

DEVELOPMENTAL ORTHOPAEDIC DISEASE IN THOROUGHBRED FOALS
AN EPIDEMIOLOGICAL COMPARISON BETWEEN A STUD IN IRELAND
AND A STUD IN AUSTRALIA

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A thesis submitted in fulfilment of the requirements for the degree of
Master of Science in Veterinary Science

Faculty of Veterinary Science

The University of Sydney

2007

SUMMARY

Developmental Orthopaedic Disease (DOD) describes problems affecting the limbs of young horses, including abnormal bone, joint and tendon development. DOD is responsible for major economic losses in the Thoroughbred industry. Investigation into the epidemiology of DOD in Australia and Ireland as described in this thesis has allowed valuable comparisons and recommendations to be made between the studs in these countries.

The project described in this thesis commenced in 1999, with the aim to:

- a) Establish the incidence of DOD on a stud in Australia and to compare this with similar data for a stud in Ireland
- b) To determine relationships between factors affecting severity and incidence of DOD in foals with respect to the country in which they are bred and raised
- c) To further identify risk factor areas associated with the development of DOD

Records of 1717 mares from a major stud in Ireland and another in Australia were made available. Foal weight, age of mare, condition of mare, foal sire and date of birth were monitored over two years. The occurrence of DOD was recorded against these data.

The incidence of DOD was found to be higher on the stud in Australia (average 49.85%) than on the stud in Ireland (average 14%). Foal weight was found to be a significant factor affecting DOD, with heavier foals showing a proportionally higher severity of the problem. The Australian stud had a higher incidence of DOD in 2000 compared to 1999 (65.2% affected vs 32.1% in 1999), whereas the Irish stud had a lower incidence in 1999 compared to 2000 (11.8% affected vs 16.2% in 2000). The dramatic increase in the incidence of DOD in Australian foals over the 1999-2000 period is representative of the increase in a major problem in the industry, as well as greater awareness of the problem

over recent years. It highlights the urgent need for further research into understanding the cause(s) of DOD. Overall recommendations arising from the study include that a large scale, long term study be undertaken in Australia. Further investigation into the nutrition of horses in Ireland and Australia would be of great usefulness in understanding DOD, as would possible genetic links. An issue requiring attention is that of developing a standard definition of the disorder. Considering the wide range of disorders which may fit under the umbrella term DOD, a clear definition is of great importance.

The incidence of DOD on one large farm in Ireland was found to be currently low and stable relative to its another large stud farm in Australia. This is a significant finding as the genetic pool of the horses share similarities on both farms, particularly as stallions shuttling between hemispheres sire many foals on both farms. Thus, the data provided herein provide an excellent basis for further valuable comparative studies investigating DOD in foals with a similar genetic background but subjected to differing environmental conditions.

DECLARATION

The work presented in this thesis is original and was undertaken whilst working on two large studs in Ireland and Australia.

The work presented in this thesis does not incorporate any material that has been previously submitted for another degree in any university. To the best of my knowledge, it contains no material previously published or written by another person, except where due reference is made.

Michelle Marshall

March, 2007

ACKNOWLEDGEMENTS

I would like to thank my supervisors Professor Wayne Bryden and Professor David Hodgson from the University of Sydney, and Professor Stuart Reid from the University of Glasgow. They have provided the support necessary both to commence the project, and for its completion. A special thanks to Stuart for making my time at the University of Glasgow so enjoyable.

I would also like to extend my gratitude to Dr Peter Thomson of the Biometry Department for his dedicated assistance in the statistical analysis that constitutes such a big part of this study. Although based away from the University and often overseas, I felt very well assisted by the University system, especially through the friendly support of Tess LaLande in the Veterinary Faculty administration. Dr Julie Cavanagh has been a wealth of assistance, encouragement and advice right throughout my candidature, as well as being a great friend, thanks Julie! Dr Imke Tammen has also been of great assistance during this thesis, she was always very approachable and understanding.

My heartfelt thanks to the two farms involved for providing the essential information for the study, as well as a good wage and some wonderful life experience! Management, office staff and farm staff in both Australia and Ireland were always willing to help. I would like to thank everyone for their efforts.

Importantly, thanks to my husband Craig and my family and friends for always supporting and encouraging me throughout the rather prolonged journey of my Masters! Things would have been a lot tougher without my mum who provided many hours of childcare for my daughters, Eva and Rosalee, thanks mum!

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ABBREVIATIONS

DOD developmental orthopaedic disease

ALD angular limb deformity

DDF deep digital flexor

OC osteochondrosis

OCD osteochondrosis dissecans

CVM cervical vertebral malformation

NRC Nutritional Research Centre

Ire Ireland

Aus Australia

CSS cervical static stenosis

CVI cervical vertebral instability

CHAPTER 1

Introduction

The term Developmental Orthopaedic Disease (DOD) describes a group of conditions affecting the growth of young animals. With reference to the horse, manifestations of this syndrome include angular and flexural deformities, osteochondrosis, subchondral bone cysts, physitis and cervical vertebral malformation/malarticulation (Harrison & Edwards, 1996). All of these disorders have been connected with the incidence of a primary lesion in the articular cartilage that produces failure in endochondral ossification. In this study the classification as per Harrison and Edwards (1996) was used as it includes the disorders commonly diagnosed in Thoroughbred foals on the farms involved in the study. The definition does not include cuboidal bone malformation, juvenile arthrosis of the pastern joint and juvenile spavin, or the incidence of bony fragments on the palmar/plantar surface of the first phalanx in Standardbreds (Pool 1993).

A major setback in the development of a greater understanding of DOD despite ongoing research is the problem of inadequate classification. Many distinct conditions are classified under the term DOD or osteochondrosis. If case definition is not adequate, confusion may result when attempts are made to identify trends in disease incidence and associations of the disease with possible risk factors. Confounding between different factors or between factors, which may have an effect on one, but not another DOD/manifestation of OCD, can lead to erroneous conclusions (Pickersgill *et al*, 1998).

The cause of DOD is not fully elucidated but appears to be an intricate interaction of different factors including genetics, rapid growth rate, high energy/protein diet, mineral imbalance, hormonal dysfunction and biomechanical trauma. The highest incidence of

DOD occurs commonly when foals are between three and nine months of age (Schofield, 1999).

Epidemiology is the study of disease at the population level (Wood, 1992), and involves assessing the relationship of various factors determining frequency and distribution of disease in a population. Interpretation of information gathered from an epidemiological study is often used in designing and implementing preventative and control programmes. One of the key benefits of epidemiological methods as a ‘research tool’ is that it enables a disease to be studied in its natural setting, usually avoiding both ethical problems and the need to extrapolate results from the experimental laboratory to the field situation. It also allows monitoring of the disease prevalence and incidence over large numbers of animals.

The use of epidemiological techniques to conduct this study investigating the incidence of DOD on a stud in Ireland and another in Australia enables evaluation and comparison of this disease within the boundaries of case definition, and the absence of replication within both countries. The scale of the study provides an ideal base for sound experimental design. Expensive costs usually incurred in longitudinal cohort studies were bypassed due to cooperation of the studs involved. Although observational studies carry the risk of confounding, the advantages are many. The study is non-invasive, evaluative, multidisciplinary and relevant to the Thoroughbred industry (Reid, 1998).

CHAPTER 2

Literature Review

2.1 Developmental Orthopaedic Disease

DOD occurs in all parts of the world. Dogs, cattle, horses, chickens, pigs, cats and man are all affected. Genetics plays an important role in DOD. Certain aspects of phenotypic selection, such as breeding for large animals and rapid growth rate, have caused an increased prevalence of DOD (Aldred, 1998). An example has been observed in a recent study involving dog breeds. Medium to large breed dogs have been found to be affected by hypertrophic osteodystrophy (Tyrrell, 2004).

It is also noted that in pigs, the prevalence of degenerative joint disease and osteochondrosis reaches close to 100% in some groups of stock, particularly breeding animals (Done and Goody, 1995).

Although genetic commonalities across mammalian species allows prediction of relevant gene location in different species (Hodgson, 2007), epidemiological studies are needed to ascertain both internal and external factors affecting these genes.

Nutrition is a common factor affecting DOD incidence in various species. It has been shown that feeding high dietary calcium to pregnant ewes caused osteochondrosis (OC) in their foetuses (Carlos *et al.*, 1989). Growth rates are associated with DOD in horses (Jeffcott, 1991), pigs (Grondalen, 1974), cattle (Dutra, 1999) and broilers (Bradshaw, 2002). Livestock production systems require nutritional management in order to reduce the risk of developing DOD within their populations.

When reviewing findings on DOD in various species, osteochondrosis dissecans (OCD) stands out as the most important cause of lameness. OCD has been reported in man (Green, 1966) and dogs (Olsson, 1977), and has also been described in growing pigs (Grondalen, 1974), cats (Ralphs, 2005) and feedlot cattle (Jensen *et al.*, 1981). Essential features of the disease in horses are similar to those found in other species (Lindsell, 1983).

Osteochondrosis is seen as a dynamic and complex process involving both pathology and repair (Van Weeren, 2005) of articular cartilage. The development of techniques to ameliorate this condition will be of benefit to all species affected.

Recent advances in proteomics (analysis of protein fractions in joint fluid), using novel biochip technology have allowed simultaneous measurement of a large number of expressed proteins, which is known as proteomic profiling (Seibert *et al.*, 2004). This emerging field of clinical proteomics involves analysis of protein expression profiles of complex samples such as synovial fluid or blood (Aldred *et al.*, 2004). The use of proteomics permits *de novo* discovery of disease-associated biomarkers. Progress in developing such techniques to identify carriers will contribute much towards the goal of reducing DOD across different species.

Although definite breed predilections have been established in dogs (Harrison & Hohn, 1975) and pigs (Grondalen, 1974), the hereditary nature of OCD in horses has not been fully established. Recent evidence suggests this condition in horses has a multifactorial basis with genetic factors being major contributors to the disorder (Philipsson, 1996; Pieramati *et al.*, 2003). Stallions that frequently produce foals with DOD are being intensively utilised (Nery *et al.*, 2006) in the Thoroughbred industry. Evidence of the heritability of OCD would enable improvement in breeding programs so as to reduce the incidence of this problem.

Epidemiology has played an important role in monitoring disease problems in different species. It can be used to assess i) the effects of preventative interventions, ii) the importance of predisposing factors in the development of a condition and iii) the aetiology of a disease (Wood, 1992). Although there is much information published on DOD within different species, large-scale epidemiological studies are relatively scarce. These studies are able to directly compare the effect of environment (and factors within), on the disease incidence within a genetically similar population.

The thoroughbred horse industry has substantial economic impact worldwide. Large populations create ideal conditions for epidemiological monitoring of DOD. Opportunities to monitor DOD in equines, as well as other species are invaluable towards increasing knowledge and reducing disease incidence.

2.1.1 DOD in the Thoroughbred Industry

In horses Thoroughbred, Standardbred, Quarter Horse and Warmblood breeds are the breeds most frequently affected. Thoroughbred racing in Australia is the third largest industry in the country, with a turnover estimated to be twenty billion dollars per year (Bailey, 1998). Australia has the second largest Thoroughbred broodmare population in the world, after the USA (Aldred, 1998). In 1998, developmental orthopaedic disease was estimated to be costing the industry an estimated \$9.8 million every season (RIRDC, 1998), and the problem has been shown to be increasing such that the cost is likely to much greater now. As many as 10% of foals born are not eligible to be sold through yearling sales due to DOD (RIRDC, 1999). A study in Australia has found the prevalence of DOD up to 32.5 % in Thoroughbred foals from 7 studs in the Hunter Valley (Pickersgill *et al.*, 1998).

Arguably, given the incidence of this disorder further investigations into the causes of DOD are urgently needed in Australia. The results of such studies will be of great benefit to the Thoroughbred industry.

Ireland has a much lower and less rapidly increasing incidence of DOD than Australia. In a study conducted in 1992 by O'Donohue, Smith and Strickland it was found that angular limb deformities and physeal dysplasia were the predominant conditions present in Thoroughbreds from birth through to 18 months of age. Only 11.3 % of animals surveyed from 46 studs (1711 animals) required treatment for DOD (O'Donohue *et al.*, 1992).

Thus, given the apparent disparity in the frequency of occurrence of DOD in Australia compared to Ireland research into the epidemiology of this group of disorders in both countries will allow valuable comparisons and recommendations to be made. This was the starting point for the studies undertaken by the author as reported in this thesis.

2.2 Types of Developmental Orthopaedic Disease

2.2.1 Angular Limb Deformities (ALDs) /Flexural deformities

2.2.1.1 Clinical Signs and Categories of ALDs

Angular limb deformities present as lateral or medial deviation of the lower leg involving carpal, hock or fetlock joints. They may also be in association with variable degrees of rotational and axial deviation.

- **Rotational** deformities may be seen either alone or in combination with other angular deformities. Outward rotation of the whole forelimb is often seen in conjunction with a narrow chest and generally improves as the foal grows and the chest broadens (Barr, 1995). Rotational deformities of the distal limb alone are more complicated, with no

straightforward treatment recommended. Rotation often accompanies valgus and varus deformity, outward and inward respectively. These deformities will often improve markedly if the underlying angular deformity is corrected (Bramlage & Embertson, 1990).

- **Axial** deformities involve offsetting of distal limb bones relative to the proximal limb e.g. ‘bench knees’, where the carpus and metacarpus are displaced laterally relative to the distal radius. This alters the axis of weight bearing through the limb and may accentuate the effect of accompanying axial deformities (Barr, 1995).

Carpal valgus or ‘knock knees’ is the most common presentation (Chan & Munroe, 1996). This term refers to outward deviation of the distal limb originating at the level of the carpus (see photo Appendix 2, p. 94).

ALDs occur as an **acquired** or **congenital** defect:

- **Congenital** deformities are present at birth and are found in the distal interphalangeal (coffin) joint, metacarpo-/metatarsophalangeal joint, carpus and rarely, the tarsus. One or more joints and limbs may be affected at one time.

- **Acquired** deformities are not present at birth, but appear as the foal develops.

Major predisposing factors include poor conformation, laxity of joints, immature bones in the carpus or tarsus, growth imbalance at the physis (i.e. excessive loading of one side of the growth plate following birth), and trauma to the growth plate (Wagner & Watrous, 1991). These factors lead to uneven stress and hence uneven growth at the growth plate. ALDs usually develop as a result of asymmetrical growth from the distal radial physis (Barr, 1995).

Immature bones in the carpus or tarsus may be affected by defective ossification. At birth the cuboidal bones of the carpus and tarsus are in the form of cartilaginous templates with osseous centres. Gradually, these bony centres expand by endochondral ossification

proceeding radially to reach the extremities of the cartilaginous precursors at approximately age 30 days, thereby assuming their mature shape and form. Defects in this process can occur in any young foal, but premature/dysmature foals are most commonly affected.

When a foal injures any of its limbs or joints, trauma is followed by pain, heat, swelling and lameness. Angulation does not occur for several weeks to months after the injury. The growing germinal cells of the growth plate are damaged, allowing premature closure on one side of the plate. As the other side of the plate continues to grow, the leg begins to deviate. This type of injury is called a physal fracture (Wagner & Watrous, 1991). If the condition is diagnosed quickly, retarding growth on the opposite side of the limb may stop further angulation. Often the condition is not recognised until the limb begins to deviate, and there is little that can be done to straighten the leg.

2.2.1.2 Pathogenesis of ALDs

• Joint Laxity

The majority of ALDs present at birth are due to joint laxity (see photographs Appendix 2 pp. 95, 99, 100). Intrauterine malpositioning of limbs can lead to asymmetric growth of the metaphysis and/or epiphysis of the carpal and small metacarpal bones, and result in joint laxity (Rooney, 1966, 1977; Fackelman, 1984). This laxity may result in the development of an angular limb deformity through asymmetric nonphysiological compressive forces (McIlwraith, 1987).

Over-nutrition of the mare in the last third of pregnancy may cause the deposition of enough intra abdominal adipose tissue to compress the uterus, leading to malpositioning of at least one limb (McIlwraith, 1987).

Following birth regular gentle exercise will help the muscles, tendons and periarticular structures of the affected limb/s to gradually strengthen and increase in tone. Most cases of ALDs associated with joint laxity that present at birth correct themselves within a few days of life (Chan & Munroe, 1996).

Cases which do not resolve spontaneously require further examination and management. Gross instability in the medial or lateral direction without bony crepitus is usually evident on examination. Multiple joints may be involved and valgus/varus deformities can occur in different parts of the limb/s. Lameness is not usually present, and the growth plate is not affected at this point (Auer, 1992).

• **Incomplete Ossification**

Incomplete ossification (hypoplasia) of the cuboidal bones of the carpus and tarsus may cause congenital angular limb deformities. Basically two types of changes are observed (McIlwraith, 1987):

- 1) the cuboidal bones are of an abnormal size and shape, and
- 2) the articular cartilage associated with these bones is increased in size.

The reduced height of the hypoplastic bone creates an angular limb deformity.

Many premature and dysmature foals showing signs of hypoplasia have been subjected to foetal growth retardation. Causes of foetal growth retardation include severe metabolic or parasitic disease in the mare, twin pregnancy, poor mare nutrition, or secondary to placental disease such as placentitis (Savage & Lewis, 1987). The most common manifestations of these problems are angular limb deformities of the **carpus** (usually valgus), often present at birth. These either remain static or worsen rapidly in the first few weeks post partum due to exercise deforming the soft cartilage structures.

There is no pain or swelling in the joint initially and usually no lameness. An increased range of movement within the joint may be seen. Some cases undergo secondary degenerative disease and remain permanently lame. Left unsupported, the bones may become crushed and deformed as the foal grows. The epiphyses adjacent to the joint may become wedge shaped (Auer, 1980).

Defective ossification is also seen in the **tarsus** and is termed collapse of the third and/or central tarsal bones. Cases are often bilateral and individuals can present with excessive flexion of the hocks ('curby conformation'), leading to a characteristic 'bunny hop' gait. This condition can also result in valgus deformity of the tarsus (Auer, 1992).

Limb support is indicated to allow ossification to progress. Complicated cases can develop osteoarthritis of the intertarsal joints resulting in chronic lameness.

• **Contracted Limb Syndrome**

Contracted limb syndrome is an uncommon syndrome describing a variety of combinations of congenital appendicular and axial contractures and curvatures in the foal. These include arthrogryposis (deformity of the limbs characterised by curvature of the limbs, multiple articular rigidities and dysplasia of the muscles), torticollis or wry-neck (lateral bending and rotation of the cervical spine), scoliosis (lateral deviation usually involving the last part of the thoracic and first part of the lumbar spine), lordosis and kyphosis (ventral and dorsal curvature respectively of the last part of the thoracic and first part of the lumbar spine), varying degrees of flexural deformity involving the carpus, fetlocks and occasionally, tarsus and asymmetric formation of the cranium or 'wry nose' (Chan & Munroe, 1996). These conditions may occur on their own, or combinations. Mild deformities may resolve given time and correct treatment.

Most cases of flexural deformities (contraction) are acquired between the ages of six weeks and six months (Auer, 1992), (see photographs Appendix 2 pp.91-93).

Club foot is a malformation of one or more feet that is permanent once it develops. In young horses it may be congenital or a result of nutritional deficiencies during growth. The affected hoof (hooves) appears smaller and more upright than unaffected feet. Although not exclusively diagnostic a hoof measurement may indicate an angle of 60 degrees or greater (Rose & Hodgson, 1993). Regular trimming of affected feet may enable the horse to be suitable for athletic use.

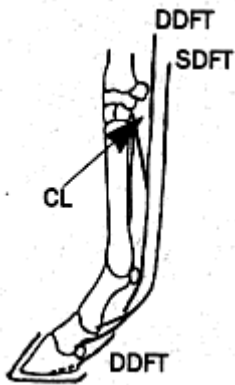
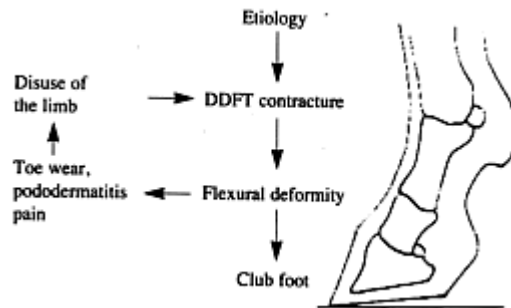


Figure 2.1. The relationship between the flexor tendons and bones in the forelimbs of the horse. CL = check ligament
DDFT=deep digital flexor tendon
SDFT= superficial digital flexor tendon
(Source: Avisar, 1997).

The deep digital flexor tendon (DDFT) is attached to the solar aspect of the coffin bone and its muscle flexes the limb during movement. When an injured limb is in disuse, the flexor muscle flexes the coffin joint, predisposing it to the development of club foot. The superficial digital flexor tendon (SDFT) is attached to the first and second phalangeal bones; when the muscle contracts, it results in knuckling of the fetlock. DDFT contraction is more common in suckling foals, while SDFT contraction is seen more often in weanlings and yearlings (Avisar, 1997).

Figure 2.2. Flow chart showing the development of club foot in a foal (Source: Avisar, 1997). The abnormal position of the toe can start a cycle that complicates flexural deformity.



DDFT= deep digital flexor tendon

• Others

Further factors postulated to contribute to congenital limb deformities include toxic insults during early embryonic life, genetic factors, influenza virus affecting pregnant mares, mares fed goitrogenic diets, hormonal influences and neuromuscular disorders (Chan & Munroe, 1996).

2.2.1.3 Specific Deformities (Chan & Munroe, 1996)

• Congenital flexural deformity of the distal interphalangeal joint

The joint shows varying degrees of flexion, such that the foal walks on its toe and the heel does not touch the ground ('ballerina foal'), (Vasey *et al*, 1996). The condition can be uni- or bilateral and may present in association with other flexural deformities.

- *Congenital flexural deformity of the metacarpo-/metatarsophalangeal joint*

There may be varying degrees of flexion of the fetlock joint, which may be uni- or bilateral and often involve the distal joints as well (Chan & Munroe, 1996). The foal tends to knuckle over at the fetlock. This condition affects the hindlimbs more commonly with metatarsophalangeal varus deformities being the most common presentation (Barr, 1995).

- *Congenital flexural deformity of the carpal joint*

Bilateral flexion is usually seen, with most cases exhibiting normal conformation of the distal limb. Affected foals are either able to stand but buckle forward at the carpus, or are unable to stand.

Unilateral cases rapidly develop overuse injuries of the opposite limb and occasionally a severe carpal varus. Surgical intervention has involved tenotomy of the insertions of the *ulnaris lateralis* and *flexor carpi ulnaris* muscle just proximal to the accessory carpal bone (Gerring, 1989).

- *Congenital contracture of the peroneus tertius muscle*

Severe flexure deformity of the tarsus; a rare condition.

- *Congenital hyperextension of newborn foals ('flaccid tendons')*

The pathogenesis and aetiology of this condition are unknown. Some consider it a physiological variant of the limb support mechanisms (McIlwraith, 1987) with others a temporary failure of agonist/antagonist muscle balance (Fackelman, 1984; Wyn-Jones, 1988). It is particularly common in premature foals (< 320 d) or dysmature foals, and is more severe where there is systemic illness or inadequate exercise. Flaccidity of flexor tendons is often accompanied by periarticular ligament laxity and joint instability.

The condition may affect either hind limbs, or occasionally all four limbs of newborn foals (see photographs Appendix 2 pp.96-98). The heavy horse breeds and the Thoroughbred appear to have a higher incidence (Chan & Munroe, 1996).

Most cases resolve spontaneously as the muscle tone and ligament strength improves in the first few days after birth. Chronic untreated cases will eventually develop subluxation of the interphalangeal joint and concomitant degenerative joint disease. The use of heel extension shoes in unresolving or initially severe cases should be considered (Barr, 1995). The results of surgical intervention using tendon shortening Z tenoplasties are variable (Fackelman & Clodius, 1972; Jansson & Ducharme, 2005).

- *Rupture of the common digital extensor tendon*

This condition usually affects both forelimbs and is invariably present along with other musculoskeletal defects. Most cases appear to occur secondary to severe primary carpal and/or fetlock flexure deformities (Yovich *et al.*, 1984). Swelling of the tendon sheath occurs over the dorsolateral surface of the carpus, and is generally noticed shortly after birth. Cases affected bilaterally are common and affected foals may develop a bowlegged, over at the knee stance due to lack of support over the dorsolateral aspect of the carpus. Ultrasonography may be used to confirm the condition and radiography of the carpus confirms the presence of hypoplastic carpal bones (Vasey *et al.*, 1996).

- *Displacement of the deep digital flexor tendon (DDF)*

This is a rare congenital condition. The DDF tendon is abnormally positioned over the medial aspect of the tarsus with the long digital extensor tendon instead of at the sustentaculum tali, which in this condition is usually underdeveloped. An abnormal 'pull' of the distal limb occurs and a varus deformity of the affected limb may result. Surgical correction is necessary and prognosis for soundness is generally good (Chan & Munroe, 1996).

2.2.1.4 Treatment of ALDs

Some degree of angular deformity (usually less than 10⁰) is common in neonatal foals and most will improve within the first 2-4 weeks post partum without any specific treatment (Auer, 1982). If the deformity does not straighten after 14 days, treatment should be considered (Barr, 1995). All types of deformities present should be taken into account when planning a treatment.

Most experts recommend angular deformities at the fetlock should be treated by four weeks of age and those in the carpus or tarsus by four months (Bertone *et al*, 1985; Mitten & Bertone, 1994; Barr, 1995; Vasey *et al*, 1996). After this time closure of the growth plates occurs and surgical intervention may not completely correct the deformity (Wagner & Watrous, 1991). Mild carpal valgus is common during the first year of life and may correct spontaneously by 10 months of age as the foal's chest widens (Bramlage & Embertson, 1990).

- *Nonsurgical management methods*

These principles of management are useful in treating angular limb deformities regardless of the other techniques utilised.

1. Confinement to a large box or small yard while the deformity is present. Excessive exercise tends to exacerbate asymmetric overloading of the angulated limb and structures in the affected region which may worsen the deformity. In particular, foals with cuboidal bone hypoplasia should be confined for 2-3 weeks until ossification is complete (Barr, 1995). Controlled exercise may help in cases of contracted tendons and other limb deformities. Passive manipulation of the affected limb/s may help relax and stretch contracted tendons.

2. As limb angulation leads to asymmetric wear of the hoof, regular rasping of the foot will restore balance. Rasping may be combined with the use of glue-on plastic corrective shoes/Equilox preparations with medial (in the case of valgus deformities) or lateral (in the case of varus deformities) extensions (Vasey, 1996).
3. Affected foals should not be allowed to become overweight. This may mean restricting the mare's diet to control milk production and/or early weaning of the foal (Barr, 1995).

External support in the form of a well padded splint and/or large bandage or tube cast will benefit neonatal foals with deformity due to ligamentous laxity or carpal bone hypoplasia/defective ossification (see photo Appendix 2 p.94). Supports can usually be removed after two to six weeks (Chan & Munroe, 1996). This procedure involves manual straightening, usually under anaesthesia or heavy sedation before the support is applied, and the limb immobilised. The use of braces has been introduced to support the limb in correct alignment but allow joint movement (McIlwraith, 1987). Radiographic re-evaluation should be undertaken every two weeks to determine the degree of ossification. Treatment is maintained until ossification is complete. It is important that splints be rested daily and casts changed after seven to ten days to reduce the chance of pressure sores and assess the response to immobilisation (Fretz, 1980).

Tube casts to support the carpus or hock should end at the metacarpo/metatarsophalangeal joint to allow weight bearing and reduce the risk of secondary tendinous/ligamentous laxity or osteoporosis. Progression of cuboidal bone ossification should be monitored radiographically at 10-14 day intervals (Auer, 1990).

Intravenous oxytetracycline (3g administered I.V.), has been reported to be successful in foals exhibiting congenital flexural deformities, with normal function restored within 72 hours after injection (Lokai, 1992). All foals were less than 14 days of age, and 'contracted foals' (extreme cases not responding to treatment) were not included. It is

postulated that the drug chelates free calcium ions thus preventing their influx into muscle fibres which results in relaxation of these fibres and passive lengthening of the muscle. Mild cases, probably due to some form of myotonia, appear to respond in 24-48 hours.

- *Surgical Intervention*

Angular deformities due to asymmetric growth at a physis are candidates for surgical intervention if they fail to respond to the above treatments. The aim of surgery is to manipulate growth, usually at the distal physis of the longbone proximal to the joint considered, to cause limb straightening.

Age of foal at diagnosis and surgical treatment influences the prognosis for foals with ALD's.

Surgery may involve either 1) hemicircumferential periosteal transection, or 2) temporary transphyseal bridging with either staples or screws and wire (see Appendix 1 p.90). As both techniques depend on continuing growth to straighten the limb, the earlier in the condition surgery is performed, the more rapid and complete will be the response.

Hemicircumferential periosteal transection

Since first described in the early 1980's (Auer 1982; Auer & Martens 1982), the use of periosteal transection and stripping has gained widespread use in the surgical management of angular limb deformities in foals (Auer, 1985, 1989, 1990, 1992; Bertone *et al.*, 1985a, 1985b; McIlwraith & Turner, 1987; Bramlage & Embertson, 1990; Mitten & Bertone, 1994). Periosteal stripping is recommended in cases of moderate ALDs originating at the metaphyses and physes, as well as cases involving wedging of the epiphysis or of the carpal bones.

It is postulated that the periosteum exerts a restraining influence on longitudinal growth of long bones. By releasing this restraint on one side of the bone it is possible to induce asymmetric growth and thereby correct existing deformities. The transection is hence done on the side of the bone that is growing less quickly, i.e. the concave side (lateral in the case of carpus valgus), (Barr, 1995).

The periosteal incision is made around 2.5 cm proximal to the physis. This site is chosen as the periosteum is firmly attached to the bone near the physis. A simple horizontal incision is probably sufficient. However, some surgeons create an inverted 'T' incision and then elevate the flaps of periosteum created from the bone. For carpal valgus deformities, the rudimentary distal ulna should be transected at the caudal end of the horizontal periosteal incision (Auer, 1990).

Temporary transphyseal bridging

The aim is to slow down the rate of growth on the more rapidly growing (ie. convex) side of the physis. For carpal valgus deformity the bridge is applied medially. The use of two screws with one or more figure of eight monofilament stainless steel wires joining them has certain advantages over the use of staples.

- The screws can be placed independently
- Immediate compression across the physis is achieved as the wire/s is tightened
- There is less risk of extrusion as the foal continues to grow

The effect of bridging will continue until:

- Growth at the physis concerned ceases
- The implants break or loosen
- The implants are removed

Implants must therefore be removed once the leg is straight or overcorrection and deviation in the opposite direction may occur.

Reported overall success rates for straightening of affected limbs with either hemicircumferential periosteal transection or transphyseal bridging are high (around 80%) (Fretz & Donecker, 1983; Bertone *et al*, 1985a,b). In very severe cases, combining periosteal stripping on the concave side with transphyseal bridging on the convex side may achieve a more rapid correction (Wagner & Watrous, 1991).

It has been reported that although hemicircumferential periosteal transection won't cause over correction and is easy to perform, it has a less dramatic degree of correction than following transphyseal bridging (Greet, 2000).

Transphyseal bridging tends to be reserved for:

- a) Severe angulation ($>15-20^{\circ}$)
- b) Older animals with less remaining growth potential
- c) Cases that have failed to respond to periosteal transection (Barr, 1995)

Surgical treatment involving tenotomy of the ulnaris lateralis and flexor carpi ulnaris muscles has been investigated (Charman & Vasey, 2008). This treatment is used for cases of carpal flexural deformity. Restoration of a straight palmar carpal angle and athletic pursuit was successful when treating less severe grades of deformity. The study indicates that contrary to the belief that low grade carpal flexural deformities are self-limiting and do not require specific treatment (Auer, 1990; Hunt, 2003; Greet, 2000), this is not always the case. Surgical solution to resolve carpal flexural deformity is recommended.

Corrective wedge ostectomy or osteotomies are surgical procedures, which can be used to correct ALD's after physeal closure has occurred. More skill, experience, equipment and expense are involved when using these techniques. This surgery is usually reserved for valuable animals (Jansson & Ducharme, 2005).

2.2.2 Osteochondrosis (OC)

Osteochondrosis develops as a result of a defect in the process of endochondral ossification (Olsson, 1978). The normal process of growth cartilage maturation and its conversion to bone is disrupted. This leads to retention, thickening and subsequent weakening of cartilage. Separation from bone may then occur.

Lesions can occur at the articular/epiphyseal cartilage complex and/or the metaphyseal growth plate, the two sites of endochondral ossification in long bones. The primary lesion of osteochondrosis directly affects the differentiation and maturation of the cartilage cells and the surrounding matrix that is destined to be replaced by bone (Jeffcott, 1991). Factors such as biomechanical trauma may affect the development of lesions.

2.2.2.1 Pathogenesis

During the normal process of bone growth at the articular/epiphyseal growth cartilage complex and the metaphyseal growth plate, proliferating chondrocytes produce and secrete the extracellular cartilage matrix. Throughout the final stage in endochondral ossification, capillary buds and osteoblasts invade the layer of mineralised cartilage matrix and the chondrocytes gradually disappear. The osteoblasts secrete osteoid and form woven bone that is later replaced by mature bone.

In cases of osteochondrosis, the capillary sprouts fail to penetrate the distal region of the mineralised cartilage matrix, which leads to the failure of the final stages of cartilage maturation, and subsequent modification of the surrounding matrix. These alterations cause retention and thickening of cartilage with subsequent weakening of the articular/epiphyseal cartilage complex.

The balance between metalloproteinases and tissue inhibitors regulates the degradation process effectively. Copper deficient foals have been found to have excessively high metalloproteinases (enzymes secreted by chondrocytes favouring degradation), which may interfere with this balance, reduce collagen cross-linking and predispose the region to biomechanical trauma and further damage (Bridges & Harris, 1988).

Males appear to have a higher incidence of osteochondrosis (Gee *et al.*, 2005). An abnormal growth pattern has been noted in affected individuals (Fisher and Barclay, 1984). Exercise modulates the effects of osteochondrosis biomechanical trauma and over exertion will exacerbate it (Pool, 1986; Bramlage, 1986; Gabel, 1988).

2.2.2.2 Clinical Signs & Diagnosis of OC

Osteochondrosis dissecans (OCD) is the stage of osteochondrosis where cartilage has separated from bone. This stage is likely to cause signs of the disease in the animal due to the development of synovitis. Clinical signs associated with osteochondrosis (OC) are fairly mild, with some cases producing no overt signs in spite of lesions on articular cartilage. Signs are usually restricted to synovial effusion (non-painful distension of the affected joint), and only slight lameness. This may be due to the confinement of lesions to certain areas within the joint. The shoulder joint is the exception with affected animals generally showing obvious lameness, shortened cranial phase to the stride and strong resentment to manipulation of the joint. This joint is a main weight bearing surface and OCD at this location is often accompanied by severe, secondary degenerative joint disease.

Other joints which may be affected are the hock, stifle, and fetlock in order of decreasing frequency. Horses with bilateral hock or stifle involvement may display a stiff, stilted

hind limb gait. Other signs of DOD may be apparent in severe cases (e.g. physal dysplasia, ALD's and contracted tendons).

Affected animals generally show signs between six months and three years of age. Foals under six months of age exhibit a tendency to spend more time lying down. This is often accompanied with swelling in joints, stiffness and difficulty keeping up with other animals in the paddock. Upright limb conformation as a result of rapid growth may also be seen.

The main signs in yearlings or older animals are joint stiffness, flexion responses and lameness of varying degrees. A mechanical influence with activation of subclinical ('silent') lesions has been suggested as these signs are often seen following the commencement of training.

• Pathological Findings

Thickened articular cartilage can become necrotic, presumably as a consequence of inadequate nutrition. Physical stress may lead to the development of cartilage fissures and dissecting cartilage flaps; degeneration of subchondral bone occurs in severe cases. In cases of OCD, free cartilage or osteochondral fragments may be present in the joint resulting in the development of synovitis. Fracture associated with severe pathological damage to the subchondral bone occurs most commonly on the trochlear ridges and the lateral or medial malleoli of the hock. The intermediate ridge of the distal tibia may also develop bony fragments. These are not fractures, but are associated with large amounts of cartilage retention and subsequent separation of the distal extremity of the bone (Jeffcott, 1991).

Bone cysts may form if cartilage damage weakens underlying bone, usually at a site of biomechanical stress or weight bearing (Olsson *et al.*, 1982). In some cases, **subchondral**

bone cysts in the medial femoral condyle cause the animal to show severe lameness as expected from a fracture, but without any joint swelling or specific site localisation of pain to a joint on examination.

Both OCD and subchondral cystic lesions are believed to be part of the same disease process. Dissecting lesions and cystic lesions overlap in their location and may occur in the same horse and even in the same bones (McIlwraith, 1987). Cracks or fissures in articular cartilage allow joint fluid to be forced into the cavity during normal motion (Aldred, 1998).

Secondary osteoarthritis (degenerative joint disease (DJD)) commonly develops wherever OC lesions have been present. A classic example is when this process occurs in the vertebral articulations of the cervical spine. This may progress to produce a stenosis of the vertebral canal causing spinal cord compression. Proprioceptive deficits and signs of ataxia (ie. wobbler syndrome) may result.

• **Radiographic Findings**

Hock

Osteochondrosis occurs in the tibiotarsal joint. The most common locations are the lateral trochlear ridge of the tibial tarsal bone and the dorsal aspect of the intermediate ridge of the distal tibia.

Stifle

Osteochondrosis affects the femoropatellar joint. The most common location is the lateral trochlear ridge of the distal femur, although the medial trochlear ridge and the distal patella can also be affected. This site has the highest incidence of subchondral cystic lesions.

Shoulders

Radiographically, osteochondrosis is seen on the mediolateral projection of the shoulder. Incongruity of the glenoid cavity and humeral head associated with abnormal contour and irregularity of the articulate surfaces is seen, as well as flattening and sclerosis of the caudal aspect of the humeral head.

Fetlock

Osteochondrosis dissecans is identifiable as flattening, erosion or fragmentation of the sagittal ridge of the dorsodistal third metacarpal/metatarsal bone.

• **Arthroscopic/Gross Pathological Findings**

Cartilage is not visible radiographically, hence direct arthroscopic or gross pathological visualisation of articular cartilage may reveal lesions which were not obvious radiographically, or may show that joint pathology is actually more extensive than radiography suggested.

2.2.2.3 Pathogenesis

Heredity/genetic predisposition

A correlation between the incidence of osteochondrosis in the progeny and one particular sire in Standardbred and Swedish Warmblood stallions has been shown (Hoppe & Philipsson, 1985). In another study by Wagner *et al.* (1986), breeding 'wobbler' mares to two stallions affected by OCD resulted in none of the offspring showing signs of ataxia, but seven out of twelve (58%) developed contracted tendons, four (23%) had osteochondrosis in the cervical spine and five (42%) had physeal dysplasia. These data may be interpreted to suggest a genetic basis to this complex of bone and joint disorders

Growth and body size

A high incidence of OC in large framed and rapidly growing animals has been noted (Stromberg, 1979). The most intense phase of growth occurs in the first three months of life, which is when osteochondrosis lesions are most likely to occur. After weaning, growth continues at a relatively rapid rate until the end of the first year of life. A third growth phase may occur around the time of puberty (18 months) (Green 1961; Goyal *et al.*, 1981). The hindlimbs appear to have a faster growth rate than the forelimb in foals, and OC is often seen in hindlimb sites.

Variables such as sex, age of dam, year and month of birth must be taken into account in the analysis of growth data and therefore the occurrence of OC. The suggestions implicating growth rate and body size in the pathogenesis of OC are largely unsubstantiated.

Nutrition

Excessive calorie intake, especially in the form of soluble carbohydrates, is an important factor in the pathogenesis of OC (Glade, 1986). High energy diets have been shown to consistently produce lesions of OC (Savage, 1991).

Foals fed diets rich in calcium in association with high energy diets have been found to develop signs of osteochondrosis (Savage *et al.*, 1993). Diets rich in phosphorus (five times NRC requirements) consistently resulted in signs of osteochondrosis (Savage, 1991). No signs of secondary nutritional hyperparathyroidism were found.

Low copper status has been linked to the formation of osteochondrosis-like lesions (Bridges & Harris, 1998). Further investigation is needed to examine the hypothesis that copper is an over-emphasised factor in the aetiopathogenesis of osteochondrosis (Gee *et al.*, 2005). Increased exposure to zinc, and possibly cadmium has also been found to

result in the development of OC in pony foals, possibly due the creation of a secondary copper deficiency (Kowalczyk *et al.*, 1986).

Endocrine contributions to OC

The endocrine system responds to feeding by increasing concentrations of insulin and glucagon depending on glucose levels. Insulin is released in response to glucose intake, acting to promote storage of glucose. Insulin also acts to promote amino acid uptake, protein synthesis and lipid synthesis.

Diets high in energy and protein are associated with a more rapid peak in insulin concentrations post prandially. High circulating concentrations of insulin can inhibit growth hormone (Glade, 1986).

Some horses produce abnormally high concentrations of insulin in response to increased glucose load. These horses are considered insulin-resistant and have been shown to be more prone to developing OCD lesions (Ralston, 1999).

A study conducted in the USA has indicated that colts and fillies with OCD had abnormally higher concentrations of insulin than their blood glucose concentrations would indicate. When these foals were fed mainly hay or diets low in glucose, their insulin concentrations returned to normal levels and they outgrew the condition by two years of age. They were, however, more likely to develop lesions between three and five months of age compared with non-insulin resistant foals (Ralston, 1999).

Lesions occurring in OC and those associated with equine hypothyroidism are reported to be similar (Glade & Belling, 1984). These authors suggested that the episodic, transient hypothyroidaemia produced by high soluble carbohydrate feeds can cause OC. Glucocorticoids have also been connected to the formation of osteochondrosis-like lesions (Glade & Krook, 1982).

Biomechanical trauma/ exercise

Conformation and body size are factors involved with development of OC lesions. Both can produce abnormal stresses on joints and growth plates (Gabel, 1988). Adequate exercise in foals is assumed to be important for skeletal development. One study, using early weaned Warmblood foals, showed a dramatic reduction in the incidence of OC in foals subjected to forced exercise and a high energy diet compared with foals fed the same diet but with limited exercise (Bruin *et al*, 1992).

Treatment

Management of OC often involves combinations of conservative therapy and surgical intervention. Conservative treatment generally involves rest (stabling or paddock) and restricting feed intake. In addition analysis of the diet and correction of imbalances is recommended. Surgical intervention involves removal of loose fragments from affected joints via arthroscopy or athrotomy.

Preventative measures include:

- 1) ensuring balanced nutrition and a steady growth pattern
- 2) avoiding excess carbohydrate and energy in the diet
- 3) providing adequate exercise after weaning
- 4) ensuring correct dietary copper status in the feed
- 5) avoiding breeding from a known genetic carrier

2.2.3 Physitis (physeal dysplasia, epiphysitis)

2.2.3.1 Clinical Signs and Diagnosis

Inflammation, thickening and flaring of the growth plates/physeal regions in the distal tibia, radius, or third metacarpal/tarsal as well as the cervical vertebrae are all signs of OC. The ends of the longbones are often enlarged, appearing to have an hourglass shape. Signs include 'big knees' or 'apple joints', lameness may be present, often mild and

intermittent. Severe cases will often have accompanying heat or pain on palpation. Radiographs will show abnormalities of the growth plate regions. Irregularity, flaring or widening of the growth plate is seen, as well as callus formation (Aldred, 1998). The condition is self limiting, disappearing as the growth plates close. However, the epiphysis and metaphysis may experience uneven longitudinal bone growth and cause limb deformities later in life.

2.2.3.2 Pathogenesis

Young, rapidly growing foals and weanlings are at most risk between four and eight months of age. Yearlings and horses up to two years of age at the commencement of training are another category in which a high prevalence of OC occurs (Turner, 1987). The condition is associated with OCD, although biomechanical trauma (excess exercise, excess weight or poor confirmation stressing immature bone) has been postulated to cause the disease (Pool, 1989). Many aspects of the disease can be related to high planes of nutrition, especially rations rich in grain, rations with inappropriate mineral balance, as well as high protein concentration.

2.2.3.3 Treatment

Treatment of physitis involves ration evaluation, to correct any deficiencies/ imbalances and to reduce bodyweight. If OCD lesions are present, these may need to be managed using surgical techniques. Any flexural deformities should be managed to reduce the trauma component leading to epiphysis. Nonsteroidal antiinflammatory drugs may be required to manage pain and stiffness, also preventing further development of flexural deformities (Turner, 1987).

2.2.4 Cervical vertebral malformation (CVM) - ‘wobblers’

2.2.4.1 Clinical Signs & Diagnosis

This condition includes malformation of the bones and joints of the cervical vertebrae and also malarticulations and degenerative changes of joints. The spinal cord is compressed in the neck due to narrowing of the vertebral canal, causing weakness, incoordination and an unsteady gait. The signs are most prevalent in the hind legs, but can also progress to involve the forelegs. Pain on palpation of the neck may be seen, as well as reluctance to turn the neck to either side.

The two most common syndromes produced are **cervical vertebral instability (CVI)** centred in the cranial vertebrae of the neck of young horses, typically developing signs in the first year of life, and **cervical static stenosis (CSS)** located caudally in the neck, usually when the horse is between 1 and 4 years of age (Turner, 1987). CVI compresses the spinal cord only when the neck is flexed, while CSS persists in all ranges of neck movement.

Cervical vertebral malformation occurs most frequently in horses six to twelve months old. Males are affected more frequently than females (Turner, 1987).

2.2.4.2 Pathogenesis

The cause of CVM is not agreed upon by researchers. Some connect CVM as a consequence of OCD in the cervical vertebrae (Jeffcott, 1991). Malpositioning in utero causing long term compression of vertebrae has also been suggested, as has chronic joint instability (perhaps stemming from a predisposition to fast growth) resulting in the development of degenerative joint disease (Pool, 1993). Imbalanced nutrition may result in abnormal bone metabolism and growth. Excessive biomechanical forces and trauma placed on developing vertebrae are also factors leading to vertebral deformities and subsequent thickening of joint capsules and ligamentum flavum (interarcuate ligament).

Over time, the ligament enlarges and buckles into the canal, contributing to spinal cord compression.

2.2.4.3 Treatment

Therapy aiming at reducing inflammation within the spinal cord using corticosteroids and phenylbutazone is short term with signs expected to return after drug administration has ceased. Early surgical intervention has greatly improved the possibility of an affected animal returning to a state of useful activity. Surgical fusion of cervical vertebrae to stabilise the area has resulted in neurological improvement over about 15 months following surgery (Turner, 1987). Compression arising from the dorsal laminae and ligamentum flavum is operated on using dorsal laminectomy, with a 12 month recovery period indicated.

2.3 Major Factors Causing DOD in horses

2.3.1 Growth Rate

Growth rate is a key factor when studying the causes of developmental orthopaedic diseases. Age of dam, year and month of birth and sex of the foal influence its subsequent growth. Differences in size/growth present following birth have been found to persist with age.

Smaller foals are less prone to rapid growth and so incur less problems with limb development. A study conducted in the USA using Thoroughbreds found that dams under seven years of age and older than 11 years had foals of lighter weight at birth than mares seven to 11 years of age (Hintz *et al.*, 1979). In these foals the cannon bone length was shorter, and the bone lighter.

Foal growth varies according to year of birth as it relates to a great many factors such as weather, management practices, feed supply, and health conditions.

Foals born later in the foaling season were heavier than those born in the first three months. Size differences in foals at different times of the year may be related to hormone concentrations in the mare changing with variation in daylight length. Colts were heavier than fillies at birth, with these differences increasing with age.

It can hence be hypothesised that foals born to dams between seven and 11 years of age, as well as those born later in the season, are more likely to develop DOD. Colts would also be expected to have an overall higher incidence of limb problems than fillies, again due to their larger size.

Growth of the foal is very rapid in the first 90 days of life. The greatest amount of elongation of bone takes place during this period; hence proper nutrition is of great importance.

Research into growth has produced estimates that Thoroughbred foals reach approximately 46% of their mature weight, and 83% of their mature height at 6 months. At 12 months, they attain 67% of their mature weight and 90% of their mature height. By 18 months, they achieve 80% of their mature weight and 95% of their mature height (Hintz *et al.*, 1979).

Compensatory growth and associated hormone changes may result in DOD. The main cause of compensatory growth patterns is inadequate nutrition for a period, followed by adequate or excessive nutrition (Williams & Pugh, 1993).

A study has shown that four of six foals which were placed on restricted feed intake and hence restricted growth for four months, followed by feed intake *ad libitum* developed

flexural deformities. Control foals fed the same diet *ad libitum* did not develop any form of DOD (Hintz *et al.*, 1976). Feed size and frequency of feeding, time of weaning (early vs late) and creep feeding are factors which may cause DOD if managed incorrectly.

2.3.2 Nutrition

Nutritional influences which increase the risk of DOD can be seen in a number of inter-related factors (Savage, 1991):

- a) Too much energy intake in the diet (versus too much protein)
- b) Low calcium/high phosphorus
- c) High energy intake, with low calcium, high phosphorus or high calcium, low phosphorus
- d) Low copper (dietary or induced by high calcium or high zinc intakes)

Research in Australia has shown that from weaning onwards, problems arise if energy levels greater than 129% of the NRC recommended levels are fed (Savage, 1993). Bone specific gravity, cortical thickness and ash content increase, all of which are associated with the development of OC. Overweight mares may be predisposed to foetal malpositioning, resulting in angular limb deformities. They also have a lowered milk production due to fatty deposits in the udder which may lead to compensatory growth spurts following weaning (Aldred, 1998).

Dietary imbalances where severe protein deficiency is combined with adequate energy intake may cause reduced bone growth without affecting weight gain. This may predispose to DOD (Gibbs *et al.*, 1989).

If a diet low in calcium and high in phosphorus is fed, the ideal 2:1 calcium to phosphorus ratio is disturbed. The excess phosphorus will cause inhibition of calcium absorption, leading to problems in bone development. Lesions consistent with OC were produced in 90% of foals fed a diet containing nearly four times the recommended

concentration of phosphorus, compared to 8% when fed to recommended NRC rates (Savage *et al.*, 1993b).

Vitamin D plays a role in calcium and phosphorus absorption, and calcium mobilisation from bone. A deficiency of this vitamin will result in weak bones (Lewis, 1995). Deficiencies will occur if there is inadequate exposure to sunlight, this is particularly unlikely in Australian conditions.

Copper deficiency will produce flexural deformities and osteochondrosis-like lesions. Diminished stability and strength of bone collagen is related to low copper levels. The cervical spine in particular is affected. The process of collagen cross-linking requires a copper-dependent enzyme, lysyl oxidase (Turner, 1987). Bridges and Harris (1988) noticed a softening of articular cartilage and suggested that low copper status may lead to reduced cross-linking of collagen by lysyl oxidase predisposing to physeal and articular fractures.

The incidence of OCD, phytitis and angular/flexural deformities have been shown to increase with low copper diets (Hurtig *et al.*, 1993). Zinc, iron and perhaps cadmium excesses in the diet may interfere with copper absorption and utilisation, leading to a secondary copper deficiency.

Pasture is an important consideration in the development of DOD. Mineral content of pastures will vary according to the soil type, plant species and improvement (fertilisers etc). The type of pasture being grazed will affect calcium and phosphorus intake. Legume pastures will contain higher concentrations of calcium and lower concentrations of phosphorus compared to grass pastures. Lush pasture may affect calcium concentrations and reduce absorption of this mineral. This type of pasture will also be high in soluble carbohydrates, a factor which has been shown to cause DOD (Savage *et al.*, 1993a).

2.3.3 Trauma /Exercise

Normal bone and joint development will not progress unless adequate exercise occurs in foals. Gradually increasing exercise loads will result in stronger bone through increasing bone cross-sectional area and decreasing porosity. High intensity exercise can increase bone density and strength in young Thoroughbred horses (McCarthy & Jeffcott, 1992). The resulting stronger bones are able to withstand to a greater degree stresses incurred through training and racing.

Excessive bodyweight, abnormal conformation, excessive exercise or uneven weightbearing are all causes of biomechanical trauma. These result in an increased stress to bones and joints. Lesions of DOD may result from excess forces acting on normal cartilage, disturbing the blood supply to the cartilage and causing failure of the process of ossification. Lesions already present are likely to be exacerbated by trauma to joints and bones.

2.3.4 Endocrine Factors

The endocrine system controls cartilage maturation and bone growth. Studies involving other species suggest that insulin, thyroid hormones, growth hormone, parathyroid hormone, peptide growth factors and calcitonin are the most likely to be involved with development of DOD in the horse (Henson *et al*, 1997).

Somatotropin or growth hormone in particular has been shown to increase the severity and incidence of OCD in pigs (He *et al*, 1994). This finding has created interest in the role of somatotropin in the development of lesions in horses.

Horses with hypothyroidism (low active thyroid hormone concentrations) will often display abnormal ossification, delayed maturation of cartilage and OCD (Vivrette *et al.*, 1984).

2.3.5 Genetics

The heritable nature of OC has been proven in the dog (Guthrie *et al*, 1990), chicken (Pierson & Hester, 1982), pig (Reiland *et al*, 1978), and man (Stougaard, 1961). These findings strongly suggest a similar pattern in horses.

Larger, early maturing ‘types’ of Thoroughbreds bring the highest prices at yearling sales. As such they are selected for by breeders. Therefore by selecting these types breeders may also be selecting for an increased risk of DOD.

A relationship between sire and the incidence of OCD has been established in Standardbreds. Two of the seven stallions studied had a much higher incidence of lesions in their progeny, although these stallions displayed no abnormalities when radiographed. This suggests that progeny testing would be useful to select sires to minimise DOD, rather than relying on radiographs of individual stallions (Schougaard *et al.*, 1990).

2.4 Conclusions

The aim of the study was:

- a) To determine if there is a higher incidence of DOD on a stud in Australia compared with a stud in Ireland
- b) To determine if there is a relationship between severity and incidence of DOD, and putative factors affecting DOD on the two studs involved

Epidemiological studies are a valuable tool in our pursuit of knowledge about DOD. The extent of the problem can be ascertained, and comparisons made between populations. An overview of previous studies relating to DOD is essential, allowing focus to be centred on those areas most pertinent to successful comparison of several populations and gaining informative, viable results to further the knowledge of DOD in the horse industry.

CHAPTER 3

Materials and Methods

3.1 General study design

Observational epidemiological methods were used to conduct this longitudinal cohort study. Factors to be included in the study were carefully considered before data collection began to address the possibility of confounding in the findings. Confounding may occur where multiple factors within a system vary, so we are reliant on having included the important ones. If these are not measured then effects may be found to be significant but attributed to the wrong variable, or real effects may be masked. (Morris & Perkins, 1998)

3.2 Data Collection

Two world class Thoroughbred breeding organisations (remaining anonymous for confidentiality reasons), agreed to provide data for the study. Age of mare, foal weights, sire of foal, date of birth and DOD scores were collected from a total of 1717 mares in Ireland and Australia. Management practices were noted to be as similar as is possible in the different countries.

Stud office records in the form of farrier reports, veterinary records and individual animal records/invoices were used as the source of data in both countries. In Australia a computer management program was accessed as the primary data source. In Ireland written reports were the primary data source. Direct observation of horses by the candidate in both countries also expanded the assessment of cases and their management.

These evaluations included photographic records and other ancillary aids (e.g., radiographs, surgical reports) to assist in the accurate scoring of DOD types. Photographs were used to assess mare condition. This condition score was assessed using the system of Huntington and Cleland (1997). Body condition scores were assessed on a scale between 'good', 'fat' and 'very fat' (see Figure 3.1).

Mares with missing data values were removed from the study.

The higher percentage of excluded mares in Australia in 1999 was due to difficulties experienced in following up 20 missed foal weights when the author was not present on the stud in question. The study was able to negate this slight increase due to the large sample of mares available.

Data relevant to the sire was not deemed eligible for inclusion in the study due to the high stallion: mare ratio occurring on the two farms.

Foals were monitored up to weanling age (six months). For many foals data collection beyond this age was compromised due to foals being sold or moving off the farm. Foals that remained on the farm until yearling age (twelve months) were monitored as a subgroup. This information was excluded from the study to maintain consistency and sound experimental design.

The severity of DOD was given a score ranging from 0-6, 0 being no DOD present to 6 being the most severe occurrence (see Table 3.1). This scoring system was developed in discussion with experts. Foals undergoing more than one treatment procedure in separate scoring categories were counted for each treatment procedure.

For the purposes of this study, DOD includes angular and flexural deformities, osteochondrosis, subchondral bone cysts, physitis and cervical vertebral malformation/malarticulation. An angular limb deformity was defined as a medial or

lateral deviation of the lower leg involving carpal, hock or fetlock joints. These deviations may occur in association with degrees of rotational and axial deviation. The scores for DOD in foals included in the study incorporates those with what is considered the most mild forms of DOD through to those with more severe manifestations. Scores for DOD were based on the treatments utilised as it was assumed those with more severe DOD were subjected to more aggressive treatment (see Table 3.1). Treatments for the various forms of DOD ranged from restricted activity ('box rest') through to those requiring more aggressive interventions such as corrective shoeing, periosteal transection and elevation and/or trans-physeal bridging.

Figure 3.1 Body condition scores of mares (Huntington and Cleland, 1997)

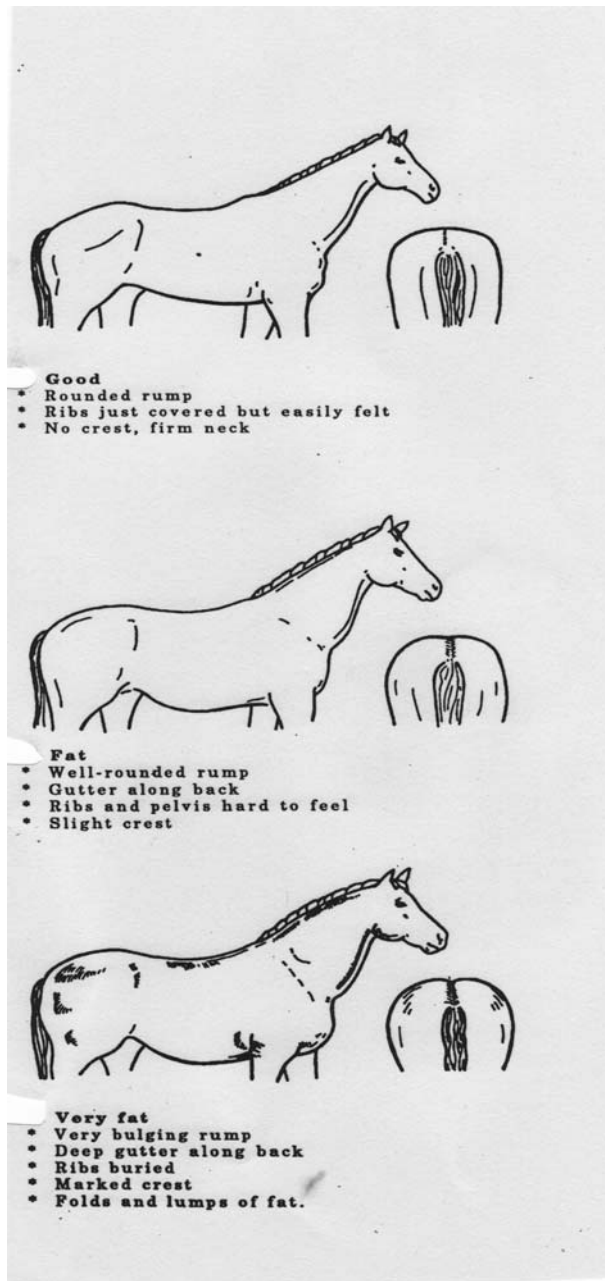


Table 3.1 DOD scoring system based on diagnoses/treatment applied

DOD Score	Category Summary (based on diagnoses/treatment)
0	<i>No DOD</i>
1	<p><i>Boxed:</i></p> <p>Stable rest period based on time taken for limbs to strengthen (several days to several months if surgery required). This treatment is based on limbs having an angulation greater than 8 degrees deviation from the sagittal plane.</p> <p><i>Windswept boxed:</i></p> <p>Hind limbs affected creating a classic ‘hooked’ appearance in hind legs (see Appendix 2, pp.96-98)</p>
2	<p><i>Equilox™ extension/s, Dalric™ shoe/s:</i></p> <p>Acrylic Equilox is used to reconstruct the toe and protect it while providing normal hoof function, this product may be filed back as changes in angulations are noticed. The use of glue-on Dalric shoes provides protection to the toe and helps stop the pain/contraction cycle. Length of treatment depends on rate of improvement.</p>
3	<p><i>Splint:</i></p> <p>External support, usually removed after two to six weeks (assessment after seven to ten days).</p>
4	<p><i>Periosteal transection and elevation:</i></p> <p>An incision is made around 2.5 cm proximal to the distal physis of the longbone proximal to the joint affected (see Appendix 1, p.90)</p>
5	<p><i>Double periosteal transection and elevation</i> (two legs require treatment)</p> <p><i>periosteal transection and elevation all four</i> (all legs require treatment)</p>

6	<p><i>Transphyseal bridge:</i></p> <p>Two screws with stainless steel wires joining the mare inserted into the bone on the more rapidly growing side of the physis, e.g. carpal bone (see Appendix 1, p.90) Compression effects slow down the rate of growth.</p> <p><i>Epiphysitis:</i></p> <p>This condition results in the ends of the longbones enlarging, lameness may be present, as well as heat/pain. Most common between four and 8 months of age</p> <p><i>Club foot:</i></p> <p>Abnormally shaped foot, with upright conformation and a foot axis of 60 degrees or more</p> <p><i>OCD:</i></p> <p>Typically presents in yearlings, lameness, swelling and distension of the joint capsule are the main clinical signs. May involve several joints (e.g. stifle and fetlock)</p> <p><i>Euthanasia:</i></p> <p>Reserved for severe deformities, sodium pentobarbitone injection administered (see Appendix 2, pp.101-102)</p>
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3.3 Statistical Analysis

Classification of DOD is ordinal as we have six scores of DOD within a DOD affected population. Due to this, the standard method for predictive modelling, such as linear or binomial logistic regression could not be used. Ordinal logistic regression models (an extension of binary logistic regression), were used (Agresti, 2002). Ordinal logistic

regression models were fitted for each of the variables using Minitab® Release 14 statistical software (Minitab Inc, 2003) to assess their association with the ordered DOD score categories.

The important reason why an ordinal scale was utilised is that the labels given to the DOD types (e.g. 0, 1, 2, 3, 4, 5, 6) are to indicate ordering only, and that the difference in response between an ordinal scale of 0 and 1 (e.g. no DOD and box rest) is not necessarily the same as between 1 and 2 (box rest and extensions/shoes) etc. Ordinal logistic regression allows modelling of the DOD type as an ordered categorical response. Cumulative probabilities are modelled [$\pi_j = P(Y \leq j)$] rather than the probability of obtaining a particular DOD [$\pi_j = P(Y = j)$]. That is,

$$\Upsilon_0 = P(Y = 0) = \pi_0,$$

$$\Upsilon_1 = P(Y \leq 1) = \pi_0 + \pi_1,$$

$$\Upsilon_2 = P(Y \leq 2) = \pi_0 + \pi_1 + \pi_2,$$

$$\Upsilon_3 = P(Y \leq 3) = \pi_0 + \pi_1 + \pi_2 + \pi_3$$

$$\Upsilon_4 = P(Y \leq 4) = \pi_0 + \pi_1 + \pi_2 + \pi_3 + \pi_4$$

$$\Upsilon_5 = P(Y \leq 5) = \pi_0 + \pi_1 + \pi_2 + \pi_3 + \pi_4 + \pi_5$$

with

$$\Upsilon_6 = P(Y \leq 6) = 1.$$

The ordinal logistic model is

$$\log_e[\Upsilon_{ij}/(1 - \Upsilon_{ij})] = \theta_j + \beta_1 x_{i1} + \dots + \beta_p x_{ip}, \quad i = 1, \dots, n; \quad j = 0, \dots, k - 1,$$

where

k = the number of ordered categories (6 here);

Y_{ij} = cumulative probability for DOD score j for the i^{th} observation;

$x_{i1}, x_{i2}, \dots, x_{ip}$ = set of covariates for the i^{th} observation;

$\beta_1, \beta_2, \dots, \beta_p$ = corresponding set of regression coefficients; and

θ_j = cut-point for a DOD score j .

That is, the log-odds of obtaining a certain DOD score or lower is modelled as a linear function of the respondent's covariates (x_1, x_2, \dots, x_p). (Thomson and Bartimote, 2003). The log odds are increased additively by β (coefficient) if x is increased by 1. Note that because the model is for cumulative probabilities, if the estimated regression coefficient (β) is positive, then an *increase* in x will result in an increase in incidence of *lower* DOD scores.

Incidence is defined as the number of cases of DOD divided by the total foals at risk per year. Incidence of DOD scores was calculated based on the cumulative model shown above. Incidence is most appropriately defined as 'cumulative incidence'.

Predictor Variables

Age of dam Age of mare at parturition was recorded as a continuous variable (year units).

Sex Sex of foal was recorded as male or female

Weight Foal weight (kg) (converted from imperial units when necessary)

Year/Country The study was conducted over two foaling seasons, 1999 and 2000. Two countries were involved – Ireland and Australia.

These variables were analysed using Minitab to fit the following ordinal logistic regression models:

$$\log_e[\gamma_j/(1-\gamma_j)] = \theta_j + \text{Country} + \text{Year} + \beta_1 \text{Age} + \beta_2 \text{Weight} + \text{Sex}$$

$$\log_e[\gamma_j/(1-\gamma_j)] = \theta_j + \text{Country} + \text{Year} + \beta_1 \text{Age} + \beta_2 \text{Weight}$$

$$\log_e[\gamma_j/(1-\gamma_j)] = \theta_j + \text{Country} + \text{Year} + \beta_2 \text{Weight}$$

$$\log_e[\gamma_j/(1-\gamma_j)] = \theta_j + \text{Country} \cdot \text{Year} + \beta_2 \text{Weight}$$

As before, γ_j is the probability of obtaining a DOD score of j or lower. The last model was included to assess the combined effect of Country and Year (i.e. interaction).

Note that the logistic model assumes a linear effect of weight on the log-odds scale. As a check of this, a quadratic model was also evaluated,

$$\log_e[\gamma_j/(1-\gamma_j)] = \theta_j + \text{Country} + \text{Year} + \beta_1 \text{Age} + \beta_2 \text{Weight} + \beta_3 \text{Weight}^2 + \text{Sex}$$

to assess any nonlinear effect of weight on DOD scores. Effects of variables on DOD type were deemed statistically significant if $P < 0.05$. Significant factors affecting DOD were tested for interactions i.e. interactions between country and year and weight. Additional assessment of these factor interactions was made by calculating the ‘Event probabilities’ for each DOD. These were averaged and graphed (scatterplot), to provide a visual summary, further demonstrating the effects of weight, country and season.

The form of ordinal logistic regression model fitted to the DOD data is known as a “proportional odds” model, in the sense that if the odds $\gamma_j/(1-\gamma_j)$ are calculated for two any two data points, the ratio of these odds does not depend on the choice of cut point j , hence the odds are always proportional. As a test of this proportionality assumption, a nominal logistic regression was fitted to the same set of data whereby separate regression coefficients are used for each cut point. While the fit of the nominal logistic regression model was significantly better as assessed by a likelihood ratio test ($\chi^2 = 131$, $df = 25$, $P < 0.001$), it was decided to retain the use of this proportional odds form of ordinal model.

This was done because of this being the only readily available software for ordinal analysis, and that the adoption of a nominal logistic regression model would lead to an unwieldy analysis, due to a substantial increase in the complexity (number of parameters) and difficulty in interpretation.

CHAPTER 4

Results

4.1 Overall incidence & DOD score figures

All mares on both studs used in the study were in good to fat condition.

In Australia the percentage of mares excluded in 1999 was 6.03% of the total mares foaled on the stud in the season, in 2000 this percentage was 2.93%. In Ireland total excluded mares represented 2.33% of the total mares foaled on the stud in the season in 1999 and 2.58% in 2000. When examining the groups of excluded mares in both countries, the total average percentage attributed to deceased foals was 1.70%, the remaining mares excluded from the study had weight data missing.

The occurrence of each DOD score was cross tabulated with each country/year using Minitab. The statistics generated as well as percentages are seen in Table 4.1. Confidence intervals for cumulative incidence are shown in Tables 4.2 and 4.4.

Evidence from the two studs for the 1999 and 2000 seasons indicated that the stud in Australia had a greater cumulative incidence of DOD affected foals in both 1999 and 2000. Both Australia and Ireland employed Equiox shoes and Dalric extensions most commonly as treatment for DOD in both years. Australia used more splint/X-ray treatments in 1999 than 2000, and indicated a much greater use of periosteal strips/bridging in 2000.

The overall incidence of DOD in Ireland at the stud was 16.2% in 1999 and 11.8% in 2000. In Australia the overall incidence was 32.1% in 1999 and 67.6 % in 2000. Data

pertaining to OCD was limited as most foals had been moved on by yearling age, either returning home with the mare or sold at sales. OCD cases diagnosed near weaning age are rare; most cases become obvious closer to yearling age.

The incidence of ALD requiring Dalric shoes and Equilox extensions peaked dramatically in Australia in the year 2000, doubling from the previous year. In contrast, the use of the same treatments in Ireland was lower in the year 2000 than in 1999. The average box rest percentage in Ireland was 2.6%, in Australia it was 11.2%. Box rest was also much higher in Australia 2000 than in 1999, as was the use of single/double periosteal strips (see Figure 4.1).

Table 4.1 Comparison of studs during 1999 and 2000 looking at size of foal crop, numbers of foals diagnosed with DOD and the treatments used.

DOD classified by treatment	Ireland 1999	Ireland 1999 %	Ireland 2000	Ireland 2000 %	Australia 1999	Australia 1999 %	Australia 2000	Australia 2000 %
	Foal crop 419		Foal crop 490		Foal crop 411		Foal crop 397	
Score 0	351	83.8	432	88.2	279	67.9	138	34.8
Score 1	10	2.4	13	2.7	6	6.3	64	16.1
Score 2	44	10.5	39	8.0	45	10.9	96	24.2
Score 3	4	1.0	3	0.6	44	10.7	21	5.3
Score 4	8	1.9	2	0.4	10	2.4	22	5.5
Score 5	1	0.2	0	0	2	0.5	33	8.3
Score 6	1	0.2	1	0.2	12	2.9	33	8.3

Key:

Score 0 - No DOD

Score 1- Box rest

Score 2 - Equiox extensions, Dalric shoe

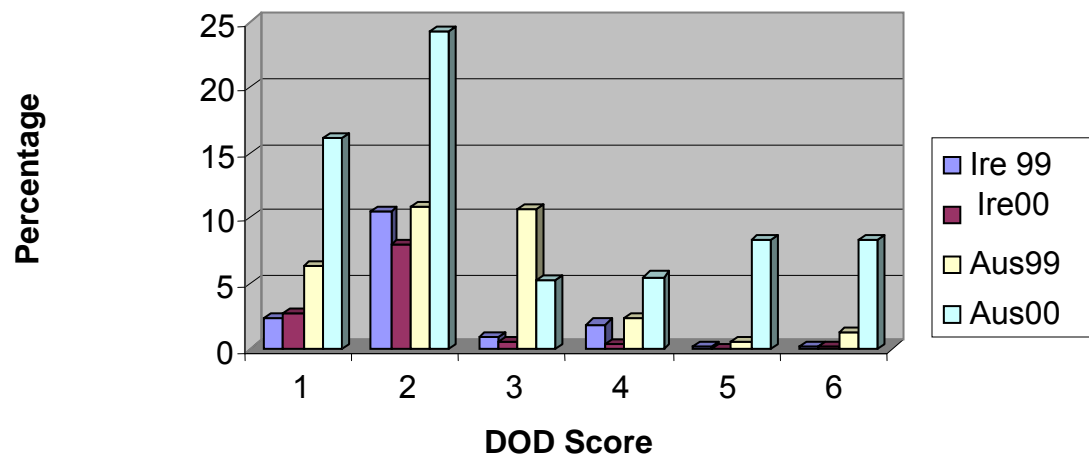
Score 3- Splint, X-ray

Score 4 – Periosteal strip

Score 5 – Double Periosteal Strip

Score 6- Bridge, physitis treatment, club foot, OCD, euthanasia

Figure 4.1: DOD Scores expressed as a percentage of total foals born



4.2 Relationships between individual variables and DOD score.

Ordinal logistic regression models were fitted for each of the variables to assess their association with ordered DOD scores. *P*-value results are summarised in Table 4.2. Year, country and weight were found to be significant factors affecting DOD.

Table 4.2 Results of the model testing collected data

Predictor	P-Value	Coef (se)	Odds ratio(e^{Coef})	95% CI	
				Lower	Upper
Year (2000)*	0.000	- 0.68 (0.11)	0.51	0.41	0.63
Country (Ire)	0.000	1.86 (0.12)	6.40	5.06	8.11
Age of dam	0.405	- 0.01 (0.01)	0.99	0.96	1.02
Weight	0.013	- 0.02 (0.01)	0.98	0.96	0.99
Sex (Male)	0.468	0.08 (0.11)	1.08	0.87	1.34

Coef (se) Estimated regression coefficient of the ordinal logistic regression model and its estimated se

CI Confidence Intervals

* Predictor variables refer to the effect of 2000 compared with 1999 (Year), Ireland compared with Australia (Country), and Male compared with Female (Sex).

Age Mare age ranged from 3 to 23 years. Age of mare at parturition was found not to significantly affect whether her foal was born with DOD.

Sex Of the 1717 mares, 819 had female foals and 898 had male foals. Over the two seasons, mares on the stud in Australia had 384 female foals and 424 male foals. On the stud in Ireland, 434 female foals and 475 male foals were born over the two years. Sex of foal was found not to significantly affect the incidence of DOD.

Weight Foal weight was found to be a significant factor affecting DOD incidence. Heavier foals were found to have more DOD problems.

Table 4.3 Average foal birth weights on the studs in Australia and Ireland over the two years

	Australia 1999	Australia 2000	Ireland 1999	Ireland 2000
Average birth weight (kg)	52.87	53.15	53.26	53.30
Average female birth weight (kg)	52.69		52.78	
Average male birth weight (kg)	53.05		53.29	

Year The year in which data were collected significantly affected the incidence of DOD. The stud in Ireland had a lower incidence of ALD in 2000 (88.2% unaffected) than in 1999 (83.8% unaffected). The stud in Australia had a higher incidence in 2000 (34.8% unaffected) versus 1999 (67.9% unaffected).

Country There is a significant difference between the studs in the two countries involved in the study. Overall, the stud in Australia had a much greater incidence of DOD than the stud in Ireland.

4.3 Interactions between DOD Type, Weight, Year and Country

DOD Type and Weight

Results are based on a linear response to weight. To check for a non-linear response, weight was squared and scatter plots were examined. Slight curvature indicates the smaller percentages of heavier and lighter foals recorded. The P value from running an ordinal logistic regression using weight squared was 0.059, a marginal effect was found.

As weight increases, DOD type increases in severity. However, the precise form of this association changes over the years and countries, as indicated in the fitted probability plots in Figure 4.2. In these figures, each curve shows the cumulative probability (Υ_j), of obtaining a score of j or lower for a given weight. The probability of obtaining a particular score (π_j) will therefore be the interval between successive curves.

Hence we can see that the probability of obtaining the highest score ($k = 6$) increases as the weight increases.

We are able to use the final models to make some predictive statements about birth weight. For example, looking at Australia (Figure 4.3) in 2000, foals born at 75 kg have 0.25 more probability of developing a DOD than foals born at 35 kg.

DOD Type and Year/country

There was a highly significant interaction between year and country ($P = 0.000$). The 95% upper confidence interval indicates that DOD was worse in Australia in 2000 than in 1999. Ireland had significantly better levels of DOD than Australia in both years, and was found to have lower levels of the disease in 2000 ($P = 0.04$) than 1999.

Figure 4.3 illustrates the event probabilities of DOD scores in Australia and Ireland over the two seasons.

Combined country/year/weight effect

The final model indicated that there were highly significant interactions between country, year and weight ($P=0.000$). An ordinal logistic regression was performed with DOD Type versus Country and Season and Weight. Season and Country combined were found to significantly affect DOD ($P=0.000$), so a combined Season/Country and Weight regression was performed with significant effects on DOD found (see Table 4.4).

Table 4.4 Results of the final combined Season/Country, Weight model

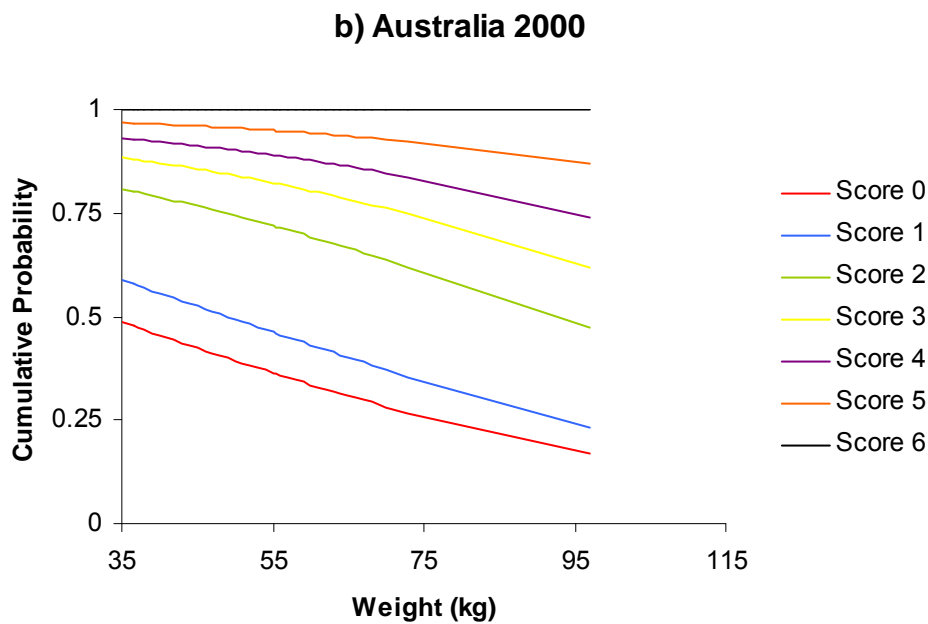
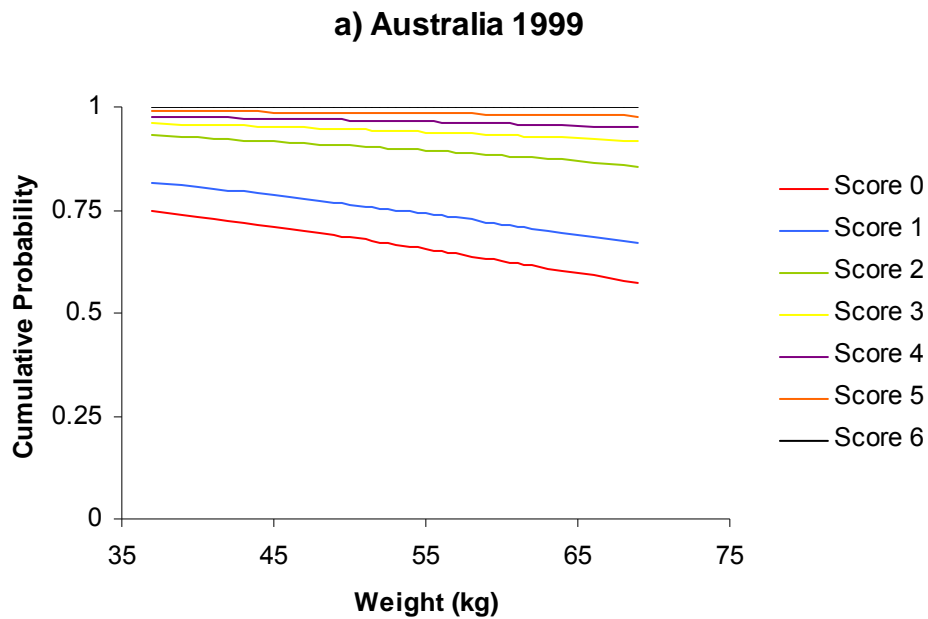
Predictor	P- Value	Coef (se)	Odds ratio (e^{Coef})	95% CI	
				Lower	Upper
Aus 1999*	0.00	- 0.93 (0.17)	0.39	0.28	0.55
Aus 2000	0.00	- 2.22 (0.16)	0.11	0.08	0.15
Ire 2000	0.04	0.40 (0.19)	1.50	1.02	2.18
Weight	0.01	- 0.03 (0.01)	0.97	0.96	0.99

Coef (se) Estimated regression coefficient of the ordinal logistic regression model and its estimated se

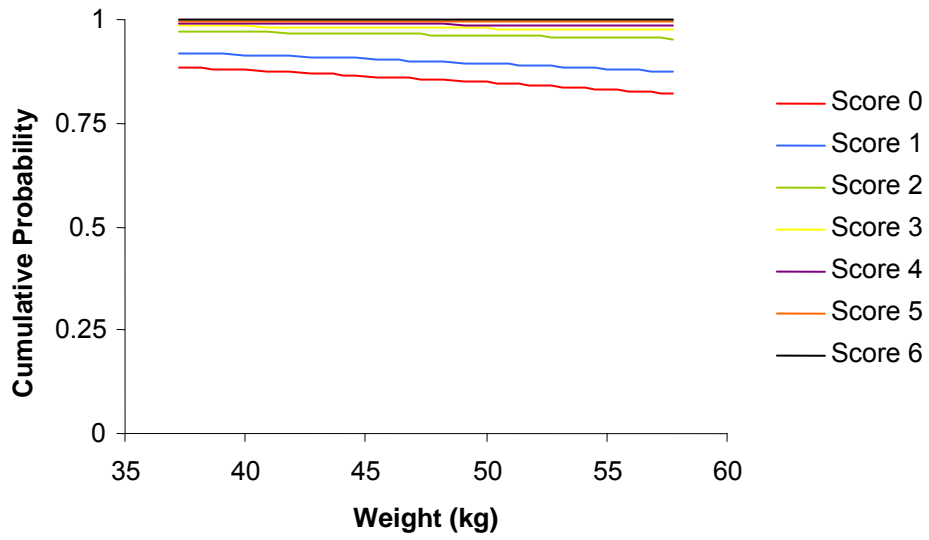
CI Confidence Intervals

* Predictor variables refer to the effect of Australia 2000, Australia 2000, and Ireland 2000 compared with Ireland 1999.

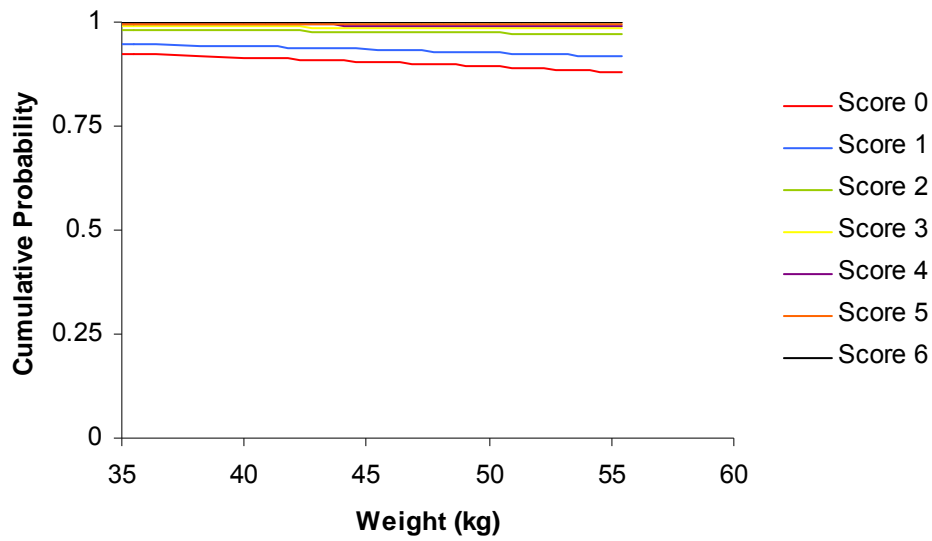
Figure 4.2: Probability plots of a foal developing a score of DOD at a specific weight in each country and year; the lines are the fitted models based on the ordinal regression, each representing a score of DOD from 0 to 6.



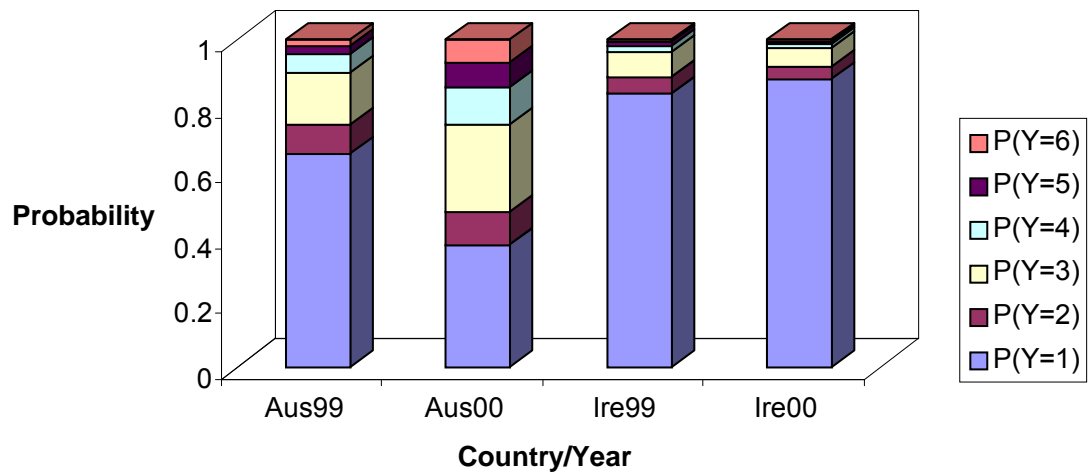
c) Ireland 1999



d) Ireland 2000



**Figure 4.3: Average Event Probabilities for DOD Scores on studs
In Australia and Ireland in 1999 and 2000**



CHAPTER 5

Discussion

A large amount of data was collected over the course of this study, including photographs, nutrition and management information, sire records and detailed cases of Score 6 DOD cases (see Table 3.1).

In order to ensure that the samples remained representative of the population as a whole, utilisation of total data was carefully considered. Data directly recorded from stud records was used to reduce data integrity problems. A sub set of recorded OCD cases from foals older than 6 months was not utilised as sequential consistency between data was not achieved. Sire effects were not used due to difficulties encountered with statistical analysis (mare/stallion ratios).

The results that were generated, however, were very encouraging, as an obvious problem in Australia has been shown graphically. The dramatic rise in the use of box rest, corrective farrier procedures, splints and periosteal strips from 32 % in 1999 to 59.4% in 2000 in Australia is of reason for concern.

When looking at data collection, differences between Australia and Ireland must be addressed. Collection of data in Australia was found to be straight forward, with detailed computer records accessible for individual animals, as well as all foaling mares being on the main area of the stud. The computer program used (Studmaster), is designed specifically for stud farm accounting and record keeping.

In Ireland, most records personally accessed were not from the computer but from log books. The stud has some foaling barns which are situated a short distance from the main area of the stud. The record keeping system was hence more dispersed due to the

dynamics of stud layout. Working in Ireland allowed confidence in accurate data recording due to sighting of most foals affected with DOD, and the co-operation of management and staff.

The study efficiently monitored foals up to weaning age (6 months), past this age only the profile of those remaining on the farms were able to be followed. Those foals remaining represented a relatively small percentage of the total group. Any development of DOD past the age of 6 months in foals remaining was noted but not included in the study. Every effort was made to maintain consistency across the populations in both countries. It must be acknowledged that on occasion foals included in the study were sent home or otherwise removed from the farm before weaning age. These foals represent a weaker profile in the study as they may have developed DOD at a later date up to 6 months of age, and this was not able to be recorded. This was the case in both countries and is an unavoidable factor due to the nature of ownership/management of thoroughbred horses (syndicates, agisted mares, movement of horses between studs).

It was noted that the number of foals moving off farm before weaning was higher in Ireland than Australia, and very difficult to track as foals were regularly moved to different locations within the farm system. In Australia foal movement was easier to track due to the computer record system.

Direct contact with foaling mares, log books, main office records and the veterinary administration system provided the data for the study. It must be noted that in Ireland this may have resulted in greater human error present in data recording than with records entered onto a computer on a daily basis. Records of scores 5 and 6 in particular, being generally procedures performed on older foals, are most likely to be affected. Timing of surgical intervention particularly in these cases may create a situation where the percentage of foals treated may not necessarily be a reflection of the true incidence. Some foals may be treated immediately, whilst others may be treated conservatively over a period of time. It is also possible that some foals were treated surgically at an early age

when their case was such that they may have responded to conservative treatment. The location of the deformity and the age of the animal at time of recognition will influence the decision of how and when to treat (Fretz & Donecker 1983).

The inclusion of box rest in the study could be seen to increase the overall percentage of DOD cases especially in Australia. It was not possible to separate foals correcting spontaneously from those requiring further treatment. Including these milder cases however, allowed direct comparison with Ireland involving mild to severe forms of the problem. Many foals go on to need further corrective procedures. Hands-on comparison of the foals given box rest in each country allowed confidence that both studs used this treatment for foals of similar degrees of ALD.

Bias in scoring foals was avoided as much as possible through using the scoring system developed (based on treatment administered rather than personal observation), however bias may have crept in via veterinary treatment trends. For example, one vet may prefer to avoid surgical corrective procedures where possible. Another on the same farm or in a different country may be inclined to use surgical procedures sooner rather than later.

Similar trends to those observed with box rest were seen with the use of Equilox extensions and/or dalric shoes in both studs. A large percentage of foals treated for DOD were included in this treatment category. In Ireland the percentage dropped off slightly in 2000. In Australia it doubled. It is noted that a greater awareness of the problem of ALD's in management circles at the stud in Australia played some role in this rise. Interpretation of the change in frequency of certain procedures must be made with caution. An increase in the popularity of one treatment may be due to it being currently favoured at the time.

Although veterinarians and staff working on the studs involved in the study often travel and communicate between Australia and Ireland, it must be noted that management practices are not identical. For example two foals may have been born with the same

degree of joint laxity, one in Australia, one in Ireland. In Ireland, vets and management may have decided to use box rest, then splint the leg; in Australia the foal may have been fitted with a corrective shoe. This also applies between seasons; the same foal born in the next year in Australia may have been splinted, with or without box rest. Although every effort was made to prevent confounding of results, situations such as this example may have occurred.

The effect of bias in scoring the foals has the potential to reduce the inferential validity of the study. This disadvantage can be overcome through conducting further trials to allow cross-sectional comparisons to be made.

The dramatic increase in the use of Equilox extensions and/or dalric shoes seen in Australia may be a reflection of changes in trends of treating DOD over the two years, with early intervention seeking to reduce possible need for treatment/corrective shoeing at yearling age. The increase in Score 6 (bridge, physitis, early OCD and euthanasia cases), from 2.9 to 8.3% does, however refute this theory slightly, indicating a rise in the overall incidence of more severe cases of DOD. Only two cases in 1999 and none in 2000 were so bad that euthanasia was carried out (wry nose). Club foot cases were minimal (one in 2000 and two in 1999). Only one case of OCD was diagnosed in the period up to weaning in 1999. The majority of the Score 6 cases in Australia (14 in 2000 and eight in 1999) were affected by physitis, a condition associated with OCD.

In Ireland, many foals do not go on to need further procedures to correct DOD. Extensions and corrective farrier work are a normal part of stud routine aiming to get the most correct leg conformation possible. Score 6 cases in Ireland in 1999 involved one case of a foal euthanised at birth due to badly deformed front and hind legs (see Appendix 2, p.101-102). In 2000, a physitis/wobbler case was recorded.

The trend shown in this study of increasing foal weight with proportionally increasing DOD directs attention towards sire effect and nutrition. In the author's experience, a

larger stallion on average producing larger foals is perceived to be a favourable trend in the thoroughbred industry. There is evidence of a genetic effect on birth weight and growth of foals from a study of Shetland pony/Shire crosses (Walton and Hammond, 1938). Although ability to run outweighs size when choosing a thoroughbred sire, this genetic aspect of breeding requires further investigation. Nutrition of mare during pregnancy, and nutrition of foals are factors which may impact on DOD, and which can be easily altered. Research followed up by feeding recommendations is a measure which has the potential to reduce the problem of DOD.

When comparing the overall incidence of DOD at the two studs, management and hemisphere differences must be acknowledged. Direct comparisons in management practices were enabled due to extended periods of time working in both countries. Each stud has similar diagnosis and treatment procedures. Veterinary and management foal checks are made after birth. Foals are closely monitored on a day to day basis by staff in both countries. Management differences between the countries include feeding and stabling times.

In Ireland, mares and foals are brought into stables every night. They are fed similar quantities of concentrates and hay in the evening and morning, and are let out to pasture in the morning. Exceptions are those requiring box rest, fostering or veterinary attention. Ireland uses stables in day to day routine, whilst in Australia; these are reserved for foals needing box rest, as well as sick animals and weanlings/yearlings.

In Australia, mares live in large paddocks. Paddock feeding is done in bulk. A grain, mineral pellets and lucerne chaff mix is provided, with no control over individual portions. Mares due to foal are brought into smaller paddocks at night for monitoring. When foaling signs commence, mares are then moved into individual yards. Post foaling with no complications, she may be in a stable for a short time, or remain in the yard for

up to a week. Mare and foal are then moved into bigger paddocks with similar aged offspring.

Given the greater confinement in day to day management of mares and foals in Ireland compared to Australia, it is possible that the underlying risk of DOD is similar but conditions and management in Australia maximise expression of clinical disease. Further studies to replicate conditions in Ireland would be necessary to pursue this possibility.

Being in two different hemispheres, climatic differences between Australia and Ireland are quite significant. Annual precipitation rate is much higher in Ireland, soil and pasture type differ, as does the severity of the seasons. Varying climate and length of season have the potential to alter harvested feed and pasture quality. This may contribute in turn to DOD levels on a seasonal basis.

Nutritional differences in hand feeding of mares were noted. Ireland feeds grass/meadow hay, whilst Australia feeds lucerne hay. Concentrate mixes in Ireland are based on oats, cooked mixes, bran and vitamin/mineral supplements. In Australia, the concentrate mix comprises lucerne chaff, whole oats and a mare pellets. Mare pellets are specifically formulated for mares on the stud and include minerals and vitamins. Soil and pasture analyses are conducted in both countries on a routine basis, and rations formulated in conjunction with these.

Nutritional analyses of hay and concentrates, as well as pasture and soil test results were specifically collected from the two farms to avoid relying on the author's memory or perceptions. Rainfall statistics were collected and considered from the Central Statistics Office in Dublin, and the ABS in Sydney. Although not carried out in this study, a questionnaire administered to farm managers would be an objective way to compare management practices on both studs.

As an epidemiology study examining the differences between a farm in Ireland and a farm in Australia, it must be considered if the differences noted are just due to different operations or really are national differences. As only one stud in each country was used it should be noted that:

- The climate and environment of these studs are very dissimilar, this creates an instant national effect.

- Although both studs use some of the same stallions, the genetic pool/sample number of mares is huge due to the scale of the stud operations. This forms an ideal foundation to base the experiment; in fact it is quite unique to be able to access such a large number of mares in each country all with the same management practices within their stud.

Many of the stallions are shuttle stallions; hence sire genetics on the two studs may be the same. Looking at the genetic aspect of the study, there is a distinct possibility that differences between Ireland and Australia's levels of DOD are either environmental, management or different veterinary and intervention approaches.

- The management operations of the studs used in the study are able to be precisely pinpointed and compared. Similarities and differences can be examined with ease for direction toward further research.

- The author has been in the unique position of visiting and working on several different studs both in Australia and Ireland, hence enabling an anecdotal surveillance of national differences in relation to DOD.

The need for further investigation has been highlighted by the high incidence of DOD found in Australia. A large scale, long term study would be desirable, with suitable team leaders coordinating the project ensuring the issue of confidentiality be adequately addressed. Ideally, replication across the industry would allow unambiguous statement

that the differences in DOD incidence really are due to Australia versus Ireland differences. Although a large undertaking, the benefits to the thoroughbred industry on an international scale would be exceptional.

CHAPTER 6

Conclusions and Recommendations

Concrete scientific studies are sure to be seen as a positive step to defining the problem of rising DOD in the thoroughbred industry, and working towards being able to reverse this trend. It has been shown by this study that Australia has a higher level of DOD than Ireland.

There is definite scope for further study to examine any possible links between factors such as nutrition and genetics of Thoroughbreds in each country, and the incidence of DOD in foals. Studs using shuttle stallions would be able to monitor genetic links with greater ease. Stallion effect in both hemispheres could be clearly defined. Some Irish mares are flown into Australia already in foal, providing the opportunity to examine the incidence of DOD in their foals before and after leaving Ireland.

Widening the populations involved to include other studs would allow comparisons in management practices; however this is easier said than done. The more studs involved, the greater the possibility of errors in data collection. The foaling season is extremely busy for all members of staff. It would be necessary for a familiar, efficient person with an understanding of the industry to reside in the area and co-ordinate collection of data. Regular visits in person to the studs involved and an absolute “no gossip” policy would be vital to the success of large-scale projects.

Any difficulties incurred through involving other studs in a study would be offset by many benefits. Replication at the study level is really very important and the more studs involved, the more valuable the data will be in drawing epidemiological inferences.

Given the increased awareness of the growing problem in Australia, it is likely that management circles in many studs would be willing to take part in further research. Inclusion of many Australian thoroughbred studs in an ongoing monitoring of DOD would be of great benefit to the industry as a whole. The stud involved in this study was situated in the Hunter Valley, NSW. This area is ideal for larger scale projects due to large numbers of breeding horses present at a relatively small number of studs. There are many similarities in record keeping and environmental factors across these Hunter Valley studs. The move towards computer records being used by studs would make accurate data collection a lot easier to achieve.

Monitoring of foals where possible to yearling age would be ideal, although difficult for very large numbers due to their sale and movement. Greater accuracy indicating DOD problems would result. A study in Ireland has shown that the peak incidence of DOD problems occurred after weaning (O'Donohue *et. al.*, 1992). Given this finding, and taking into account disease definition, monitoring animals for longer periods of time would allow greater understanding of the problem.

A very important consideration in developing the potential of engaging the assistance of studs for further study is that of confidentiality as touched on above. Any possibility of damaging the reputation of a stallion, mare or offspring is not acceptable given the high standards, competitiveness and amount of capital circulating in the industry. Researchers must be aware of this and respect the need for confidentiality with the studs involved. The industry by the same token needs to be open to whatever findings and course of action is advised. The stud owners and managers involved in this study are to be complimented on their forward thinking and commitment to furthering knowledge about DOD in the thoroughbred industry. It would be a very positive outcome if this report assists in the development of future research and strategies which would benefit the Thoroughbred, and indeed the entire equine industry worldwide.

CHAPTER 7

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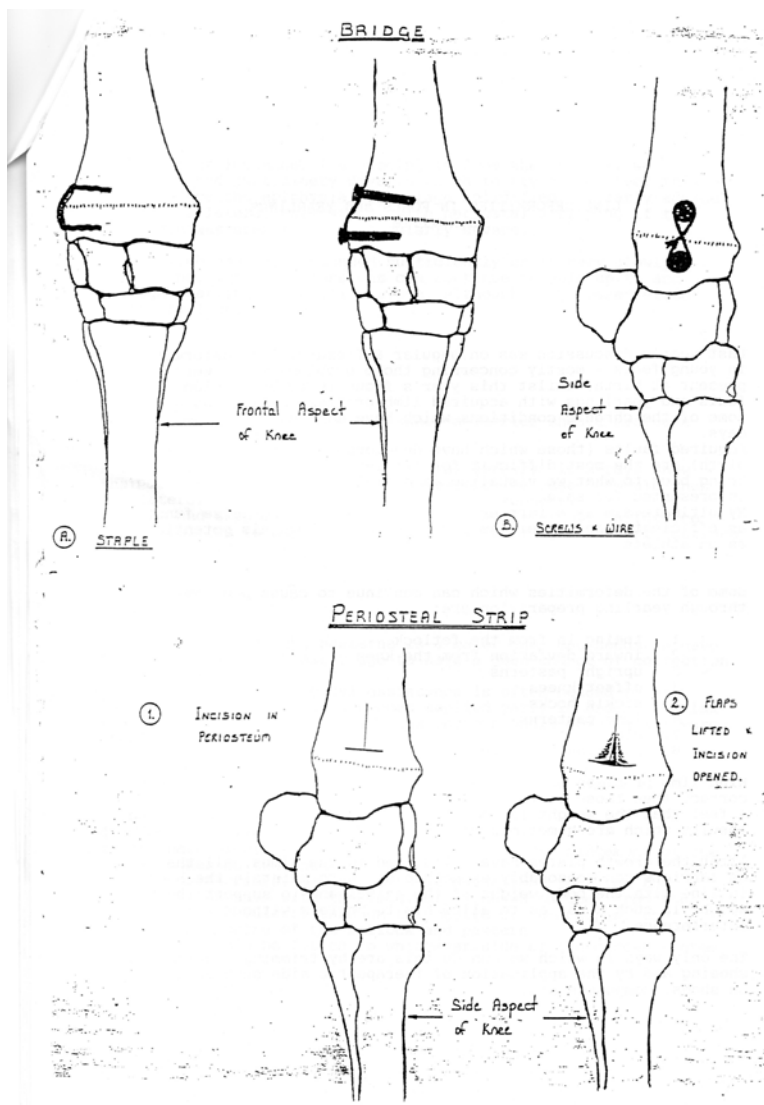
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CHAPTER 8

APPENDICES

Appendix 1. Diagrams of surgical intervention techniques used to treat ALDs (Hunter Institute of Technology, 1999)



Appendix 2. Photographs taken by the author during the course of this study



ALD contracted hind pastern



ALD contracted hind pastern



ALD contracted knee



Foal with front valgus deviation, showing splint treatment



Hind joint laxity causing severe valgus deformity



Windswept hindquarters



Windswept hindquarters



Windswept hindquarters and severe joint laxity



Severe joint laxity



Severely contracted foal unable to stand unassisted



Deceased foal



Deceased foal showing severe deformity of limbs as well as asymmetric formation of the cranium

