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The significance of femoral anteversion as it relates to canine hip dysplasia

by

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LIST OF SYMBOLS

Characters

A - Acetabular changes
B - Borderline
E - Excellent
F - Fair
G - Good
H - Femoral head changes
L - Left femur
N - Femoral neck changes
O - Osteophytes present
R - Right Femur
S - Subluxation of femoral head
U - Unilateral

Symbols

> - Greater than

Dysplasia Evaluation grade given by:

* - Iowa State University Board Certified Radiologists
^ - Orthopedic Foundation for Animals

Extent of variables

1 - Mild
2 - Moderate
3 - Severe

INTRODUCTION

Canine hip dysplasia is a radiographic and clinical syndrome in which there is an incongruency between the femoral head and the acetabulum. This incongruency leads to the formation of osteoarthrosis of the involved joint (Figure 1).
Canine hip dysplasia is frustrating for breeders, pet owners, veterinarians and veterinary surgeons. Many factors have been implicated in hip dysplasia (Bardet 1983, Brass 1989, Hauptman 1980, Riser 1973, Nunamaker 1976). It is generally accepted that hip dysplasia is a multigene disease with a heritability of .42 (Henricson, 1966). The concept of a disparity of growth between skeletal and muscle development resulting in incongruency of the components of the hip joint, namely the femoral head and the acetabulum, (Riser 1973), is well accepted. The lack of muscle mass allows subluxation of the hip joint and increased biomechanical forces acting upon the dorsal rim of the acetabulum, growth plate of the femoral head, the greater trochanter, and the joint capsule.

Femoral torsion, as it relates to hip dysplasia, has long plagued both human and veterinary orthopedic surgeons. Increased anteversion in the canine femur has been associated with canine hip dysplasia (Hauptman 1985, Montavon 1985, Nunamaker 1973, 1974, Prieur 1987). Femoral torsion has been studied extensively as it relates to human congenital hip

Figure 1. Radiograph of a canine with bilateral hip dysplasia

dysplasia. Surgical corrections have been used in children with increased anteversion. However, numerous techniques currently used to correct hip dysplasia and prevent secondary osteoarthrosis do not consider femoral torsion as a variable to a successful outcome of surgery. The question, therefore, arises as to the true importance of this angle in hip dysplasia. Calculating the normal femoral torsion angle has generated much data in both human and veterinary medical fields (Montavan 1985, Nunamaker 1973, 1974). A method of calculating the angle of femoral torsion of the canine femur, as described by Montavan, et al., was adopted for this thesis. The goal of this thesis was to compare the angle of femoral torsion in normal dogs, i.e., dogs found to be sound on standard evaluation of the coxofemoral joint, with the angle in dogs diagnosed with hip dysplasia.

Definitions

Subluxation of the femoral head is a radiographic and clinical phenomenon in which the femoral head is less than fifty percent within the acetabulum. Radiographically, subluxation can be characterized by increased or uneven joint space and shallow acetabulum (Figure 2).

Femoral torsion (Figure 3) is the twist of the femur and is characterized as an angle between two planes. One plane, the femoral shaft axis, occurs through the transcondylar axis

Figure 2. Radiograph of a canine with bilateral femoral head subluxation

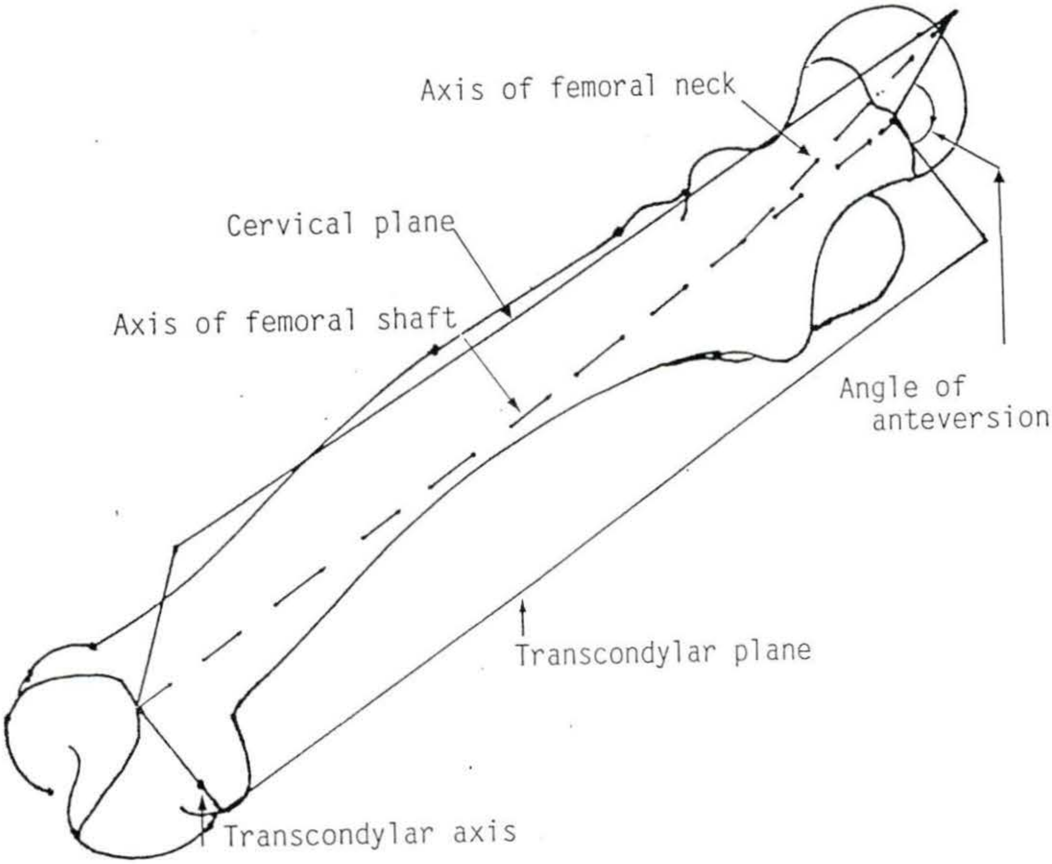


Figure 3. Planes of the femur

parallel to the femur and the other plane through the axis of the femoral neck and shaft (Figure 4).

Femoral anteversion is the angle formed when the neck axis lies cranial to the transcondylar plane and is given a positive value.

Femoral retroversion is the angle formed when the neck axis lies caudal to the transcondylar plane and is given a negative value.

Femoral inclination is the neck shaft angle, or the angle between the axis of the femoral neck and that of the femoral shaft.

Historical Perspective

Congenital hip dysplasia in humans is a syndrome of the coxofemoral joints noted at birth in infants. The syndrome is characterized by a subluxation or luxation of the femoral head out of the acetabulum. There are many synonyms for this condition including: congenital subluxation, congenital luxation, congenital dislocation, depending on the severity of the conditions (Henricson 1966). All refer to the same disease.

Congenital hip dysplasia or congenital dislocation of the hip has an incidence in neonates of 1.3-1.7 per 1,000 births (Barlow 1962, von Rosen 1962, Rabin 1965, Salter 1968). Approximately 88% of these spontaneously stabilize (Barlow 1962). The condition has been described since the eighteenth

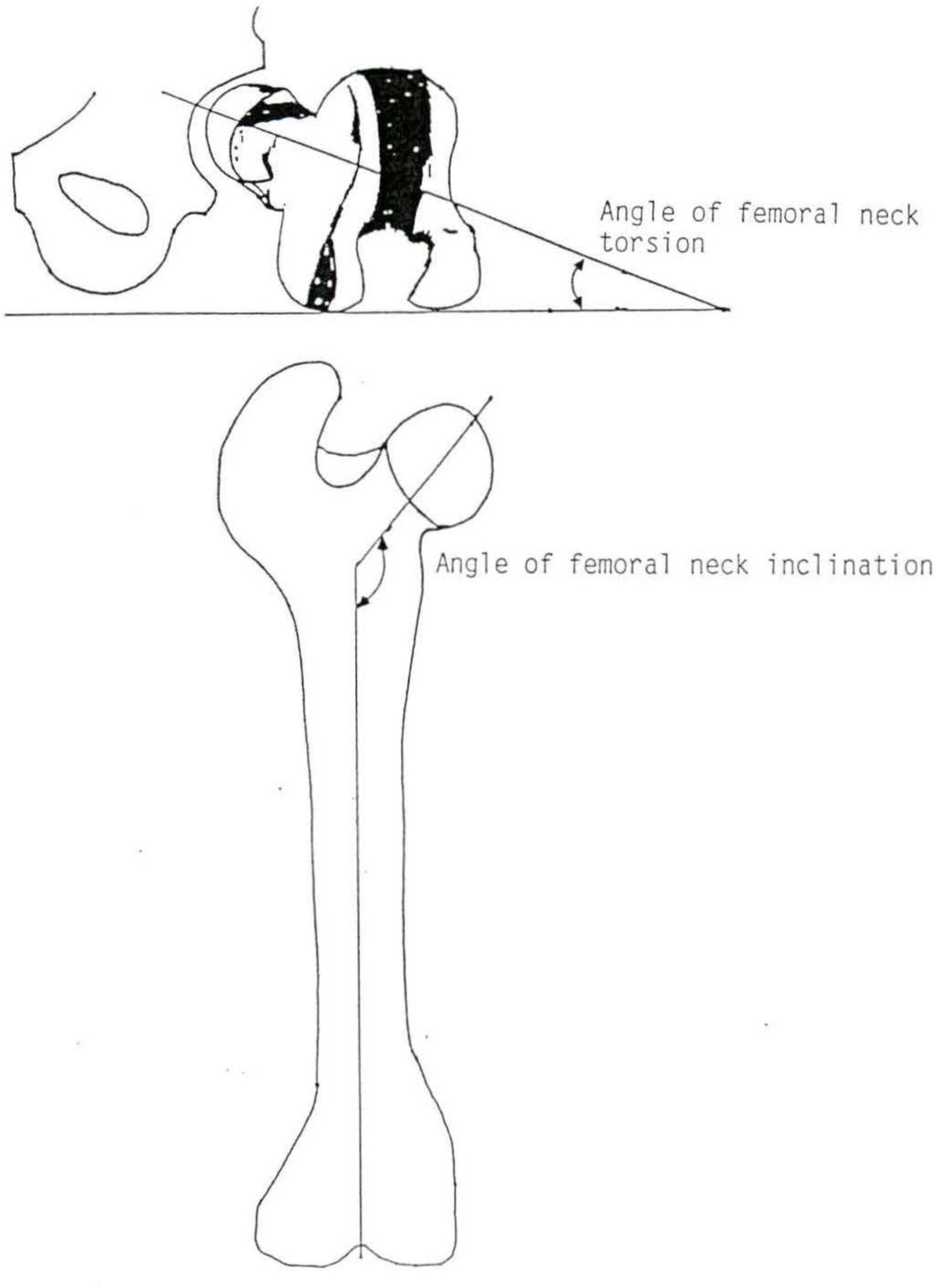
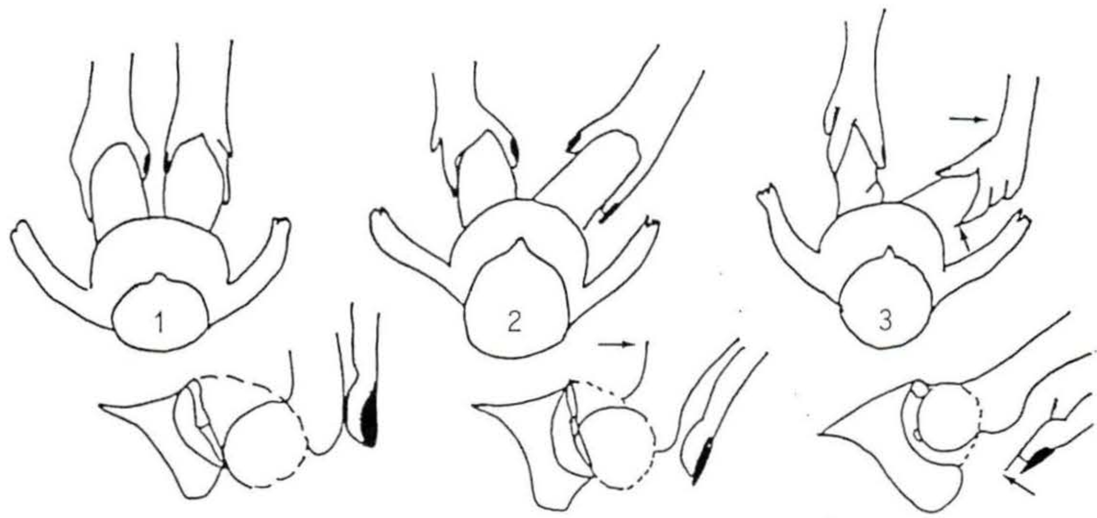


Figure 4. Representation of the canine femoral torsion (a) and inclination (b) angle

century; however, it was not recognized as congenital until Roser in 1879 demonstrated the lesion in newborns. Unfortunately Roser's work was not acknowledged until investigators from 1910 to 1912 provided descriptions of how this condition could be diagnosed in newborns (Henricson 1966). In 1935 and 1948 Ortolani described a series of maneuvers involving abduction and adduction of the femur to produce luxation and replacement of the femoral head within the acetabulum. These maneuvers are now referred to as the Ortolani sign (Henricson 1966). Barlow took Ortolani's maneuvers one step further to discover hips which were not dislocated but were dislocatable (Barlow 1962) (Figure 5).

The etiology of congenital hip dysplasia is believed to be a result of ligamentous laxity and other exogenous factors (Salter 1968, Rabin 1965, von Rosen 1962, Wilkinson 1963, Andren 1961, Wynne-Davies 1970). It must also be understood that the initial factors responsible for the occurrence of hip dysplasia may not play a role in the continuation of this condition (McKibbin 1970). Eighty-eight percent of dislocatable hips stabilize; therefore, joint laxity cannot be seen as the sole culprit in the continuation of this syndrome (Barlow 1962). It appears that much confusion in the literature lies in the failure to make a distinction between those factors which have caused this initial luxation, such as joint laxity, birth position, sex (and therefore hormonal a.



b.

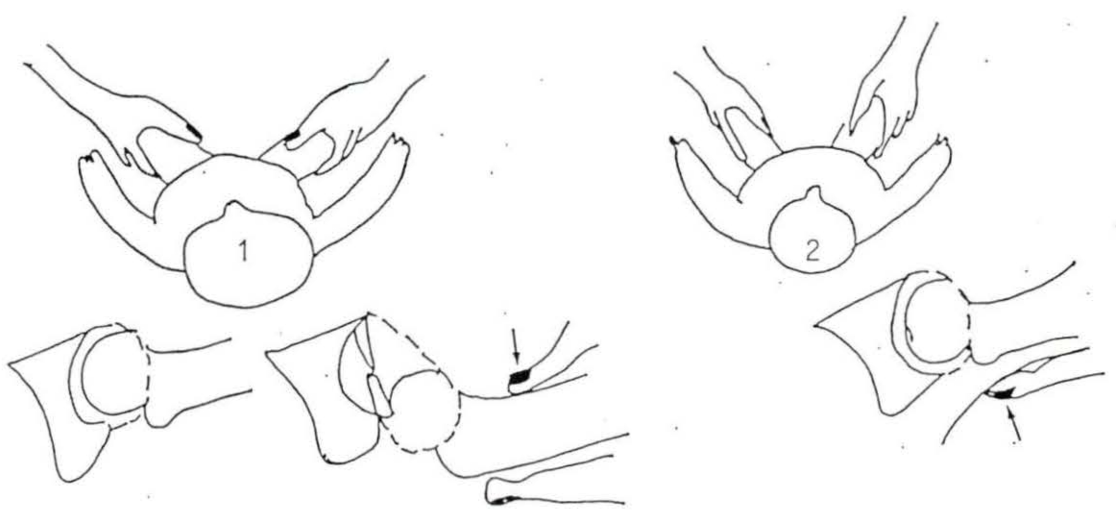


Figure 5. (a) Ortolani and (b) Barlow maneuvers

involvement); and those conditions which are present in the child which do not stabilize spontaneously, namely acetabular dysplasia and femoral anteversion. Again, the controversy continues as to what is the cause and what is the effect (McKibbin 1970). Most investigators agree that increased acetabular anteversion and increased femoral anteversion is present in children with persistent hip luxation (Wilkinson 1963, Fabry 1973, Salter 1968). It is generally agreed that persistent luxation results from the lack of forces necessary to decrease femoral anteversion and change acetabular position (Salter 1968).

Hip Dysplasia in the Neonate

Mansson and Norberg's work in 1961 raised the possibility that high estrogen levels lead to hip dysplasia (Henricson 1966). This work was agumented by Pierce et al. in a separate study (Henricson 1966). Andren and Borglin (1961) found higher concentrations of urinary estrone and estradiol-17B within the first postnatal days in infants with congenital dislocation of the hip. Unfortunately, these findings have not be corroborated (Wynne-Davies 1970). Estrogen levels, however, may play some role. There is a male:female ratio of 1:4 in patients displaying this condition (Wilkinson 1963, Henricson 1966, Rabin 1965, Sherk 1981, and Andren 1961). Another factor which may predispose a patient to dislocation is breech presentation. The stifles of these infants are in hyperextension increasing tension on the hamstring muscles, predisposing to dislocation during or shortly following birth (Wilkinson 1963). Even among breech presentations females favor the condition 2:1 (Andren 1961). A higher incidence of congenital dislocation of the hip was noted in Navajo and Canadian indian tribes with the practice of swaddling the infant with hips in adduction and extension (Salter 1968). The left hip is twice as frequently involved in congenital dysplasia for reasons unknown. Dunn speculated this to be a result of the proximity of this limb to the maternal spine; thereby providing less room for the left limb to move (Dunn 1976). Both birth positions vertex or breech can ultimately result in a superior posterior luxation of the femoral head. When the limb is in extension the iliopsoas tendon forces the femoral head posteriorly and laterally, this is caused by pressure from the short iliopsoas tendon as it courses across the joint capsule to join with the lesser (3rd) trochanter. This further results in a torsional force on the joint capsule and subluxation of the femoral head. The altered force of the joint capsule prevents the femoral head from returning to its original position within the acetabulum. Children born in breech position have their hips flexed, legs abducted and knees extended (Wilkinsen 1963). This results in excessive tension on the hamstrings and dislocation of the femoral head posteriorly and inferiorly. This posterior inferior luxation however gives way to posterior position following birth as the iliopsoas muscle assumes more of a role (Visser, 1984). However, in older children a superior anterior luxation position is more common (Edelson 1984).

Although some controversy still exists, most investigators believe the bone structures (acetabulum and femoral head) to be within normal limits (McKibbin 1970, Salter 1968). The soft tissue structures, namely joint capsule and ligament of the femoral head, are lax and elongated reflecting a possible luxation within the uterus (McKibbin 1970, Wilkinson 1963, Wynne-Davies 1970, Salter 1968). This luxation, if persisting for a time *in-utero*, could result in production of secondary bone changes (McKibbin 1970, Wilkinson 1963, Barlow 1962, Salter 1968).

Two separate studies showed that correcting the placement of the dislocated hip at birth, with subsequent hip immobilization in a reduced, abducted period for 2 months, produced normal hips (Sherk 1981, von Rosen 1962, Henricson 1966).

Hip Dysplasia in the Canine

In contrast to the human condition, hip dysplasia in the canine is not thought to be a congenital condition. However, this thinking may change as methods for early detection of hip dysplasia improve. Many factors have been investigated in the canine in the search for a model for congenital hip dysplasia in humans (Smith 1963, Henricson 1966). Smith et al. (1963), using the canine as a model, concluded that the presence of the joint capsule and ligament of the femoral head during growth was essential in the development of hip congruency (Smith 1963). Joint laxity and therefore incongruency of the femoral-acetabular relationship is well accepted as a prerequisite for the development of hip dysplasia (Riser 1973, 1987, Henricson 1966). Riser's studies indicate a disparity of primary muscle mass and a disproportionately rapid skeletal growth resulting in an inability of the soft tissues to maintain joint stablility. This results in natural biomechanical forces acting upon inappropriate areas of the joint components. Riser points out that animals with a higher pelvic mass:pelvic size have less problems with hip dysplasia (Riser 1973, 1981, 1987).

The degree of involvement of the joint varies between individuals and between legs of an individual. The dysplastic canine joint may manifest as a subluxation or complete luxation. The degree of osteoarthrosis and rapidity of its development also vary between dogs and between legs in the same dog. However, the condition in the dog is essentially bilateral with 89% to 93% of the dogs showing bilateral involvement (Henricson 1966, Riser 1981). Unlike humans, there appears to be no favoring of one leg over the other for the development of the disease or its severity. There is also no sex predilection (Henricson 1966). Canine hip dysplasia may affect any breed; however, large breeds are more affected. Within the large breeds, certain breeds appear to be more affected. This, however, may be a factor of over representation as a particular breed becomes more popular. Certainly chondrodystrophic dogs, especially the English Bulldog and Basset Hound, could not be considered to have normal hip conformation. These breeds, however, are already considered to have many skeletal malformations (Henricson 1966).

Dysplasia occurring at or later than six months of age will be manifest as osteoarthrosis, because the bony tissues are no longer capable of plastic deformation (Riser 1973, 1981). Animals younger than 6 months are capable of bony changes; therefore, incongruency at this age results in a shallow acetabulum due to the bending and wear of the acetabular rim. The fossa also becomes filled with new bone. The femoral head epiphysis begins to drift and marginal lipping occurs as the forces of weightbearing concentrate on a small area of the head and articular surface. These forces stimulate production and resorption of bone in the metaphysis. The femoral neck may also drift into a varus position (Riser 1973, 1989).

Similar to the human medical literature, the veterinary medical literature abounds with techniques for measuring femoral torsion. Many of the veterinary investigations used techniques extrapolated from the human medical literature. Tomography and fluoroscopy have been advocated (Nunamaker 1973). Fluoroscopy provides superior accuracy in measurements; however, these measurements are difficult to reproduce in different facilities, and it is very time consuming (Nunamaker 1973). Computed tomography and magnetic resonance imaging are not currently used in veterinary medicine for the purpose of angle determination. They are restricted by cost, availability, and morbidity of the procedure. (Browning 1982).

Human Pathophysiology

The hip joint must be considered in terms of its components, the femoral head and the acetabulum, and the intricate relationship of the two. The acetabulum has a certain orientation (Figure 6 and 7). Acetabular inclination is the angle between the transverse axis and the line of intersection of the plane through the acetabular rim and frontal plane. Acetabular torsion is the angle between the sagittal axis and the line of intersection of the plane through the acetabular rim and transverse plane. In Anteversion the plane through acetabular rim is oriented anteriorly. In Retroversion the plane through the acetabular rim is oriented posteriorly. The neonatal acetabulum is oriented forward and lateral. This orientation changes as the child takes an erect position (Salter 1968).

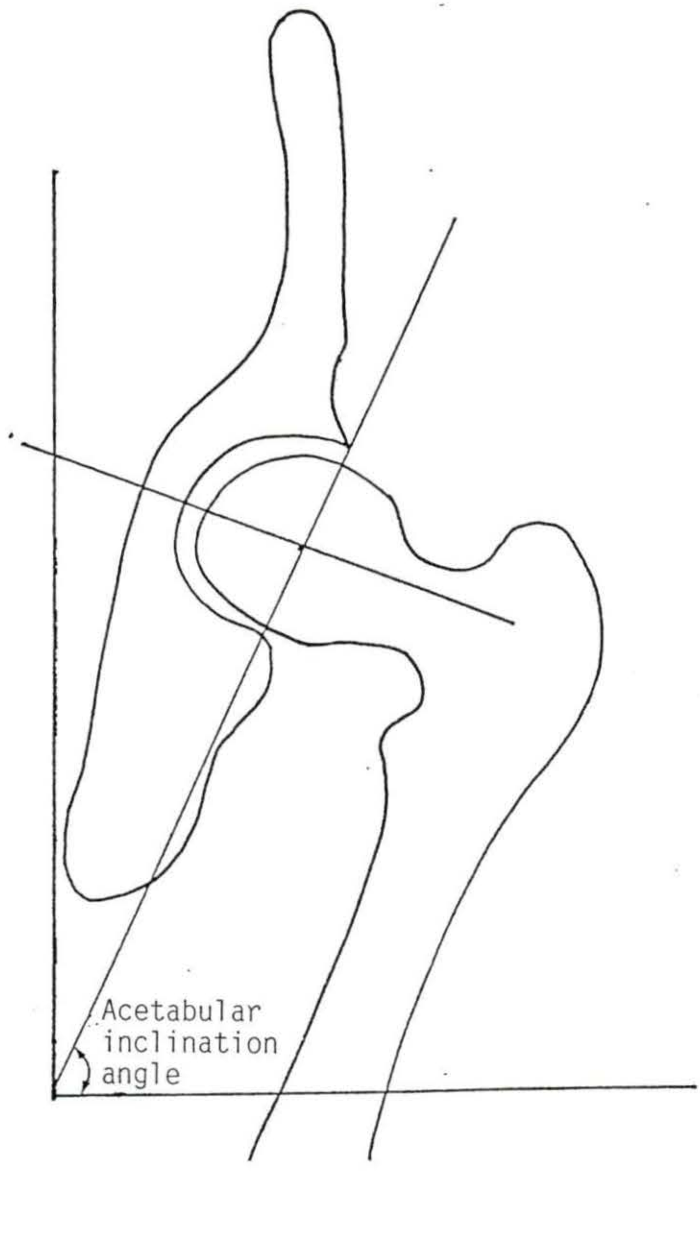


Figure 6. Representation of the human acetabular inclination

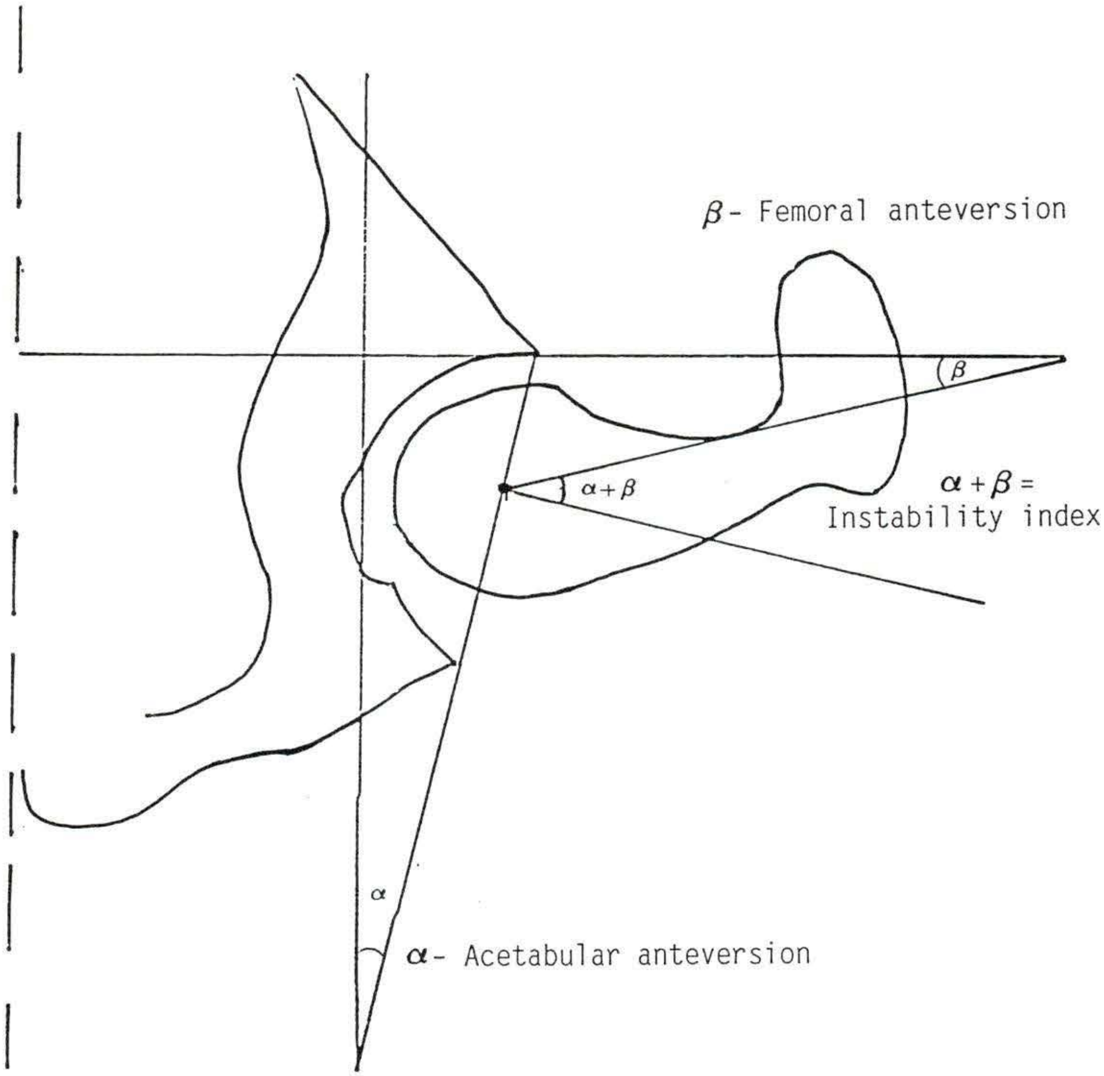


Figure 7. Frontal view of the human coxofemoral joint illustrating the instability index

The neonate acetabulum has a 53° inclination angle which decreases to 48° in the adult according to Lanz (1951). The acetabular orientation as seen in the standard frontal plane radiographic view is best evaluated through the acetabular angle (Visser 1984) (Figure 8). The degree of the acetabular angle is dependent on the acetabular anteversion (Visser 1984). The acetabular angle is produced at the intersection of a line drawn from the superior lateral projections of the acetabular rim to the superolateral margin of the triradiate cartilage intersecting Hilgenreiner's line (which is a horizontal line across the superiolateral margin of each triradiate cartilage which meets Perkins line at the lateral acetabular boundary). The torsion of the acetabulum is usually in anteversion. A few cases of retroversion were noted (McKibbin 1970, Fernandez 1965). The degree of anteversion, using standardized measurement positioning as described by McKibbin, is approximately 16.5° in the adult and approximately 7° in the neonate (McKibbin 1970, Visser 1984). Ferrer-Torrelles (1990) and McKibbin (1970) found the acetabular anteversion to be approximately 10° higher in the adult than the child. Acetabular anteversion is considered to be normal if it is less than or equal to 20° in children three years and older (Visser 1984).

The femoral orientation also has two components: inclination and torsion. The angle of inclination is larger in children

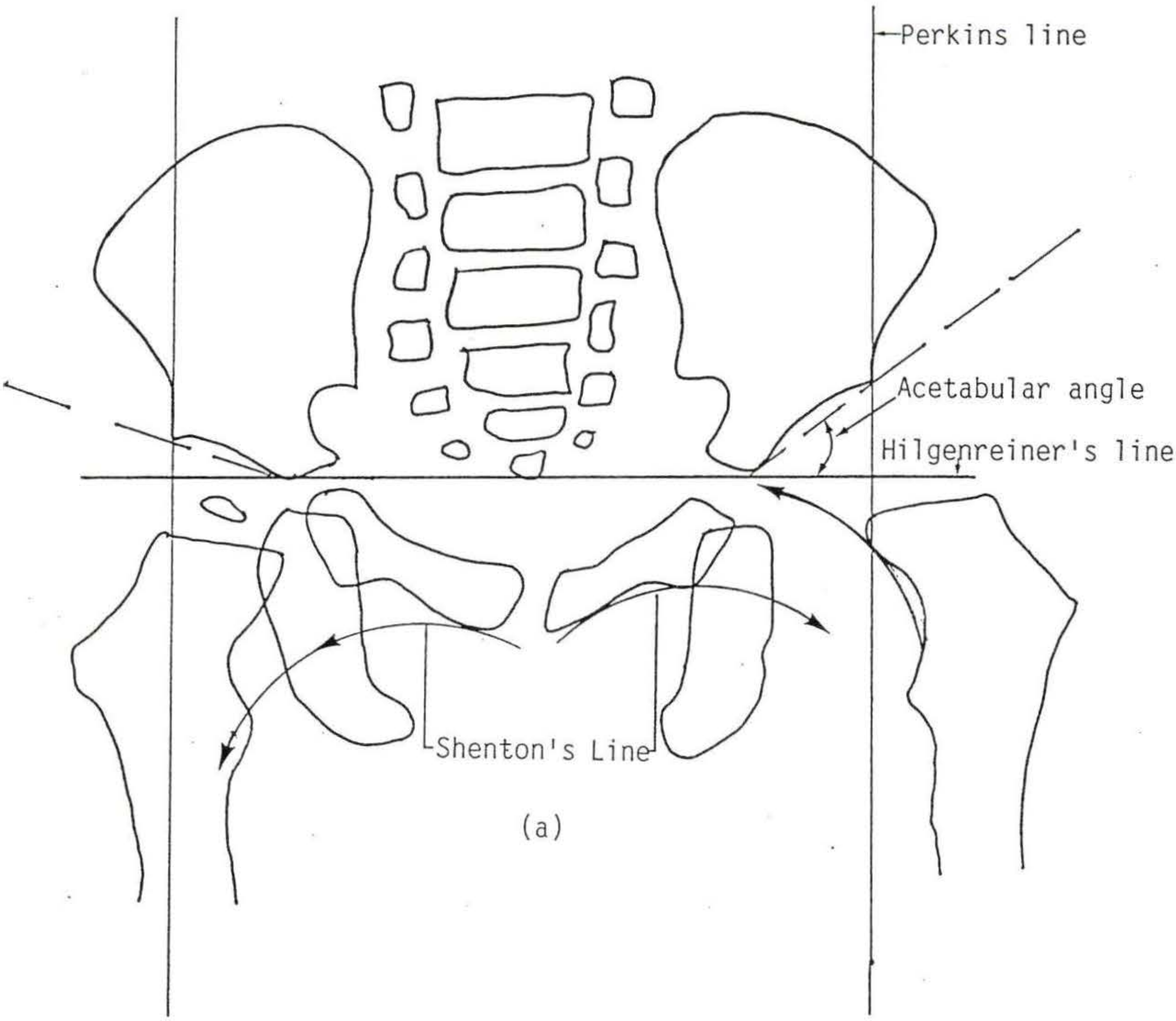
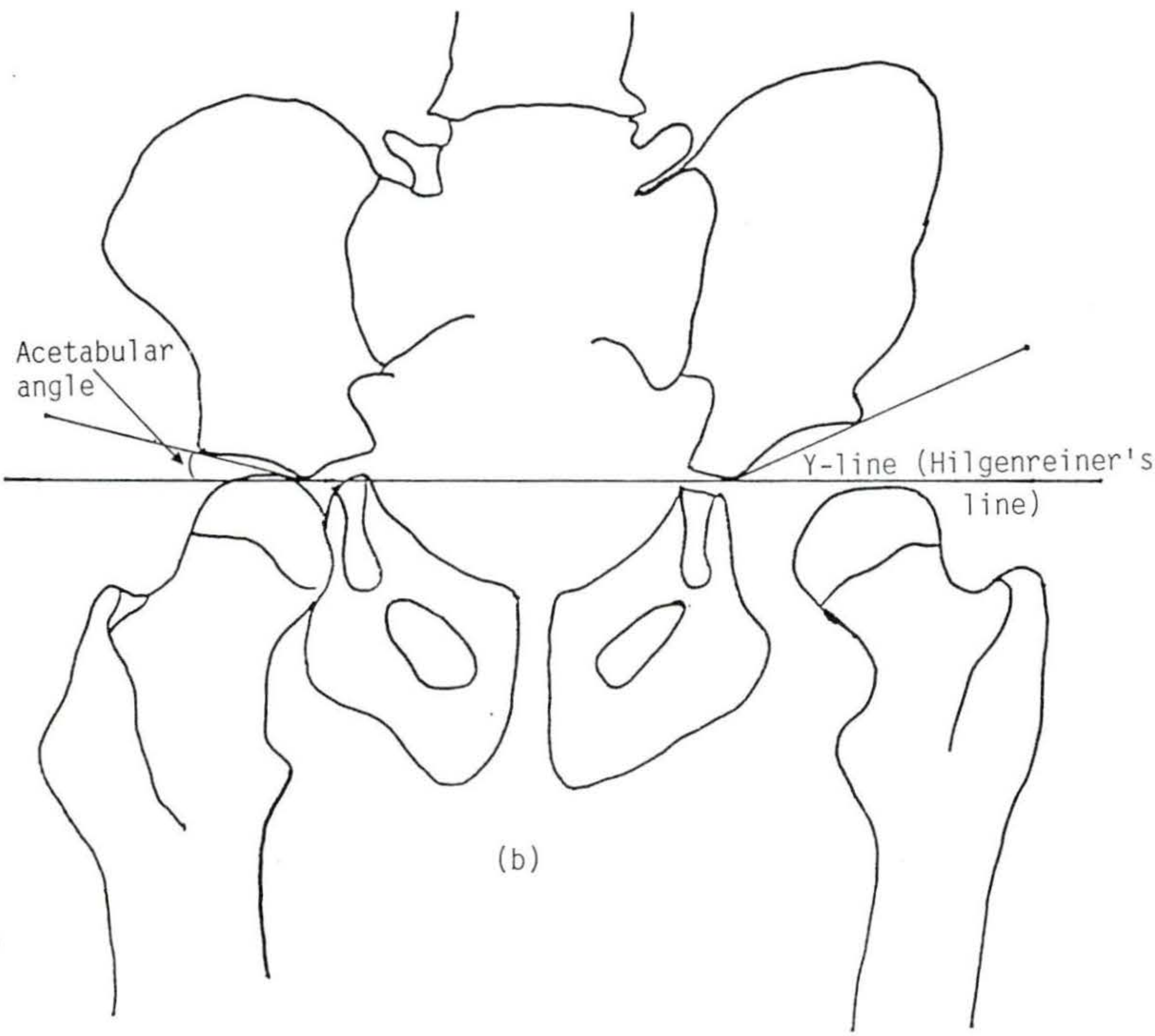


Figure 8. Representation of the Shenton's line, and Perkin's line (a), acetabular angle neonate (b), acetabular angle adult (c), Hilgenreiner's line (Y line)



(b)

Figure 8. Continued

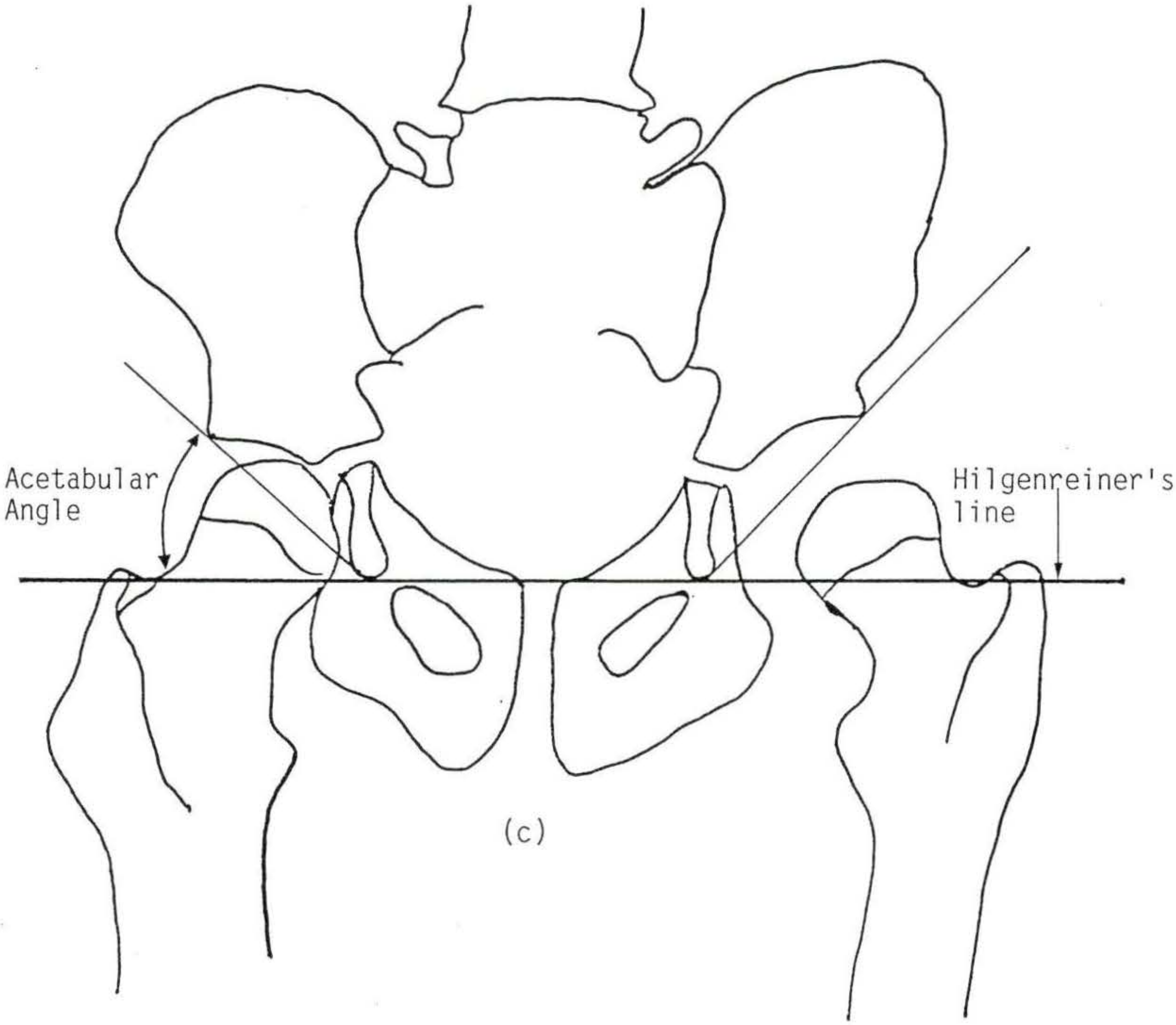


Figure 8. Continued

than in adults. The angle in the child at birth is approximately 134°. It increases to 144° during the first year and then decreases to 126° in adulthood (Visser 1984, Ferrer-Torrelles 1990). Femoral anteversion has been measured as 30° at birth; it decreases with age to 10° or less (Salter 1968, Visser 1984). Measuring femoral anteversion in vivo has been a problem since it was first tried in the early 1900's. The available technologies have prompted many different techniques during this time period. Most techniques involved radiographic views perpendicular to one another and then trigonometric calculations to determine the angle of femoral torsion (Dunlap 1953, Herrlin 1984, Ogata 1979, Ryder 1953, Reynolds 1959). More current techniques utilize tomography and fluoroscopy (Reikeras 1982). Fluoroscopy presents many problems in reproducibility in positioning, exposure time and exposure levels to the patient, and the availability of the equipment required. The most current technique of CT scan produces a more accurate assessment of femoral anteversion (Sullivan 1982, Browning 1982). This technique, however, can not be used on children of less than six months of age because ossification of the femoral heads is necessary, and it has high radiation exposure (Sullivan 1982). CT scan, along with magnetic resonance imaging, is indispensable for the evaluation of the hip joint as a unit (Sullivan 1982).

The relationship between the femur and the acetabulum has been described by Mckibbin with an instability index (Figure 8). This was measured on anatomical specimens. He measured the normal values to be between 20° and 58°. The greater the value the more likely hip dislocation was present. This index is an angle which is the sum of acetabular anteversion and femoral anteversion. It can be measured as the angle between the axis of the femoral neck and a line perpendicular to a line drawn through the anterior and posterior boundaries of the acetabulum. Computed tomography allows calculation of the instability index, acetabular torsion angle and femoral neck anteversion (Visser 1984).

Increased acetabular anteversion has not been a consistent feature in hip luxation. Studies have shown increased anteversion to be present in an equal number of normal and dislocatable hips (Anda 1991, Edelson 1984). Anda's 1991 study found acetabular anteversion to an equal extent in dislocated and nondislocated hips. Femoral torsion was found to be increased in dislocated hips. Poor correlation was found between femoral anteversion and acetabular anteversion. He, therefore, concluded that femoral anteversion developed independently of the orientation of the acetabulum. Edelson's 1984 study found neither an increase in femoral anteversion nor acetabular anteversion in patients with congenital hip dysplasia. The difference in the two studies may be accounted for by the age of the subjects chosen for the studies. Anda's subjects were adults with a mean age of 33 years. Edelson's subjects were children between the ages of three months and two and one-half years. If one views increased femoral anteversion as secondary to chronic luxation and discontinuity of the hip joint then Anda's older subjects may be showing secondary changes consistent with chronic luxation.

Using standard frontal view radiography the CE-angle or center edge angle as described by Wiberg in 1939 can be used to evaluate femoral head coverage. This angle is independent of femoral anteversion unless there is lateralization of the femoral head (Visser 1984). Subluxation of the femoral head increases the CE-angle in abduction and decreases the angle in adduction. The center of the femoral head is always chosen as centralization of the acetabulum despite any enlargement of the femoral head due to osteoarthrosis which would change the center of mass. The angle is described as lying between a line drawn from the center of the femoral head perpendicular to a line connecting the center of rotation of each femoral head and a line drawn from the center of the head to the superiolateral edge of the acetabulum (Sartorius 1989) (Figure 9). A CE-angle greater than or equal to 20° is considered normal in children three years and older.

A central theme in the literature is the concept of the hip joint developing together. The femoral head and acetabulum

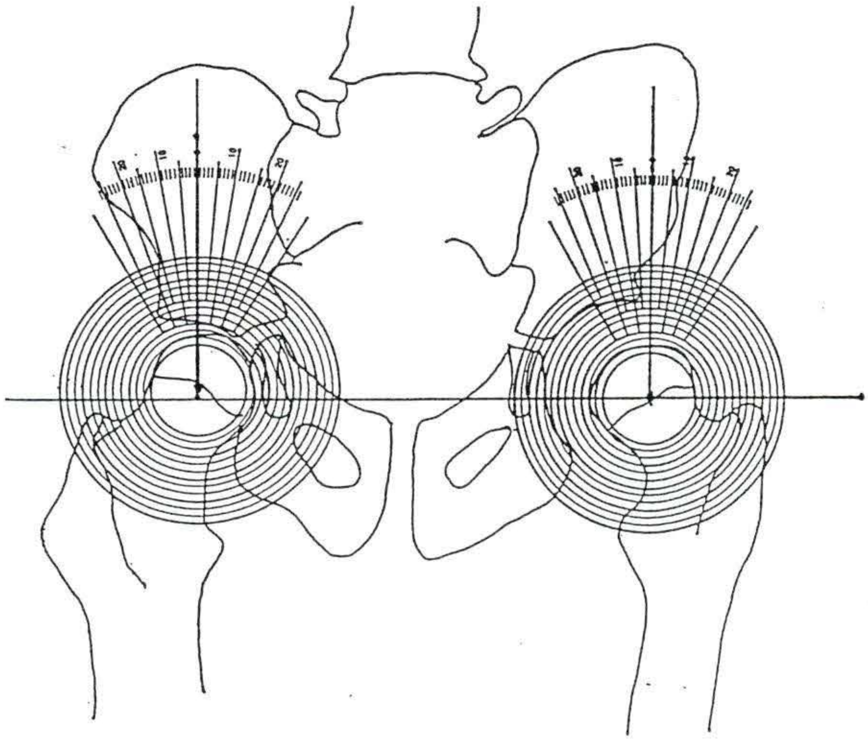


Figure 9. Right coxofemoral joint is normal with positive CE-angle. Left coxofemoral joint is dysplastic with a negative CE-angle.

must develop in synchrony to provide the proper forces required for normal development of each component of the hip joint (Harris 1976, Browning 1982). Factors which may influence congruency, such as increased femoral torsion and inclination and increased acetabular anteversion and decreased acetabular depth, have all been incriminated in producing continued hip luxation in humans with congenital hip dislocation (Salter 1968, Browning 1982, Visser 1984, 1980). Femurs which tend to remain luxated or are luxatable following the first few months of life have been found to have increased anteversion (Visser 1984, Fabray 1973, Salter 1968). Increases in acetabular inclination and anteversion also occur (Visser 1984, Salter 1968). Studies have shown that reduction of the hip and maintenance of reduction resulted in a return to more normal acetabular inclination and anteversion values (Salter 1968, Visser, 1984).

Therapy in Human Coxofemoral Dysplasia

Treatment is based on restoration of congruency between the femoral head and acetabulum to avoid the development of osteoarthrosis. The manual and surgical manipulations of the coxofemoral joint are geared to achieve an acetabular angle of no greater than 25°. Treatment is influenced by age of onset and progression of the condition. In children from three months to three years of age, hip reduction is achieved through traction and abduction. Should this fail to achieve an acceptable acetabular angle, surgical treatment is sought.

Proper reduction of the femoral head into the acetabulum within the first four years of life has been associated with restoration of a normal acetabular angle (Visser 1984). Reduction of the femoral head in one year old infants shows improved acetabular angles. Improvement of the angle decreases with treatment at increasing age up to the age of four. Improvement of the acetabular angle has been seen in eight year old children if the reduction was done prior to four years of age (Visser 1984, Harris 1976), but only five degrees of improvement occurred if the reduction was performed after the first three years of life (Visser 1984).

Children not responding to traction and abduction and with acetabular angles greater than 25° are candidates for intertrochanteric osteotomy (Visser 1984). Derotation osteotomies were found to be most efficacious in patients with increased femoral anteversion and valgus deviation of the femoral head (Monticelli 1976). Patients in which severe subluxation is not corrected with manual internal rotation and abduction of the femora are not candidates for this procedure. Reduction with centralization of the femur is not possible (Monticelli 1976).

Open reduction is utilized in patients in whom closed reduction manipulation was not possible. This procedure can then be followed with a derotational osteotomy (Blockey 1984). Open reduction, however, can result in the production of severe osteoarthrosis (Blockey 1984).

Patients who do not achieve a significant decrease in acetabular angles are then subjected to pelvic osteotomies. Many techniques are available. Early techniques required no internal luxation and functioned as self-correction procedures. These included deepening of the acetabulum through reeming, cortical grafting above the joint capsule to induce coverage of the head by transformation of the synovial capsule to fibrocartilage, and ilial osteotomy with medial rotation of the distal segment as described by Chiari (Visser 1984). Later techniques such as the Pemberton, Eppright, Wagner and Salter (Visser 1984) osteotomies involved peri-acetabular incomplete osteotomies. Steel and Greenfield (Visser 1984) further modified these techniques by including other osteotomies of the pubis and ischium (Visser 1984).

Salter's technique is limited by the amount of coverage and correction it can achieve. Its use is contraindicated in acetabular angles requiring more than ten degrees of angle correction (Visser 1984). It involves an osteotomy through the ilium at the deepest point of the ischial notch to the inferior aspect of the inferioanterior iliac spine. A wedge shaped piece of bone taken from the iliac crest is placed into the ilial osteotomy with the widest portion of the wedge facing laterally to maintain an anterior and inferior rotation of the distal fragment of the pelvis. Kirschner wire fixation is then utilized to stabilize the osteotomy during healing. The degree of anterior rotation of the distal fragment is approximately one-half of the degrees of angle of the wedge. This technique provides improved anterior head coverage. Should more than ten degrees of angle of correction be required, complete osteotomies should be employed because these can provide more flexibility in manipulation.

The intertrochanteric osteotomy producing centralization of the femoral head is shown to produce growth of the acetabular roof and therefore successful coverage of the femoral head in most cases. (Blockey 1984) It is believed that pelvic osteotomies should be reserved for those patients with continued subluxation but centralization of the femoral head into the acetabulum before the age of six years. Complete osteotomies are usually delayed until closure of the triradiate cartilage at fourteen years of age. (Visser 1984) Chronic subluxation with secondary osteoarthrosis is best treated with the earlier surgical procedures until hip replacement is required.

Veterinary Pathophysiology

The most accepted theory of hip dysplasia in the canine is that developed by Riser. This theory explains the developing deformities of the femoral head, neck, and acetabulum as secondary to lack of muscle mass sufficient to maintain congruency of the coxofemoral joint components (Lust 1972). Normally the canine femoral head should be seated well within the acetabulum so that nearly ninety-percent of the femoral head is covered by the dorsal rim of the acetabulum. The joint space created between the acetabulum and the femoral head should be uniform throughout the craniodorsal aspect (Figure 10). Biomechanically, subluxation of the femoral head and increased femoral neck angle of inclination increase the forces associated with continued congruency of the coxofemoral joint (Arnoczky 1981). Increased forces such as those which occur with subluxation are placed eccentrically in the hip leading to shear and thus alteration of the articular cartilage associated with the head and acetabulum (Weigel 1992).

Forces at the hip joint can be calculated using the technique of force plate analysis. Force plate analysis measures indirectly the forces acting at the joints during different gaits. Force plate data provide ground reaction forces and these are then related to the body weight of the animal.

Arnoczky (1981) found that as subluxation of the femoral head occurred there was an increase of the moment about the femoral head resulting from body weight. This occurred because the distance from the femoral head to the center of

Figure 10. Radiograph of a canine with normal hip conformation

the body increased. The abductor muscle force must therefore increase to retain balance, and this in turn results in increased force generated at the hip joint. He calculated the force acting on the hip in a concentrically located femoral head with the limb in neutral position. A hip force angle of 69^0 was found to be 4.4 times the force at the spine (F_o). When one centimeter of subluxation of the femoral head occurs, a force of 5.2 times F_o results; the corresponding hip force angle decreases to 61^0.

An increase in femoral neck inclination results in both an increase in the hip force and the abductor muscle force (Arnoczky 1981). An increase in the femoral neck inclination angle causes a shortening of the distance between the femoral head and the greater trochanter. This distance represents the lever arm of the moment of the hip joint. This shortening produces a compensatory increase in the force required by the abductor muscles and therefore increases the total forces acting on the femoral head (Weigel 1992).

The components of the canine femoral hip have not been extensively studied as a unit. No studies are available involving acetabular angulation. There have been no studies using MRI to view the relationship between the coxofemoral joint components. Normal acetabular angles and CE-angles have not been defined for the canine. However the Norberg angle has been established for the canine. This angle, like the CE-angle, reflects the degree of subluxation of the femoral head from the acetabulum. It utilizes the center of the femoral heads and the dorsocranial acetabular margins to create the angles. The normal hip will have a Norberg angle of 105^0. The subluxated hip will measure less than 105^0 as the femoral head shifts laterally (Morgan and Stevens 1985).

Similar to the human medical literature, the veterinary literature, abounds with techniques for measuring femoral torsion. No studies have evaluated acetabular angles. Many of these investigations use techniques extrapolated from human literature. Tomography and fluoroscopy are also used. The use of computed tomography and magnetic resonance imaging are not currently in the veterinary medical literature.

Dueland's thesis (1981) concluded that increased femoral anteversion would lead to the development of coxofemoral arthropathy and therefore should be evaluated in the treatment of hip dysplasia. This conclusion was based on osteotomies increasing the femoral anteversion in the developing dog and from evaluating several joint component parameters (synovial fluid volume and membrane characteristics) and femoral torsion and inclination in Labrador Retrievers, ranging from twelve weeks to seven years of age. Dueland's study showed that dogs with normal hip conformation have a mean angle of torsion of 5.4° -+ 4.8° (n=20). Mean inclination angles were 140.2° -+ 4.5° (n=113). Further unpublished studies by Harter, Dueland,

and Lust found no development of coxofemoral disease in animals with differing angles of femoral torsion and inclination (Lust 1985).

Hauptman et al. (1985) studied angles of inclination and anteversion and concluded there were no differences in these angles between dysplastic and nondysplastic dogs. Radiographically normal hips produced anteversion angles of 15.4° -+ .8°. These angles were achieved using the method of Nunamaker, et al. (1973). This method utilizes a transverse plane for radiographic positioning. Nunamaker had established a mean normal femoral anteversion angle of 26.97°. Femoral torsion angles in the dog have been seen to slightly increase from birth to maturity (Hauptman 1980). Femoral osteotomy, to experimentally increase femoral torsion in immature beagles corrected within eight degrees of normal values during the healing and growth period (Schneider 1963).

Therapy for Canine Hip Dysplasia

The controversy of which came first, increased anteversion or joint laxity resulting in increased femoral anteversion, remains. Debate continues in the consideration of femoral torsion and surgical procedures used to prevent secondary osteoarthrosis via stabilization of the coxofemoral joint (Wallace 1987). Surgical procedures in the veterinary field have mimicked those developed for human congenital hip luxation. Acetabuloplasties were performed by Brinker in 1968.

The intertrochanteric osteotomy concerns itself with angles of inclination and femoral torsion (Prieur 1987). This technique is used to correct coxovalga and femoral anteversion to provide congruency of the hip joint. Hohn and Janes introduced a pelvic osteotomy in 1969. This procedure mimicked Salter's human pelvic osteotomy; however, it also involved an osteotomy of the ischium. This procedure was performed alone, with a combination of capsulorrhaphy or intertrochanteric osteotomy (Nunamaker 1974). Pectineal myotomy, myectomy, and tenotomies were performed in the treatment of hip dysplasia (Nunamaker 1975). The pectineus muscle is an adductor of the hip. Transection of this muscle provided temporary relief of pain and improved gait. Schrader designed a periacetabular technique extrapolated from Steel (Schrader 1986). He further combined this technique with an intertrochanteric osteotomy following recommendations based on human medicine of accessment of the CE-angle value (Schrader 1986). Schrader rotated the pelvis 60° to 70° for satisfactory coverage of the femoral head. Schrader observed less than satisfactory results when osteoarthritic changes were already present at the time of surgery. He also felt that the combined technique of intertrochanteric osteotomy and pelvic osteotomy was not necessary as the pelvic osteotomy would produce satisfactory femoral head coverage. Schrader felt that hips which could not be reduced by standard Ortolani procedures were not candidates for triple pelvic osteotomy. Another pelvic triple osteotomy was established by Slocum and Devine in 1986 which involved osteotomies of the ilium, ischium and pubis. The degree of rotation of the pelvic segment was based on the degree of Ortolani sign and the Barlow sign observed. Animals with osteoarthritic changes were not considered good candidates for this procedure. Also patients with severe subluxation or very shallow or elongated acetabula were excluded from this surgical technique. Animals with severe femoral head and acetabular deformation are considered candidates for femoral head and neck excision arthroplasty or total hip replacement procedures (Hoefle 1974, Dueland 1975). A more recent technique, extrapolated from modification of the human medicine technique of placing a bone segment over the fibrous capsule of the acetabulum to induce a fibrocartilagenous change in the capsule, is the BOP shelf arthroplasty as described by Jensen and Sertl (1988). This technique currently utilizes a biocompatible orthopedic polymer which is available as a block or fiber. The material is paced over the dorsal rim of the acetabulum to induce bone production and laterally extend the dorsal rim thereby appearing to deepen the acetabulum. The authors of this technique in veterinary medicine report good clinical results. Progressive radiography during healing has demonstrated considerable osteoarthritic changes of the femoral head and acetabular segments. Restrictions of age or degree of osteoarthrosis have not been suggested for using this technique.

The femoral neck lengthening technique devised by Slocum and Devine (1988) utilizes a procedure to change coxovalga by effectively lengthening the femoral neck. This involves a longitudinal osteotomy of the proximal portion of the femur beginning at the level of the intertrochanteric fossa and extending distally to the proximal one-third portion of the femoral shaft. The proximal osteotomy is then widened more than the distal one through the use of biocompatible wedges. Stabilization of the osteotomy and wedge placement is with cerclage wire and Kirschner wire fixation. This technique has been used in combination with the triple pelvic osteotomy in patients with severe subluxation of the femoral head.

METHODS AND MATERIALS

Fifty-three dogs, between the ages of seven months and seven years and ten months, undergoing evaluation for hip dysplasia at the Iowa State University, College of Veterinary Medicine, were subjects in this study. All dogs were tranquilized using a mixture of butorphanol/ zylazine/ glycopyrrolate in the following ratio respectively: 40 mg / 40 mg / 1mg. The mixture is administered at one milliliter per 40 pounds given intravenously. The standard craniocaudal radiographic view of the femur was taken with the hindlimbs fully extended and parallel to the table top with patellas centered directly over the trochlear groove (Figure 11). Correct positioning of the animal was determined by radiographic appearance of symmetry of the obturator foramina and location of the patellas. A mediolateral view of the femur was taken with the beam centered on the femoral head (Figure 11). The dog was placed in lateral recumbency with the femur parallel to the table top and the coxofemoral and stifle joints flexed at 90°. The opposite femur was held in abduction. An aluminum filter was placed under the femoral condyles to prevent overexposure. Correct radiographic positioning was verified by superimposition of the femoral condyles and fabella. Radiographic interpretation was performed by one of two board certified radiologists. Some radiographs were also interpreted by radiologists of the Orthopedic Foundation for

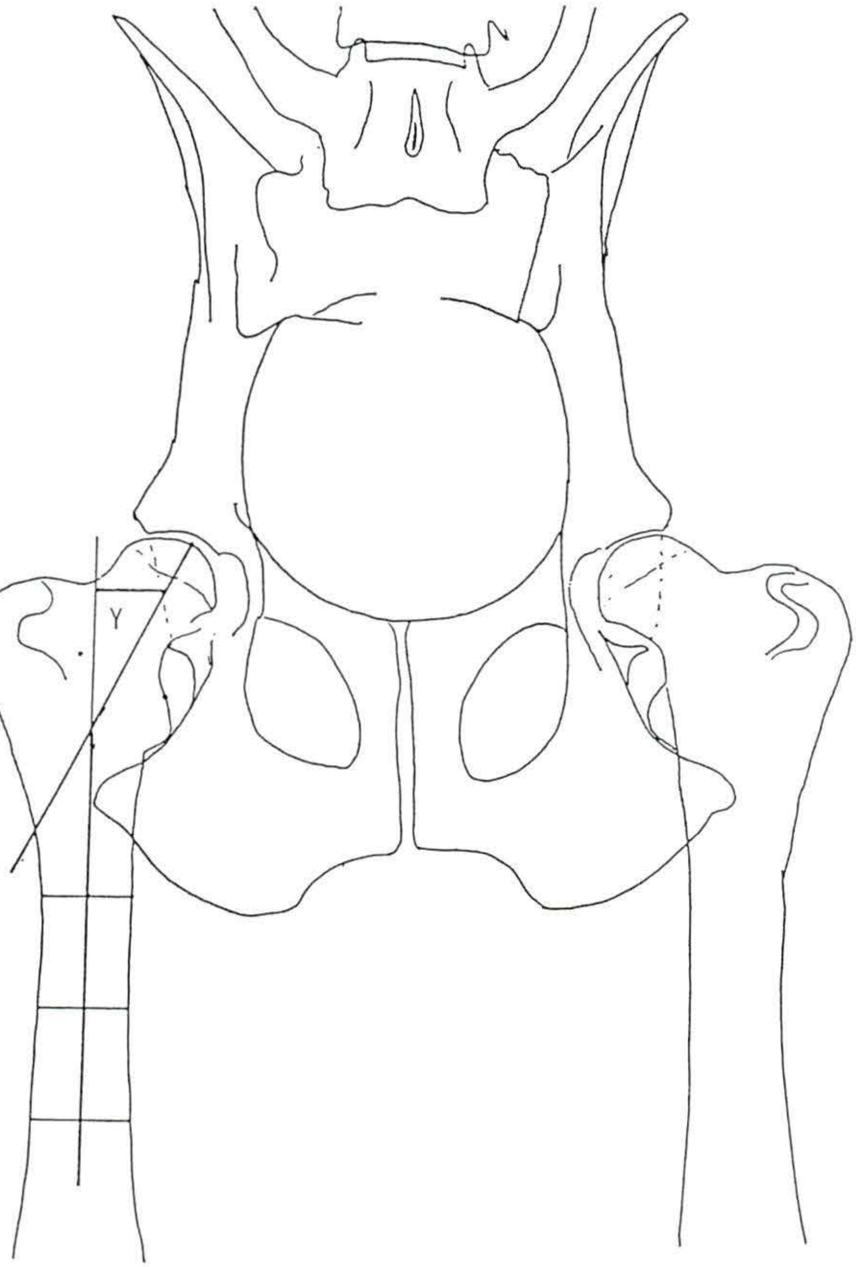


Figure 11. Depiction of the method of calculation of the canine angles of femoral inclination and torsion

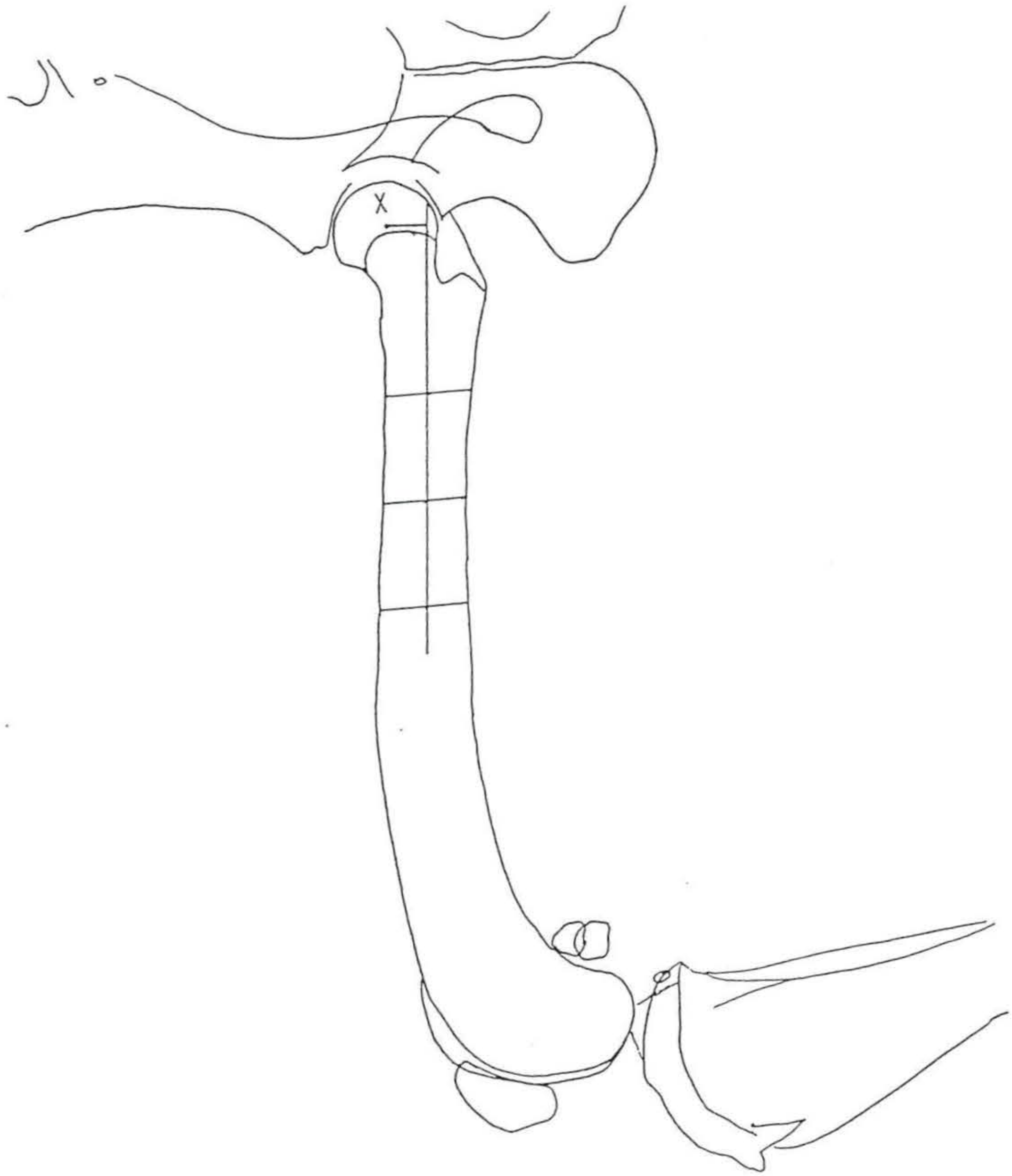


Figure 11. Continued

Animals, Inc. The characteristics used to define hip dysplasia were subluxation of the femoral head and evidence of secondary degenerative joint disease. The degree of dysplastic changes were characterized by the radiologists and the Orthopedic Foundation for Animals, Inc. Radiographic measurements of anteversion for the right and left femur were calculated as described by Montavon et al. (1985). This involved the radiographic positions previously described and trigonometric calculations to derive the angle of femoral torsion. The angle of femoral neck inclination is calculated using the craniocaudal view. The angle of inclination is affected by the angle of femoral torsion by the following relationship: tangent of the real angle of inclination = tangent of the measured angle of inclination / cosine of the measured angle of anteversion. This value was then subtracted from 180° (Ogata 1979). The technique for calculating the angles of femoral torsion and anteversion is described below.

Craniocaudal View

Goniometrically derived concentric circles are drawn on a transparency. The center of the femoral head is acquired by locating the circle which best fits the radiographic outline of the femoral head. The point of junction of the contour of the trochanteric fossa and the intertrochanteric crest is identified and marked. A compass is positioned at the center point of the femoral head and expanded to the marked point at the trochanteric fossa. A semicircle is drawn thereby transferring this distance to the medial aspect of the femur. These two points were used to draw a line bisecting the long axis of the femoral neck. An area of the proximal femur was chosen which shows the most uniformity in shape. Three parallel lines were drawn approximately one centimeter apart. The center point of each line was determined and marked. A line was then drawn through all three center points to bisect the long axis of the femoral shaft. A line drawn from the center of the femoral head perpendicular to the long axis of the femur shaft was measured in millimeters, a distance "y". The angle created by the line bisecting the femoral neck and the line bisecting the femoral shaft was the measured angle of inclination of the femoral neck.

Mediolateral View

The goniometric circles were again used to locate the center of the femoral head. A uniformly shaped area of the proximal femur was again chosen to perform the same manipulations for determination of the long axis of the femoral shaft. A line was drawn from the center of the femoral head, perpendicular to the line representing the long axis of the femoral shaft. This line was measured a distance "x" in millimeters.

Trigonometric Functions

The angle of femoral torsion is represented by the function: Tangent of the angle of anteversion = the distance "x"mm / the distance "Y" mm.

Image Analysis

Image analysis using a Zeiss SEM-IPS image analysis system (Zeiss-Kontron; IBAS version 2.00) was performed as described below. Hand and image analysis derived angles were compared using analysis of variance.

Images of the femur were acquired using image analysis by placing radiographs on a copy stand equipped with a Chromapro lightbox and diffuser. The images were then captured with a Sony 3 CCD color video camera. The image analysis software allowed for calibration of internal scaling to measure in mm. The computer generated circles replicating the goniometric circles used in the hand method of measurement. The lateral view of the radiograph was manipulated to achieve the best fit for the curve of the femoral head with a specific circle. The image was then captured and displayed by the computer. Four points, marking the four corners of a rectangle along the most linear portion of the bone were marked. These points were used to determine the placement of a line bisecting the long axis of the femur. A second line was drawn perpendicular to the first line and passing through the center point of the best fit circle. The length of this line was measured (L_1-Lateral).

For the craniocaudal view, the same steps were used for locating the center point of the femoral head, determination of the long axis of the femur, and production of the line perpendicular to the femoral long axis(L1-dorsal ventral). In addition, the point of intersection between the intertrochanteric ridge and the trochanteric fossa was marked interactively. The computer then drew a circle the radius of which was the distance from the femoral head center to the point of trochanteric intersection. A second point was chosen where the arc of this circle intersected the medial aspect of the proximal femur. These two points were used as center points for two new circles with identical radii to the first circle drawn. A line drawn between the point of intersection of these two circles, which was marked interactively, and the femoral head center is the long axis of the femoral neck. This line represented the hypotenuse "c" of a right triangle. Side "b" was represented by the perpendicular line from the femoral head center to the long axis of the femur. The points where the side "c" and side "b" intersect the long axis of the femur represented side "a". Side "a" was denoted as the measurement

L_2-dorsal ventral. The following formulas were then used to calculate the parameters:

1) Angle of Inclination = 180 - arctangent (L_1-dorsal ventral/L_2-dorsal ventral)

2) Angle of Anteversion = arctangent (L_1-lateral/L_1-dorsal ventral)

3) Real Angle of Inclination = 180 + arctangent(tangent of the measured angle of inclination/cosine of the measured angle of anteversion)

RESULTS

The dogs radiographed in this study were generally large breed dogs. The breeds and represented numbers, given in parenthese, were Australian Kelpi(2), Belgian Tervuren(3), Black Labrador Retriever(1), Brittany spaniel(2), Chesapeake Bay Retriever(4), Chow Chow(1), German Shepherd(5), Golden Retriever(2), Great Pyrenees(1), Mastiff(2), New Foundland(1), Rottweiler(14), Saint Bernard(4), Samoyed(7), Siberian Husky(1), Standard Schnauzer(1), Vizsla(1), Yellow Labrador Retriever(1). The sex distribution was twenty-six male dogs and twenty-seven females. There were twenty-nine dysplastic dogs and twenty-four nondysplastic dogs. Table 1 provides the radiographic interpretation of coxofemoral congruency, OFA classification, osteophyte formation, anatomic changes, age, sex, and breed for the fifty-three dogs.

No statistical difference at $p < .05$ was found using analysis of variance to compare the two methods of generating the angle of femoral torsion and angle of inclination. Therefore, all further analyses were performed using hand generated data. Hand generated data derived from Montovan's technique for the calculation of the femoral torsion and femoral inclination angles is provided in Table 2. Analysis of variance was used to compare the angle of femoral torsion

Table 1. Radiographic interpretation of dysplasia of each canine patient according to breed, age, and right and left limb.

CASE #	BREED	SEX	AGE (mos)	SIDE	DYS	EVAL
604258	Rottweiler	M	26	R	no	*G
				L	no	
601613	German Shepherd	M	74	R	no	*SOAN
				L	yes	
600521	Samoyed	M	13	R	no	*G,^E
				L	no	
606392	Siberian Husky	F	15	R	yes	*1,2,SAN
				L	yes	R>L
607549	Golden Retriever	F	32	R	no	*F,^G
				L	no	
605432	Rottweiler	F	7	R	no	*normal
				L	no	^G
605430	Rottweiler	F	7	R	no	*G,^G
				L	no	
605607	Chesapeake Bay Ret	F	24	R	yes	*ASN
				L	yes	^2
604512	Samoyed	F	29	R	yes	*S(L>R)AN
				L	yes	2
600781	Vizsla	M	27	R	no	*G,^G
				L	no	
610495	St. Bernard	M	14	R	yes	*2S3
				L	yes	^2SA
588618	Yellow Labrador Ret	M	69	R	yes	*An3,^3
				L	yes	
605811	Belgian Tervuren	M	28	R	no	*E,^G
				L	no	

DYS - Presence of Dysplasia
EVAL - Evaluation of Radiographs

Table 1 Continued

605809	Belgian Tervuren	M	28	R	no	*G,^G
				L	no	
601676	Standard Schnauzer	F	25	R	no	*G,^G
				L	no	
605810	Belgian Tervuren	F	26	R	no	*G,^G
				L	no	
604669	Samoyed	M	24	R	no	*G,^E
				L	no	
604962	Mastiff	M	33	R	no	*G,^G
				L	no	
592691	Mastiff	F	67	R	no	*G,^G
				L	no	
605191	Chesapeake Bay Ret	M	35	R	no	*E,^G
				L	no	
605190	Chesapeake Bay Ret	F	29	R	no	*G,^G
				L	no	
610550	St. Bernard	M	46	R	yes	*1-2$S_{L>R}$N
				L	yes	
606904	Rottweiler	F	24	R	no	*G,^G
				L	no	
606903	Rottweiler	M	24	R	yes	*S
				L	yes	
606197	Rottweiler	M	24	R	no	*E,^G
				L	no	
603034	Rottweiler	F	24	R	no	*G-E
				L	no	^F
605006	Australian Kelpi	F	42	R	yes	*2-3,SAN
				L	yes	
591800	Australian Kelpi	M	53	R	no	*G,^G
				L	no	
606792	Rottweiler	M	27	R	no	*G,^E
				L	no	

Table 1 Continued

606791	Rottweiler	F	47	R L	no no	*G,^E
600083	German Shepherd	F	38	R L	yes yes	*1-2S_L
606023	Samoyed	F	30	R L	no no	*G ^G
606024	Samoyed	F	61	R L	yes no	*Trauma? *G_L^G
605635	St. Bernard	F	75	R L	yes yes	*2L>R,AN S2
610776	Chesapeake Bay Ret	F	9	R L	yes yes	*S3
608595	Rottweiler	M	30	R L	no no	*G,^E
608596	Rottweiler	F	30	R L	yes yes	*S1-2NA, R>L,^1
608172	Great Pyrenees	F	21	R L	yes yes	*SO_L
611591	Samoyed	M	68	R L	yes yes	*3AN
611586	Samoyed	M	24	R L	yes no	*S
611278	German Shepherd	M	24	R L	yes yes	*3AH
602678	Chow Chow	F	48	R L	no yes	*S_LA
611248	New Foundland	F	26	R L	yes yes	*S1HA1
610043	German Shepherd	M	94	R L	yes yes	*3$O_{R>L}$AN
611172	Rottweiler	F	52	R L	yes no	*2SNA2

Table 1 Continued

606492	Brittany Spaniel	F	14	R	no	*Bor
				L	no	^F
608173	Black Labrador Ret	F	35	R	yes	*Bor
				L	yes	^F
608396	Golden Retriever	M	31	R	yes	*S1HN1
				L	yes	^2HNA
611027	Brittany Spaniel	M	9	R	yes	*S3AN1
				L	yes	
609842	German Shepherd	M	25	R	yes	*1HN
				L	no	
611281	Rottweiler	F	8	R	yes	*$S_{R>L}3A_R$
				L	yes	
610345	Rottweiler	M	10	R	yes	*AS3
				L	yes	L>R

Table 2. Angle of inclination and torsion for the right and left limb given in degrees.

CASE	RINC	LINC	RTORS	LTORS
604258	152.65	148.75	29.733	36.87
601613	144.59	143.08	35.70	39.80
600521	153.21	156.90	36.87	40.37
606392	146.99	141.93	41.35	42.52
607549	136.88	142.05	43.92	39.62
605432	134.85	147.34	39.10	46.11
605430	140.91	148.00	26.57	31.70
605607	158.02	158.18	25.63	24.62
604512	146.53	150.16	36.47	31.77
600781	145.75	152.14	28.07	32.62
610495	149.80	158.54	33.08	43.15
588618	146.42	139.65	42.72	58.40
605811	144.98	146.29	34.52	43.03
605809	137.30	135.68	32.15	36.87
601676	143.10	143.25	33.68	33.18
605810	140.73	141.90	40.15	37.15
604669	146.83	138.53	32.73	45.00
604962	146.58	150.09	42.35	35.83
592691	141.76	139.64	42.88	45.00
605191	136.80	140.46	33.68	35.22

RINC - Right Rear Leg, Angle of Inclination
LINC - Left Rear Leg, Angle of Inclination
RTORS - Right Rear Leg Angle of Torsion
LTORS - Left Rear Leg Angle of Torsion

Table 2 Continued

605190	142.51	149.30	41.18	47.11
610550	140.77	150.67	45.00	49.63
606904	138.22	139.49	35.60	37.87
606903	149.43	139.97	46.85	46.58
606197	138.18	146.56	29.17	36.38
603034	143.10	145.37	33.68	33.27
605006	131.14	136.86	38.13	33.17
591800	136.13	139.69	40.92	37.33
606792	151.28	150.26	48.37	45.00
606791	147.28	147.65	40.60	24.30
600083	143.73	138.66	31.60	34.33
606023	141.90	157.71	37.15	37.57
606024	142.16	151.40	29.75	26.57
605635	156.65	156.32	41.18	42.18
610776	146.45	151.23	39.80	42.62
610494	156.62	161.92	45.00	45.00
608595	141.92	147.90	51.50	49.90
608596	141.33	144.84	48.37	55.00
608172	155.74	142.19	36.15	48.83
611591	154.93	159.67	49.18	39.28
611586	138.60	144.40	34.52	36.25
611278	146.05	163.32	30.97	33.68
602678	152.15	152.15	46.47	46.47
611248	143.52	150.49	38.67	34.52

Table 2 Continued

610043	134.86	142.82	41.42	34.52
611172	148.64	146.60	33.27	36.25
606492	140.45	142.55	32.00	28.30
608173	145.06	146.04	26.57	34.60
608396	144.43	148.93	19.43	28.17
611027	133.28	158.37	32.00	34.98
609842	140.84	164.23	34.08	41.18
611281	146.04	157.41	37.87	38.67
610345	159.27	145.73	62.23	57.72

and angle of inclination between dysplastic and nondysplastic dogs. There was no significant difference in angles between the two conditions. The mean angle of femoral torsion for the right and left femur in all dogs is given respectively, 37.55° and 39.17°. The mean angle of femoral torsion of the right leg and left leg for nondysplastic animals are given respectively, 36.94° and 38.15°. For dysplastic dogs given in the same order, 38.05° and 40.02°. A two way analysis of variance with a randomized incomplete block was performed to consider any variation due to breed. There was no significance between the dysplastic and nondysplastic group.

The corrected angle of inclination was calculated and these values statistically analyzed. There was no statistical difference between dysplastic and nondysplastic dogs, for the difference right leg to left leg, in the angle of inclination. When all dogs were considered without attention to breed, the angles of inclination for dysplastic and nondysplastic dogs were statistically different for the right and left leg considered separately. When breed variation was considered using an analysis of variance, randomized incomplete block, there was no significance between right leg and left leg considered separately, in dysplastic and nondysplastic dogs. The mean value for the right and left leg angle of inclination in nondysplastic dogs was 142.63° and 145.73°, respectively.

The mean values for angle of inclination for dysplastic dogs was 146.34° and 149.85° right and left respectively.

DISCUSSION

Congenital dislocations of the hip in human and canine hip dysplasia are different entities. The extrapolation of information from the human medical literature for treatment of canine hip dysplasia has been considerable. Unfortunately many of the steps taken to characterize congenital dislocation of the hip in humans have not been performed in the canine. Limitations have included availability of imagining modalities and financial considerations. Veterinary clients may or may not chose to have procedures performed which may involve risk or the chance of future surgeries. Therefore the aim has been to find a single solution to hip dysplasia which will work in most cases. The canine population is extremely heterogenous. Hip dysplasia has been found to be a challenge. Screening through the Orthopedic Foundation for Animals, Inc. (OFA) has resulted in a decrease in frequency of hip dysplasia in 79 % of breeds, from 1972 to 1980 (Corley, 1992). A recommendation concerning the breeding of canine species with a high incidence of hip dysplasia has been to review the certification of the sire and dam for at least several generations. Due to the mode of inheritance, this may not guarantee an owner that an animal will be free of dysplasia. Animals are certified by the OFA at twenty-four months of age; this age will include the majority of animals who will become dysplastic (Corley 1985, 1987). Veterinarians have not routinely screened the coxofemoral joints of very young puppies throughout the growth period. The normal acetabular angle has not been determined. Nor do we know the significance of this angle in canine hip dysplasia. Although femoral anteversion is still discussed in congenital dislocation of the hip in humans, it is seen as an effect of hip dysplasia leading to secondary osteoarthrosis in humans. Increased femoral anteversion has been shown to correct once centralization of the femoral head within the acetabulum is achieved in humans. There are specific ages for this occurring in the human and a specific amount of anteversion which can be corrected over this time frame. With the advent of newer imaging modalities some investigators find no difference in angles of anteversion in humans with and without congenital hip dysplasia. Again this may be a factor of the age at which these patients were evaluated. These parameters have not been fully explored in the canine. This study has shown that dogs with hip dysplasia do not differ significantly in their angles of femoral anteversion from normal dogs.

This study found that the angles of inclination were significantly different between dysplastic and normal dogs when the right leg of normals was compared to the right leg of dysplastic dogs and when the left legs were also similarly compared. This is not consistent with what has been reported in the literature (Hauptman 1985). When breed was considered this difference was not significant. A possible explanation is that the sample size of each breed represented in this study is too small to afford conclusive statistics. Hauptman's study utilized two specific breeds and a cross between the two breeds. His sample size was small as compared with the total numbers of this study. It may be necessary to consider large sample sizes to draw conclusive results concerning angle of inclination.

The effect of age was not considered in this study. All dogs were mature enough to image the epiphysis and therefore provide an accurate assessment of femoral head coverage and congruency of the coxofemoral joint with standard radiographic views. This study represented a realistic population of animals presenting to a veterinary clinic. Previous studies were performed utilizing a single breed or restricted sample population.

Consideration of surgical procedures to provide congruency of the coxofemoral joint should involve careful evaluation of the components of the hip. Directly relating human medical techniques to the dog has not proven to be effective in preventing osteoarthrosis. Unlike humans, the intertrochanteric osteotomy has not proven to be effective in halting osteoarthrosis of the hip when performed in young dogs. Correction of coxo valga and large anterversion angles has produced radiographic congruency in the hip joint;

however, osteoarthrosis is a common finding in adult dogs who have undergone this procedure at two years of age and younger. Perhaps the procedure is not performed at the appropriate age or perhaps the case selection for this procedure is poor. The triple pelvic osteotomy, however, has shown considerable promise in the prevention of osteoarthrosis in the canine. Experience has shown that dogs with very shallow acetabula and severe subluxation or luxation of the femoral head are not good candidates for this procedure as coverage of the femoral head cannot be achieved. Likewise dogs with radiographic presence of osteoarthrosis continue to show progressive osteoarthrosis despite improved femoral head coverage. However, clinically all dogs appear to do well following surgery. Force plate analysis of the operated limb indicated more use of this leg compared to the affected nonoperated side following the post-operative period (McLaughlin 1991).

Given that subluxation of the femoral head produces increased femoral head forces, the effect of the triple pelvic osteotomy is to decrease that force by providing coverage of the femoral head and disperse the force along the dorsal rim of the acetabulum. This may account for the positive clinical and radiographic paucity of osteoarthrosis when this surgery is performed prior to the occurrence of osteoarthrosis. The progression of osteoarthrosis in the joint with osteoarthrosis prior to the triple pelvic osteotomy may be due to the progression of the inflammatory components inherent in degenerative joint disease, regardless of the decreased forces acting upon the joint. Nonetheless, it is advantageous to perform this surgery on very young dogs as they will be capable of conforming and maximizing the effects of congruency between the femoral head and acetabulum.

The intertrochanteric osteotomy may not be as effective a procedure as the femoral head lengthening technique described by Slocum (1988). The reason lies in the effective length of the lever arm. With the intertrochanteric osteotomy the lever arm is not increased as the osteotomy results in a decreased angle of femoral neck inclination without a concomitant increase in distance between femoral head and greater trochanter. The femoral neck lengthening technique however, by increasing the distance from femoral head and greater trochanter, decreases femoral neck inclination and increases the lever arm, thus decreasing the force acting on the femoral head. The femoral neck lengthening technique should be considered in conjunction with the triple pelvic osteotomy when the acetabulum is shallow and providing poor coverage of the femoral head. It should also be considered when the degree of subluxation is so great that rotation of the pelvis does not offer congruency of the femoral head and acetabulum.

In summary the angle of femoral neck anteversion was not found to be significantly different in the normal canine versus the dysplastic canine. The angle of femoral neck inclination however was found to be significantly different in the normal canine versus the displastic canine. Procedures for the treatment of hip dysplasia should be based on sound biomechanical studies of the hip. Further studies using other radiographic modalities to better evaluate the luxation of the hip and the congruency provided by the various surgical techniques are needed. Retrospective studies evaluating radiographic signs of osteoarthrosis and congruency versus age at which the procedure is performed should be considered.

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