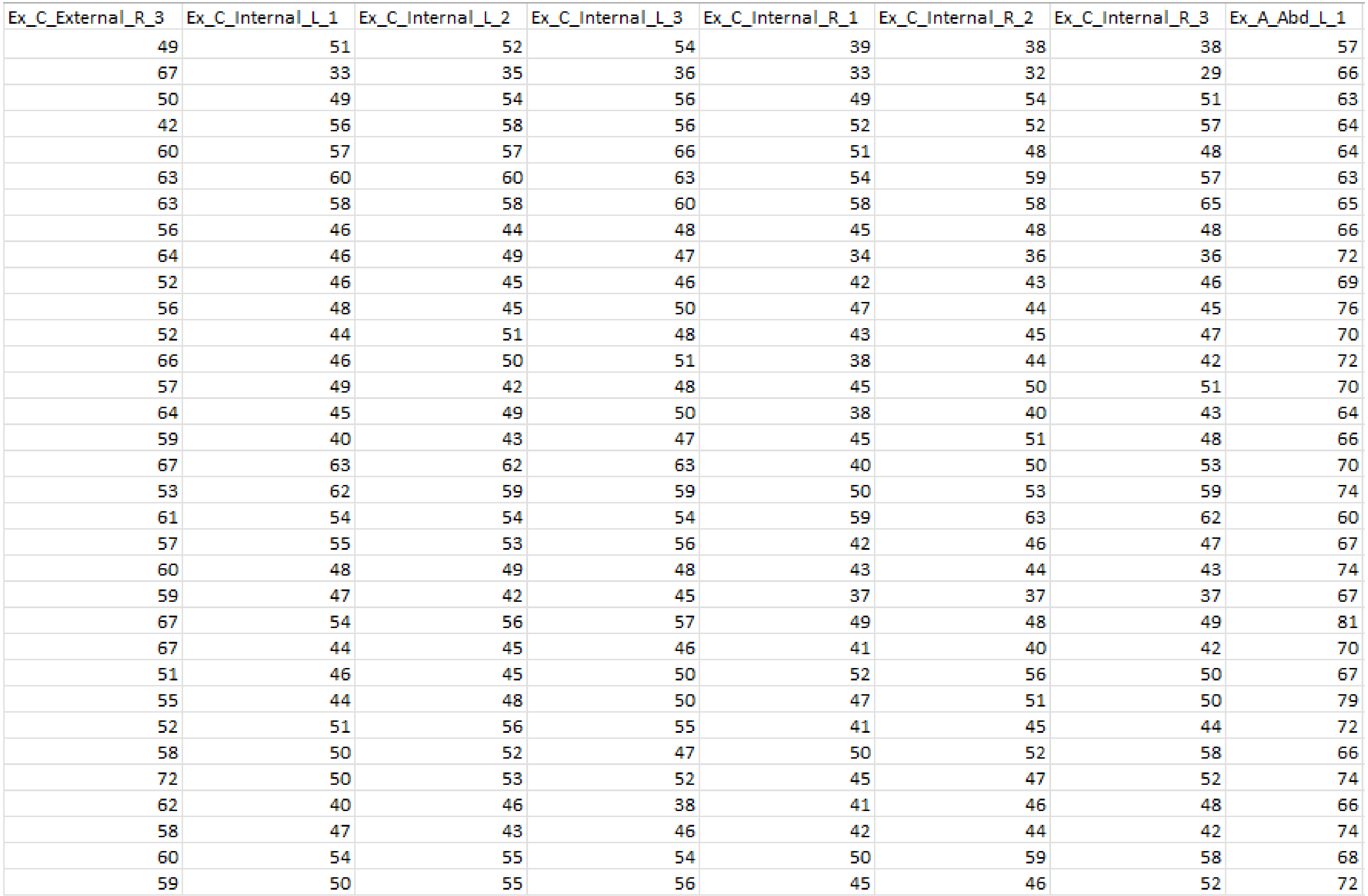
Index	Data_check	Patient_name	Age_mn	Female	Weight	Laxity	Norberg_angle	Evaluat	Limb	Abd_1	Abd_2	Abd_3	Mean_	CV_Abd	External_1	External_2	External_3	Mean_Ext	CV_Ext	Internal_1	Internal_2	Internal_3	Mean_Int	CV_Int
166		Callum	8	0	52	0,48	105,3	R	R	59	63	64	62	4,27%	46	54	42	47,33333333	12,91%	38	44	43	41,66666667	7,71%
167		Queen cassandra	8	1	45	0,43	105,1	R	R	67	68	68	67,66667	0,85%	51	51	51	51	0,00%	56	60	59	58,33333333	3,57%
168		Ruche	8	1	49	0,42	113,5	R	R	69	65	66	66,66667	3,12%	56	58	59	57,66666667	2,65%	59	52	60	57	7,65%
169		Hilden	8	1	47	0,44	108,9	R	R	66	65	68	66,33333	2,30%	55	47	55	52,33333333	8,83%	57	57	62	58,66666667	4,92%
170		Dancing Andante	8	1	44	0,59	101,2	R	R	77	73	77	75,66667	3,05%	72	76	73	73,66666667	2,83%	63	64	65	64	1,56%
171		Cassius	8	0	54	0,42	116,4	R	R	74	72	73	73	1,37%	67	73	75	71,66666667	5,81%	61	63	58	60,66666667	4,15%
172		Chandler	8	0	54	0,31	105,4	R	R	75	73	71	73	2,74%	62	62	60	61,33333333	1,88%	52	52	55	53	3,27%
173		Dancing Dynasty	8	1	45	0,53	105,2	R	R	66	65	68	66,33333	2,30%	55	58	59	57,33333333	3,63%	61	62	67	63,33333333	5,08%
174		Tshiano	10	1	49	0,41	102,1	R	R	61	62	64	62,33333	2,45%	66	65	68	66,33333333	2,30%	57	54	51	54	5,56%
175		Emily-D	9	1	52	0,55	105	R	R	57	63	61	60,33333	5,06%	56	58	58	57,33333333	2,01%	48	51	48	49	3,53%
176		Uni-Show	9	0	61	0,49	92,9	R	R	58	60	57	58,33333	2,62%	64	60	63	62,33333333	3,34%	31	32	42	35	17,38%
177		Azaria	10	1	54	0,48	105,1	R	R	65	65	70	66,66667	4,33%	60	65	65	63,33333333	4,56%	46	52	52	50	6,93%
178		B-Cool	9	0	52	0,56	114,9	R	R	64	64	65	64,33333	0,90%	63	68	65	65,33333333	3,85%	38	46	50	44,66666667	13,68%
179		Miss World	9	1	51	0,51	109	R	R	58	60	58	58,66667	1,97%	60	68	67	65	6,71%	54	55	51	53,33333333	3,90%
180		Azira	10	1	52	0,59	108,6	R	R	66	64	68	66	3,03%	65	69	65	66,33333333	3,48%	50	53	52	51,66666667	2,96%
181		Divashka	9	1	50	0,41	112,3	R	R	64	66	63	64,33333	2,37%	67	70	69	68,66666667	2,22%	41	45	38	41,33333333	8,50%
182		Harlenhugh	10	0	60	0,57	109,9	R	R	58	60	58	58,66667	1,97%	64	68	65	65,66666667	3,17%	55	57	58	56,66666667	2,70%
183		Smithton	7	0	49	0,4	110,1	R	R	60	61	61	60,66667	0,95%	61	59	62	60,66666667	2,52%	61	60	61	60,66666667	0,95%
184		Zuke	6	0	47	0,56	100,6	R	R	62	60	62	61,33333	1,88%	70	70	73	71	2,44%	57	54	53	54,66666667	3,81%
185		Luzinah	6	1	35	0,57	105,2	R	R	64	67	68	66,33333	3,14%	56	54	57	55,66666667	2,74%	58	56	56	56,66666667	2,04%
186		Cambodia	9	1	45	0,66	95,6	R	R	62	61	62	61,66667	0,94%	62	68	66	65,33333333	4,68%	40	37	38	38,33333333	3,98%
187		Farzaneah	9	1	55	0,56	110,4	R	R	62	61	56	59,66667	5,39%	56	60	60	58,66666667	3,94%	43	48	50	47	7,67%
188		Bellarose	6	1	38	0,61	105,1	R	R	60	63	63	62	2,79%	63	66	64	64,33333333	2,37%	46	50	46	47,33333333	4,88%
189		Hadleigh	10	0	58	0,54	105,1	R	R	69	65	70	68	3,89%	60	65	70	65	7,69%	46	45	45	45,33333333	1,27%
190		Zakhaberzarov	9	0	60	0,6	105,1	R	R	63	65	68	65,33333	3,85%	56	62	65	61	7,51%	53	53	54	53,33333333	1,08%
191		Zahunti	10	0	48	0,62	102,8	R	R	65	63	60	62,66667	4,02%	64	60	55	59,66666667	7,56%	54	57	47	52,66666667	9,74%
192		Zunti	10	0	59	0,48	111,9	R	R	59	62	61	60,66667	2,52%	61	61	60	60,66666667	0,95%	60	60	60	60	0,00%
193		Razonah	5	1	28	0,74	111,1	R	R	62	64	65	63,66667	2,40%	72	71	77	73,33333333	4,38%	49	60	54	54,33333333	10,14%
194		Bavezshka	5	1	28	0,63	106,5	R	R	63	65	66	64,66667	2,36%	65	69	61	65	6,15%	56	57	56	56,33333333	1,02%
195		Bravuka	10	1	52	0,49	106,7	R	R	67	66	67	66,66667	0,87%	64	67	66	65,66666667	2,33%	55	52	58	55	5,45%
196		DJ Cool	10	0	63	0,41	104,1	R	R	60	67	66	64,33333	5,88%	63	65	67	65	3,08%	61	64	60	61,66666667	3,38%
197		Zurokkha	5	0	34	0,65	113,7	R	R	69	71	70	70	1,43%	78	79	79	78,66666667	0,73%	56	58	56	56,66666667	2,04%
198		Jay-Dee	10	1	58	0,58	106	R	R	68	70	70	69,33333	1,67%	70	69	71	70	1,43%	63	52	52	55,66666667	11,41%



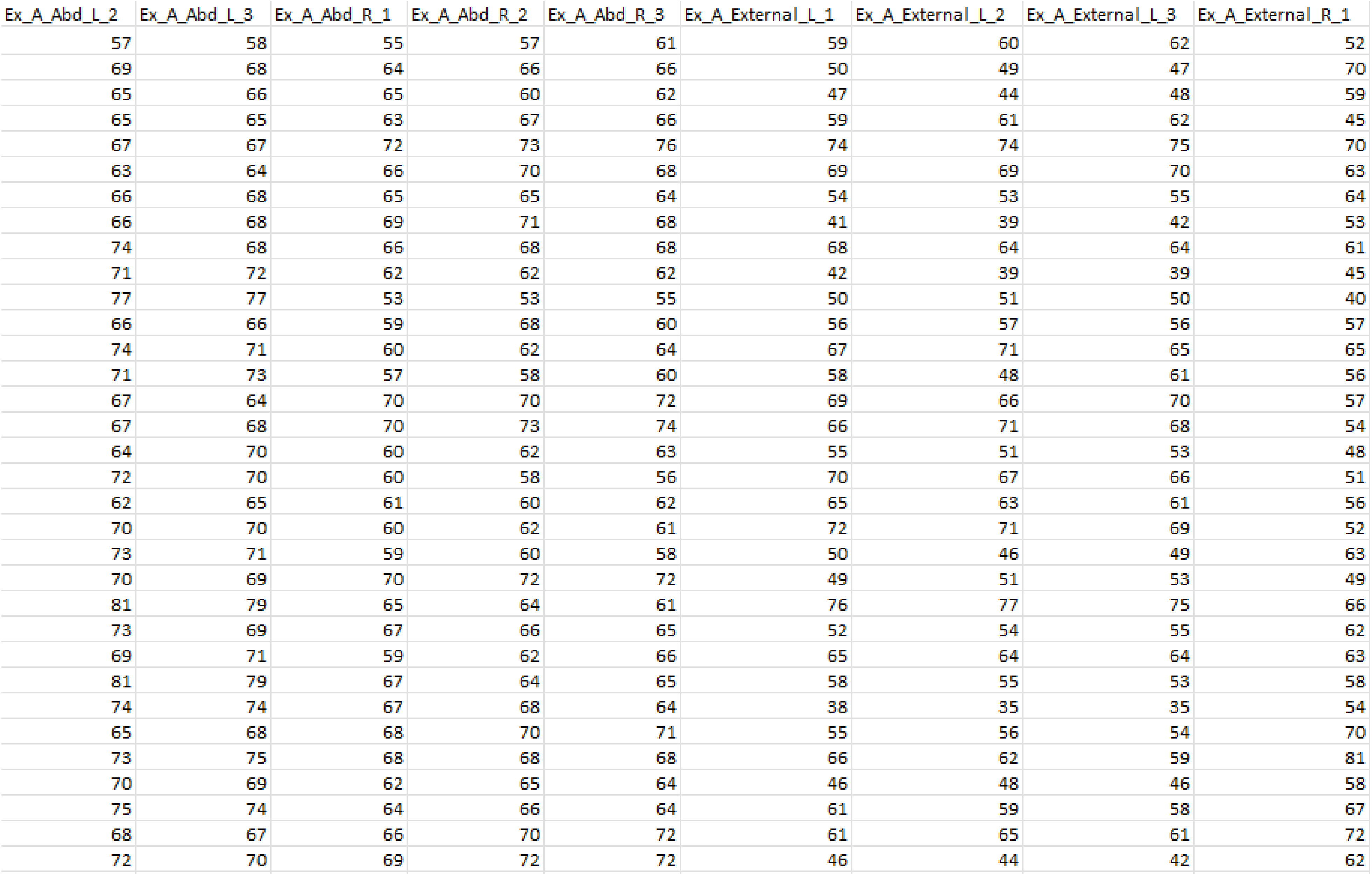
Patient	Microchip	Agem(m)	Sex	Weight	Laxity_L	Laxity_R	Na_L	Na_R	Ex_C_Abd_L_1	Ex_C_Abd_L_2	Ex_C_Abd_L_3
Callum	933071000191790	8	m	52	0.5	0.48	105	105.3	64	65	65
Queen cassandra	933071000191780	8	f	45	0.4	0.43	111.6	105.1	65	68	69
Ruche	933071000178322	8	f	49	0.61	0.42	112.8	113.5	68	70	69
Hilden	933071000191825	8	f	47	0.53	0.44	105.1	108.9	60	64	63
Dancing Andante	933071000191786	8	f	44	0.56	0.59	104.2	101.2	66	67	68
Cassius	933071000191787	8	m	54	0.34	0.42	113.6	116.4	68	65	64
Chandler	933071000191788	8	m	54	0.31	0.31	109	105.4	67	68	69
Dancing Dynasty	933071000191784	8	f	45	0.46	0.53	105.4	105.2	70	71	70
Tshiano	933071000191817	10	f	49	0.34	0.41	110.6	102.1	74	76	74
Emily-D	933071000178250	9	f	52	0.47	0.55	105	105	67	65	67
Uni-Show	933071000178314	9	m	61	0.55	0.49	94.5	92.9	74	74	74
Azaria	933071000191801	10	f	54	0.47	0.48	107.2	105.1	71	70	72
B-Cool	933071000191816	9	m	52	0.43	0.56	111.4	114.9	72	75	75
Miss World	933071000178309	9	f	51	0.53	0.51	112.7	109	69	69	67
Azira	933071000191802	10	f	52	0.59	0.59	108.7	108.6	71	70	69
Divashka	933071000191812	9	f	50	0.57	0.41	114.2	112.3	69	73	72
Harlenhugh	933071000191819	10	m	60	0.61	0.57	111.2	109.9	75	77	72
Smithton	933071000191657	7	m	49	0.45	0.4	102.5	110.1	77	71	68
Zuke	933071000191652	6	m	47	0.43	0.56	102.1	100.6	68	70	72
Luzinah	933071000191651	6	f	35	0.48	0.57	105	105.2	64	65	67
Cambodia	933071000191791	9	f	45	0.56	0.66	101.4	95.6	66	67	67
Farzaneah	933071000191778	9	f	55	0.55	0.56	100	110.4	66	68	71
Bellarose	933071000191670	6	f	38	0.6	0.61	106.5	105.1	75	73	80
Hadleigh	933071000191820	10	m	58	0.54	0.54	109.8	105.1	71	70	72
Zakhaberzarov	933071000191780	9	m	60	0.53	0.6	102.8	105.1	71	71	66
Zahunti	933071000191806	10	m	48	0.57	0.62	111.2	102.8	71	72	73
Zunti	933071000191809	10	m	59	0.49	0.48	110.4	111.9	72	73	73
Razonah	933071000191701	5	f	28	0.65	0.74	102.5	111.1	72	72	72
Bavezshka	933071000194880	5	f	28	0.54	0.63	108.8	106.5	77	76	77
Bravuka	933071000178399	10	f	52	0.45	0.49	107.4	106.7	73	73	72
DJ Cool	933071000178229	10	m	63	0.41	0.41	105	104.1	68	70	69
Zurokkha	933071000191705	5	m	34	0.63	0.65	111.1	113.7	74	71	69
Jay-Dee	933071000178231	10	f	58	0.69	0.58	115.8	106	73	74	73



Ex_C_Abd_R_1	Ex_C_Abd_R_2	Ex_C_Abd_R_3	Ex_C_External_L_1	Ex_C_External_L_2	Ex_C_External_L_3	Ex_C_External_R_1	Ex_C_External_R_2
67	66	72	52	49	46	48	47
69	67	67	55	57	54	63	59
72	69	72	46	49	48	46	47
74	73	72	45	48	49	42	43
67	70	72	57	56	55	55	61
71	69	71	60	60	62	63	64
70	70	75	49	53	51	61	60
69	71	70	45	49	49	52	55
70	66	66	52	54	54	60	68
63	65	66	45	1	49	51	55
56	56	58	57	58	61	54	52
64	63	64	52	57	55	57	58
66	63	65	56	59	59	65	70
62	66	59	62	64	62	53	60
65	65	69	53	55	57	61	64
68	69	68	59	63	62	61	60
62	61	62	47	52	52	66	73
75	69	72	65	67	69	59	53
63	62	61	62	67	65	57	62
60	61	62	65	67	66	62	54
64	66	67	63	70	70	58	62
68	68	69	56	55	50	52	58
69	73	69	55	60	58	60	67
76	69	67	60	65	63	68	70
62	65	64	55	57	60	53	59
71	72	69	60	63	63	55	57
68	67	68	40	42	45	54	55
73	73	70	65	66	66	58	52
75	72	73	65	64	68	70	73
75	71	74	57	60	65	59	60
76	79	75	60	60	63	57	54
74	75	74	67	65	69	59	57
75	73	77	63	63	64	56	57



Ex_C_External_R_3	Ex_C_Internal_L_1	Ex_C_Internal_L_2	Ex_C_Internal_L_3	Ex_C_Internal_R_1	Ex_C_Internal_R_2	Ex_C_Internal_R_3	Ex_A_Abd_L_1
49	51	52	54	39	38	38	57
67	33	35	36	33	32	29	66
50	49	54	56	49	54	51	63
42	56	58	56	52	52	57	64
60	57	57	66	51	48	48	64
63	60	60	63	54	59	57	63
63	58	58	60	58	58	65	65
56	46	44	48	45	48	48	66
64	46	49	47	34	36	36	72
52	46	45	46	42	43	46	69
56	48	45	50	47	44	45	76
52	44	51	48	43	45	47	70
66	46	50	51	38	44	42	72
57	49	42	48	45	50	51	70
64	45	49	50	38	40	43	64
59	40	43	47	45	51	48	66
67	63	62	63	40	50	53	70
53	62	59	59	50	53	59	74
61	54	54	54	59	63	62	60
57	55	53	56	42	46	47	67
60	48	49	48	43	44	43	74
59	47	42	45	37	37	37	67
67	54	56	57	49	48	49	81
67	44	45	46	41	40	42	70
51	46	45	50	52	56	50	67
55	44	48	50	47	51	50	79
52	51	56	55	41	45	44	72
58	50	52	47	50	52	58	66
72	50	53	52	45	47	52	74
62	40	46	38	41	46	48	66
58	47	43	46	42	44	42	74
60	54	55	54	50	59	58	68
59	50	55	56	45	46	52	72



Ex_A_Abd_L_2	Ex_A_Abd_L_3	Ex_A_Abd_R_1	Ex_A_Abd_R_2	Ex_A_Abd_R_3	Ex_A_External_L_1	Ex_A_External_L_2	Ex_A_External_L_3	Ex_A_External_R_1
57	58	55	57	61	59	60	62	52
69	68	64	66	66	50	49	47	70
65	66	65	60	62	47	44	48	59
65	65	63	67	66	59	61	62	45
67	67	72	73	76	74	74	75	70
63	64	66	70	68	69	69	70	63
66	68	65	65	64	54	53	55	64
66	68	69	71	68	41	39	42	53
74	68	66	68	68	68	64	64	61
71	72	62	62	62	42	39	39	45
77	77	53	53	55	50	51	50	40
66	66	59	68	60	56	57	56	57
74	71	60	62	64	67	71	65	65
71	73	57	58	60	58	48	61	56
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73	71	59	60	58	50	46	49	63
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73	69	67	66	65	52	54	55	62
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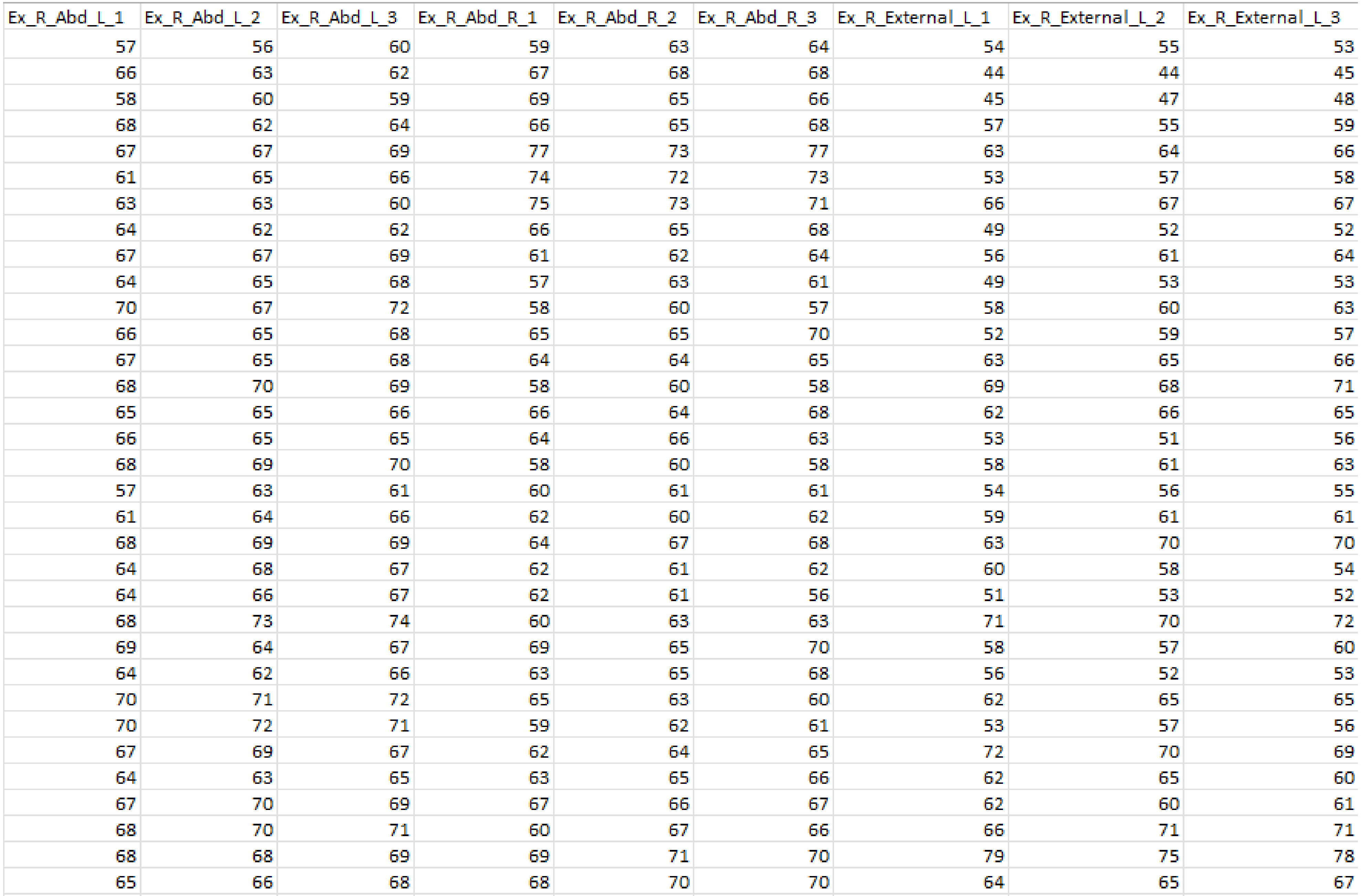
81	79	67	64	65	58	55	53	58
74	74	67	68	64	38	35	35	54
65	68	68	70	71	55	56	54	70
73	75	68	68	68	66	62	59	81
70	69	62	65	64	46	48	46	58
75	74	64	66	64	61	59	58	67
68	67	66	70	72	61	65	61	72
72	70	69	72	72	46	44	42	62

Ex_A_External_R_2	Ex_A_External_R_3	Ex_A_Internal_L_1	Ex_A_Internal_L_2	Ex_A_Internal_L_3	Ex_A_Internal_R_1	Ex_A_Internal_R_2	Ex_A_Internal_R_3
62	68	43	45	47	36	38	42
75	76	50	49	54	38	39	39
61	61	47	52	45	60	62	62
49	42	47	54	54	62	67	73
67	70	48	50	50	50	58	54
68	69	58	67	62	49	51	56
68	71	43	36	36	40	45	49
44	42	49	46	46	47	55	57
68	68	48	37	45	52	51	55
47	41	33	35	39	41	38	42
48	49	44	47	46	32	35	37
53	49	45	46	49	49	47	51
69	69	49	50	53	40	40	40
58	58	42	47	46	48	49	46
59	59	60	56	59	51	50	52
60	60	36	44	43	39	32	38
48	46	58	61	61	49	60	50
54	52	54	55	53	58	58	56
52	52	48	49	53	48	48	45
53	53	47	52	52	33	36	42
64	67	53	54	49	43	44	47
45	44	42	48	50	48	49	52
66	66	64	63	62	48	51	51
62	67	49	53	54	44	53	56
59	60	49	52	57	52	55	60
55	58	32	42	44	45	50	50
55	57	40	50	43	49	46	48
68	71	47	44	46	50	55	54
78	79	56	60	58	61	65	59
56	57	38	42	42	39	44	45
64	64	47	47	48	50	50	52
74	75	60	57	61	56	55	55
63	63	42	40	38	50	51	50



Ex_R_Abd_L_1	Ex_R_Abd_L_2	Ex_R_Abd_L_3	Ex_R_Abd_R_1	Ex_R_Abd_R_2	Ex_R_Abd_R_3	Ex_R_External_L_1	Ex_R_External_L_2	Ex_R_External_L_3
57	56	60	59	63	64	54	55	53
66	63	62	67	68	68	44	44	45
58	60	59	69	65	66	45	47	48
68	62	64	66	65	68	57	55	59
67	67	69	77	73	77	63	64	66
61	65	66	74	72	73	53	57	58
63	63	60	75	73	71	66	67	67
64	62	62	66	65	68	49	52	52
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68	70	69	58	60	58	69	68	71
65	65	66	66	64	68	62	66	65
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68	69	70	58	60	58	58	61	63
57	63	61	60	61	61	54	56	55
61	64	66	62	60	62	59	61	61
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68	73	74	60	63	63	71	70	72
69	64	67	69	65	70	58	57	60
64	62	66	63	65	68	56	52	53
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70	72	71	59	62	61	53	57	56
67	69	67	62	64	65	72	70	69
64	63	65	63	65	66	62	65	60
67	70	69	67	66	67	62	60	61
68	70	71	60	67	66	66	71	71
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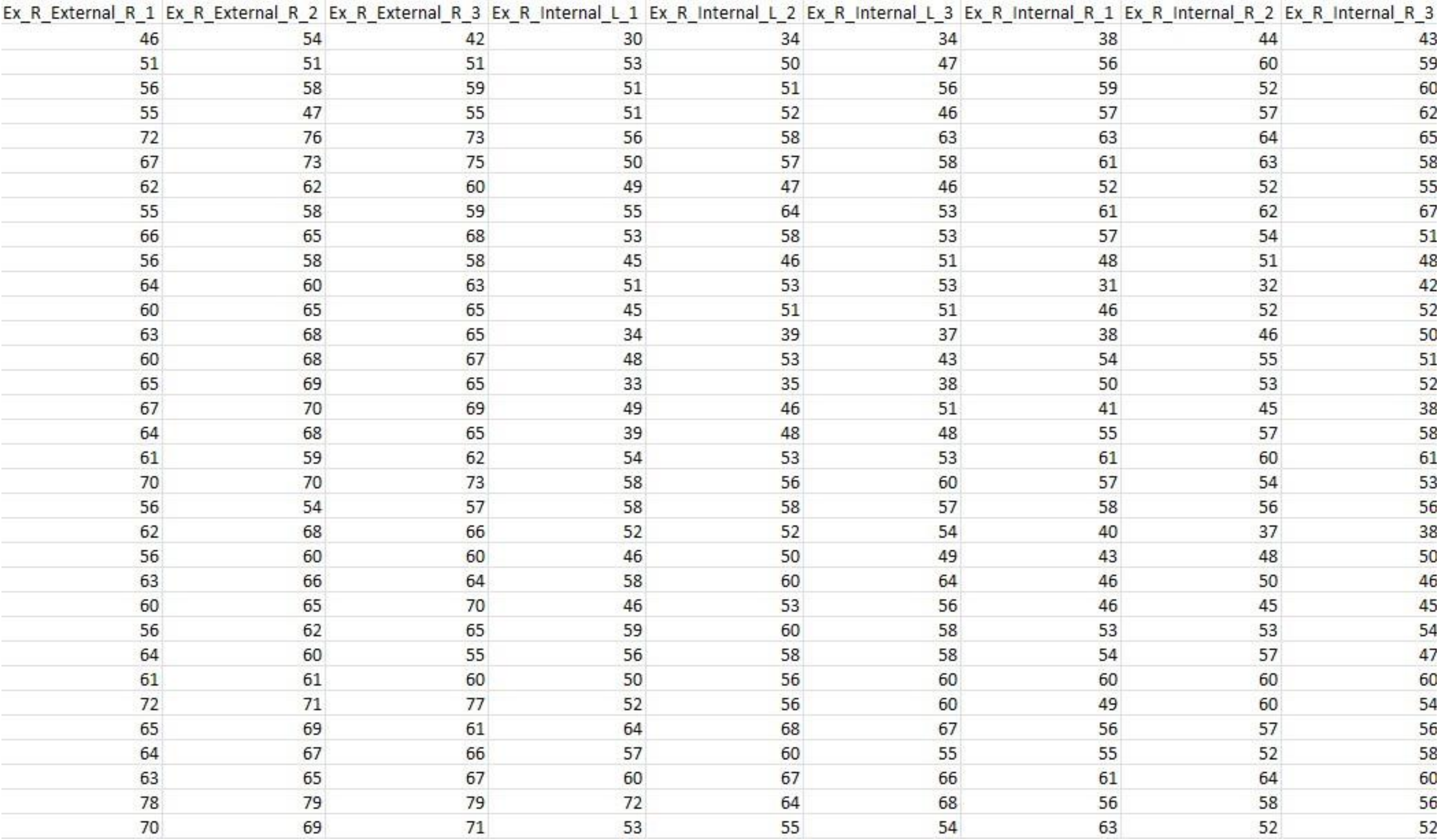
65	66	68	68	70	70	64	65	67



Ex_R_External_R_1	Ex_R_External_R_2	Ex_R_External_R_3	Ex_R_Internal_L_1	Ex_R_Internal_L_2	Ex_R_Internal_L_3	Ex_R_Internal_R_1	Ex_R_Internal_R_2	Ex_R_Internal_R_3
46	54	42	30	34	34	38	44	43
51	51	51	53	50	47	56	60	59
56	58	59	51	51	56	59	52	60
55	47	55	51	52	46	57	57	62
72	76	73	56	58	63	63	64	65
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62	62	60	49	47	46	52	52	55
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67	70	69	49	46	51	41	45	38
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63	65	67	60	67	66	61	64	60
78	79	79	72	64	68	56	58	56
70	69	71	53	55	54	63	52	52