THE PREVALENCE OF CONGENITAL LIMB DEFORMITIES IN A POPULATION OF NEW ZEALAND STANDARDBRED FOALS AND THEIR INFLUENCE ON RACING SUCCESS

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ABSTRACT

This thesis reports on the retrospective studies carried out on two Standardbred studfarms in New Zealand that aimed to describe and investigate the prevalence of, and risk factors for, congenital limb deformities over the 2004/05 and 2005/06 breeding seasons.

A historical cohort study of 1,189 horses was used for describing the prevalence of limb deformities over two breeding seasons. Limb deformitiy data were routinely collected within one week of birth and foals were only scored once. Foals were described as either having a limb deformity or not. Risk factors investigated were sex, mare age, parity, farm, season, birth month and sire. Simple descriptive statistics were used to describe the prevalence of limb deformities, types of limb deformities and, treatments used. Univariable and multivariable logistic regression was used to investigate the risk factors for limb deformities. Within the multivariable model it was found that birth month, mare age, farm and season were all associated with the prevalence of limb deformities.

A subset of the historical cohort, consisting of all foals born in the 2005/06 season (n=627) was analysed to investigate the association between limb deformities and subsequent racing success. Univariable and multivariable logistic regression and linear regression were used to investigate the association between limb deformities, and racing success. Other variables including birth month, mare age, farm and sex and the association of these with racing success were also investigated. In the final multivariable model, birth month and sex were significantly associated with total starts of the racehorse at the completion of their 3-year-old season and birth month was significantly associated with total stakes.

ACKNOWLEDGEMENTS

I would like to thank all of those who gave me support throughout the time I was completing my Masters. First and foremost I would like to those in the industry that made this research possible, without whom, valuable industry research could neer take place. I would also like to thank my supervisors and colleagues for their support throughout the project and my family and friends for their unconditional support. It is my hope that industry research continues to be completed by those passionate about the racing and equine industries in New Zealand.

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LIST OF ABBREVIATIONS

DOD	Developmental orthopaedic disease
=	Equal to
>	Greater than
≥	Greater than or equal to
HRNZ	Harness Racing New Zealand
IQR	Interquartile range
<	Less than
LD	Limb deformity
Ln	Natural logarithm
NZ	New Zealand
95% CI	Ninety five percent confidence interval
OCD	Osteochondritis dissecans
%	Percent
Ref	Reference value
TH-MSD	Thyroid hyperplasia with concurrent musculoskeletal disease

CHAPTER 1 - INTRODUCTION

BACKGROUND

Limb deformities are a common source of wastage in the first year of a horses life (Jeffcott 2004). They may also be a cause of wastage later in life, however, few studies have investigated the effect of limb deformities on racing success (Anderson *et al.* 2004b; Weller *et al.* 2006b), and conclusions are controversial.

Limb deformities pose a significant problem for horse breeders. They can be associated with a horse not being successful for several reasons. Horses born with severe limb deformities result in an immediate wastage problem and monetary loss for the breeder and these horses are usually euthanased if there are no viable treatment options. Horses that are treated require intensive care and treatment can also be costly and time consuming, representing a further indirect cost to the breeder. Furthermore, there is limited knowledge on what treatment options are successful and if the treatments (Mitten 1995; Baker 2011) or limb deformities (Anderson *et al.* 2004a; Weller *et al.* 2006a) affect the horses chance of success later in life.

The New Zealand Standardbred industry is the second largest racing industry, after the Thoroughbred industry (Anonymous 2010). The number of foals branded in the 2010/11 breeding season was 2,257 and this decrease from 2,782 born in 2006 represents a greater need for increased production efficiency within the industry as this decrease is a direct result of a decrease in the number of mares bred per season.

To investigate the current knowledge of the prevalence of congenital limb deformities in horse populations and to describe the effect they have on racing performance the following areas will be reviewed:

- The New Zealand Standardbred industry
- Growth and development of the equine fetus and foal
- Developmental orthopaedic diseases in growing horses and its relationship with congenital limb deformities
- Congenital limb deformities and the association between these and racing success

LITERATURE REVIEW

The New Zealand Standardbred industry

The Standardbred industry in New Zealand is the second largest racing code after the Thoroughbred industry and generates over $402 million in Gross Domestic Product (GDP), which represented 24.6% of the total value added for the NZ racing industry in the 2008/2009 racing season (Anonymous 2010). Although this represents an increase of $75 millon in the total value added from that reported in 2004, after adjusting for inflation, this represents a real increase of only $8.5 million*. Over 16,000 participants are involved in the breeding and racing of Standardbreds in New Zealand (Anonymous 2010). These participants range from owners and breeders to volunteers in the industry, illustrating the importance of the racing industry to the wider community. The number of participants has increased by almost 6,000 people since 2004 (IER 2004). In comparison with the Thoroughbred industry, the total value added and number of participants involved in the Standardbred industry has increased since these were last reported by the New Zealand Racing Board in 2004. The Harness industry has almost 8,000 individual race starters per season and there were a total of 268 Harness race meetings held in New Zealand in the 2008/2009 racing season (IER 2010).

Twenty-two countries participate in Harness racing (Tanner *et al.* 2010). Based on the number of individuals to race per season and the number of races held in one season, New Zealand is currently ranked tenth (Tanner *et al.* 2010). The value added to New Zealands economy from the sale of Standardbreds at auction was $12.7 million during 2008/09 season (IER 2010). This increase of $3.7 million from 2004 is likely to be due to at least in part, inflation rate increases over this time. After adjusting for inflation, the value of Standardbreds sold at auction has still increased by over $1 million since 2004*. It was estimated that the New Zealand harness racing industry annually generates more than $37 million in export sales. This represents a 115% increase in the exports outlined in the 2004 report (IER 2010). As the number of horses exported since the 2004 report has decreased, this increase has been largely driven by a greater yield for harness racing exports. Most (85%) of New Zealand Standardbred horses exported are exported to Australia, with the remainder being exported to North America (IER 2010).

*Official Inflation rates obtained from www.rbnz.govt.nz – Accessed: 10th November 2011

In a preliminary examination of the Standardbred industry in New Zealand, it was found that 30% of horses in the 2001/02 foal crop were never registered to a trainer (Tanner *et al.* 2010). Early wastage is therefore a problem for the Standardbred industry in New Zealand, and it is likely that a proportion of these foals were never registered due to unacceptable physical assessments due to limb deformities. Between 2006 and 2010, the number of mares served in a season has decreased from 3,907 to 3,729, and the number of foals branded has decreased from 2,782 to 2,257 (HRNZ.co.nz). Because of the declining number of mares served and foals being branded, the need for increased efficiency in the industry is paramount.

As there are many well-bred horses to choose from, conformation becomes an important selection criteria for breeders and buyers. It is a common perception that horses with correct conformation will be more successful than those with conformational defects. The aim of racehorse breeders worldwide is to maximise sale and racing potential of their foals. Therefore, the ultimate goal of horse breeders in New Zealand is to produce viable foals that are physically capable of performing their intended activity (Morley and Townsend 1997).

Growth and Development of the normal Equine Fetus and Foal

The growth and development of the fetus and foal is a function of the genetics of the foal and the environment to which the mare and foal are exposed to during and after pregnancy. Nutritional factors such as energy, protein and mineral intake of the mare during pregnancy can influence the growth and development of the foal (Allen *et al.* 1996; Arndt and Eversfield 2002; Hintz 1996).

Growth of the fetus occurs through a process of cell division and enlargement initiated by the fertilization of the egg at the time of conception (Frape 2004). After the cells differentiate, the various embryonic tissues are formed and soon after birth further growth is accomplished by enlargement of the individual cells (Frape 2004). The potential for a maximum rate of growth, as measured in kilograms of daily body weight gain, persists until around 9 months of age, at which time the rate of growth gradually decreases and plateaus when the adult size and shape of the horse are attained (Frape 2004).

Within hours of birth, foals are able to stand, suckle and move at speed (Firth 2011). This is an evolutionary advantage that enables herbivores to escape from predators during this vulnerable stage in their life (Firth 2011). Movement at speed requires both neurological capability and development of the musculoskeletal tissues at birth (Firth 2011). In foals born with angular or flexural limb deformity (LD), the development of these tissues is less than perfect. However, the etiology is not well understood and may lie in an area not yet investigated intensively in horses, namely the environment of pregnancy (Firth 2011).

The formation of limbs in the horse occurs through a serious of events in utero either directly from the limb mesenchyme or from the blastema (Figure 1.1) (McIlwraith and Trotter 1996). When fully developed, the the structural parts of the limb consist of muscles, tendons, bones and cartilage (McIlwraith and Trotter 1996).

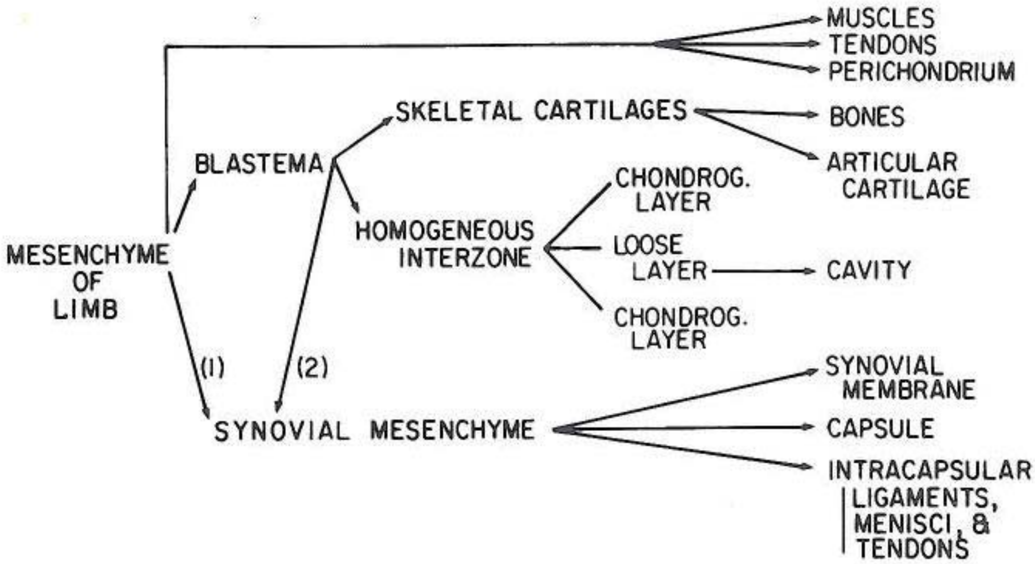


Figure 1.1: Schematic representation of the morphogenetic events in the formation of a synovial joint (McIlwraith and Trotter 1996).

Skeletal development in the foal

The skeletal development of the foal begins in the latter stages of gestation (Smith 2010). The formation of bone is a determining factor in adequate joint development of the fetus (Firth 2011). In the foal, the long bone consists of diaphysis (shaft), metaphysis and epiphysis (McIlwraith and Trotter 1996).

The epiphysis and metaphysis are separated by the physis (metaphyseal growth plate) (Firth 2011). During late fetal and early postnatal development, the epiphysis undergoes ossification (McIlwraith and Trotter 1996). Ossification is the process of bone formation which usually begins at a particular primary ossification center in the bone's pre-existent cartilaginous matrix of the future diaphysis, and later at the physis by endochondral ossification (Firth 2011). The development of the epiphysis can be delayed by hypothyroidism (Allen *et al.* 1994; Firth 2011). Bone growth is a dynamic process and will continue until physeal closure (Witte and Hunt 2009). The timing of physeal closure (closure of the growth plates) is important as this restricts the period of time that mangaement techniques can successfully be used to correct conformation in the growing foal.

The formation of bone is a determining factor for adequate joint development by the time of birth, and has implications for immediate and later life (Firth 2011). Ossification of the different types of bones within the legs occurs at different stages throughout gestation. Primary ossification of the diaphysis in the long bones becomes radiographically evident from approximately 60-135 days gestation (Firth 2011). Secondary ossification centres at the end of longbones is apparent radiographically from 265-335 days gestation, and doesn't appear to vary greatly in different bones, with the more proximal bones beginning ossification earlier than those more distal (Firth 2011).

Factors affecting growth and development of the foal

There are many potential factors affecting the growth and development of the foal and the development of the musculoskeletal tissues. Environmental factors before and during pregnancy affect the development of the foal. The etiological factors for LD in foals may lie in an area not already investigated in horses, however this is currently poorly understood (Firth 2011).

Several overseas studies have reported gestation lengths for mares to be between 330-345 days (Marteniuk *et al.* 1998; Morel *et al.* 2002; Sharma and Dhaliwal 2010) however a recent study on a Thoroughbred stud farm in New Zealand indicated that the mean gestation length in mares was 352 days (Van Rijjsen *et al.* 2010). Hintz et al. (1979), and Van Rijssen et al. (2010) found that foals born late in the season had shorter gestation lengths than those born early in the season. Furthermore, Hintz et al. (1979) found that horses born later in the season were heavier and taller than those born early in the season and Allen et al. (1996) found that foals born with congenital hypothyroidism and dysmaturity syndrome were from mares with significantly longer gestation period than controls.

Maternal nutrition has been shown to affect the development of the fetus through alterations in metabolic programming (Becvarova and Buechner-Maxwell 2012). This phenomenon is known as fetal programming and suggests that during fetal growth and development permanent alterations in the structural development and/or fetal metabolism occur in response to the intrauterine conditions which are, in part, due to the nutritional status of the mare (Becvarova and Buechner-Maxwell 2012). Nutritional and mineral status of the pregnant broodmare is associated with the growth and development of the foal. In the study conducted by Allen et al. (1996), pregnant mares receiving greenfeed, not receiving mineral supplementation, left their "home farm" during pregnancy, or grazed irrigated pasture were all at a higher risk of producing foals with dysmaturity than controls. Thus, nutritional status of the broodmare may play a role in the development of the foal during pregnancy.

Developmental orthopaedic diseases in growing horses and its relationship with congenital limb deformities

Developmental orthopaedic disease (DOD) encompasses all orthopaedic problems that cause growth disturbances seen in the growing foal (McIlwraith 2004). The term DOD specifically includes: osteochondritis dissecans (OCD), subchondral cystic lesions, angular limb deformities, physitis, flexural deformities, cuboidal bone abnormalities and juvenile osteoarthritis (McIlwraith 2004). The causes of DOD are multifactorial (Figure 1.2) and the exact pathogenesis is poorly understood (Jeffcott 2004). Each has different and complex aetiopathogenesis, but are all primarily related to growth, nutrition and management (Finkler-Schade 2007; Jeffcott 2004). The incidence of DOD is high and represents significant wastage or inefficiencies in the breeding industry (Alvarado *et al.*, 1989; Grondahl and Engeland, 1995;Storgaard Jørgensen *et al.*, 1997) . Up to 10% of foals with DOD are also not marketable for sale and this represents a further loss for the industry (Jeffcott 1996). It is likely that a significant proportion of these foals have angular and/or flexural deformities.

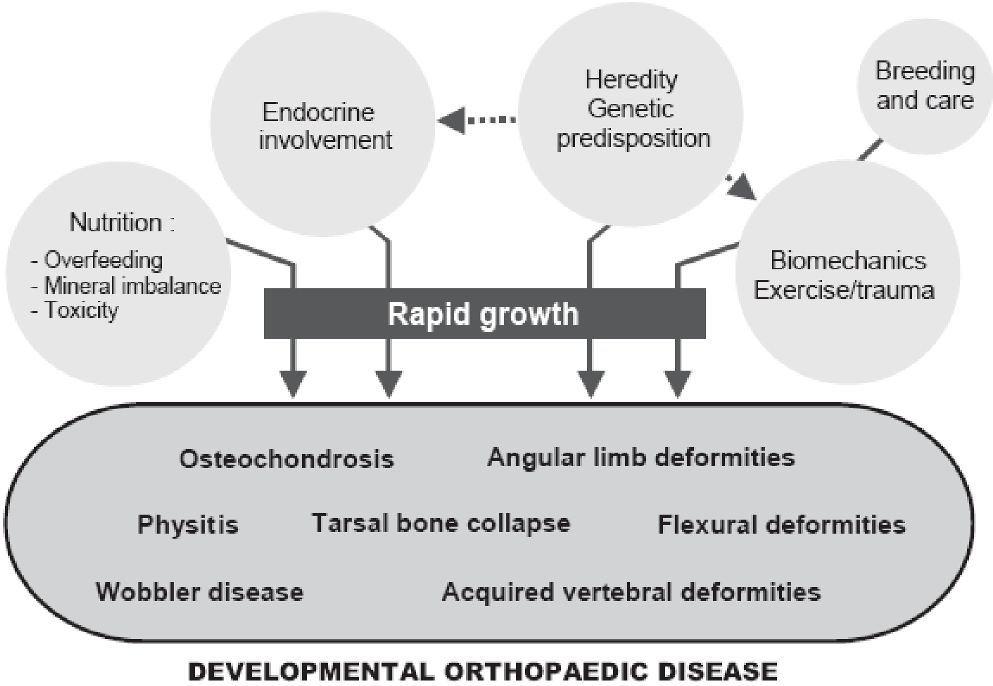


Figure 1.2: The multifactorial nature of Developmental orthopaedic disease (DOD) (Blanchard 2005).

Introduction to congenital limb deformities

Congenital limb deformities, consisting of angular and flexural limb deformities, are those present at birth and are common in new born foals (Lowis 2005). In horses, congenital defects are one of the most common reasons for embryonic, fetal , and neonatal mortality and morbidity and are often associated with weak foals (Hutson *et al.* 1977). Limb deformities are undesirable to horse breeders because of the perceived negative association between limb deformities and/or conformation and racing success and injury. Furthermore, limb deformities often require intensive management over time, which represents a significant time and monetary cost to the breeder. Thus, there is an industry bias towards horses without limb deformities (commonly referred to as having correct conformation) for future racing and as breeding prospects. Various factors in the history of the mare and foal may predispose a foal to perinatal conformational problems, although epidemiological research into causative factors is lacking (Witte and Hunt 2009). Further epidemiological based research is required in this area to understand the prevalence of limb deformities in different populations and to attain further knowledge about potential risk factors.

Congenital angular limb deformities

OVERVIEW

Angular limb deformities are defined as conformational deviations in the frontal plane i.e. the deformities are viewed from the front of the horse (Trumble 2005). These are axial deviations that are based on the relationship of the limb distal to a particular joint (Trumble 2005). Angular limb deformities can be further categorised as Varus or Valgus. Varus deformities occur when the deviation occurs lateral (towards the midline of the body) to the axis of the limb (Figure 1.3) (Greet 2000) and a valgus deformity occurs medial (away from the midline of the body) to the limb (Figure 1.4) (Greet 2000) .

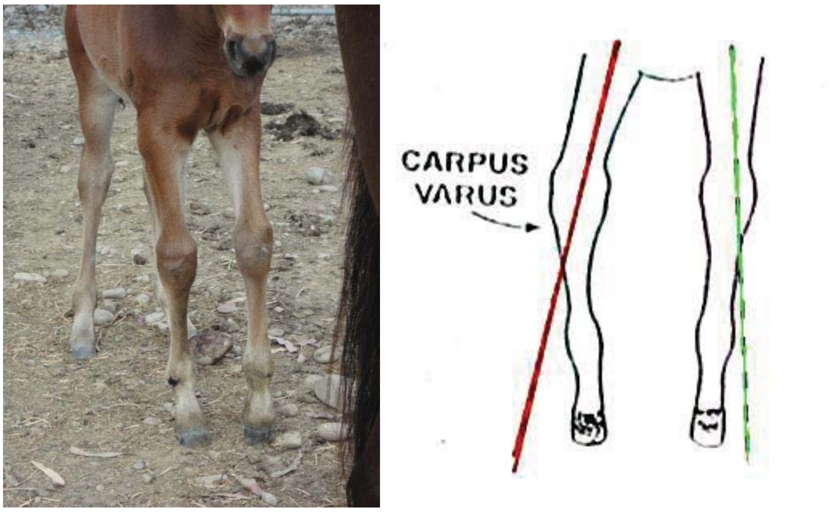
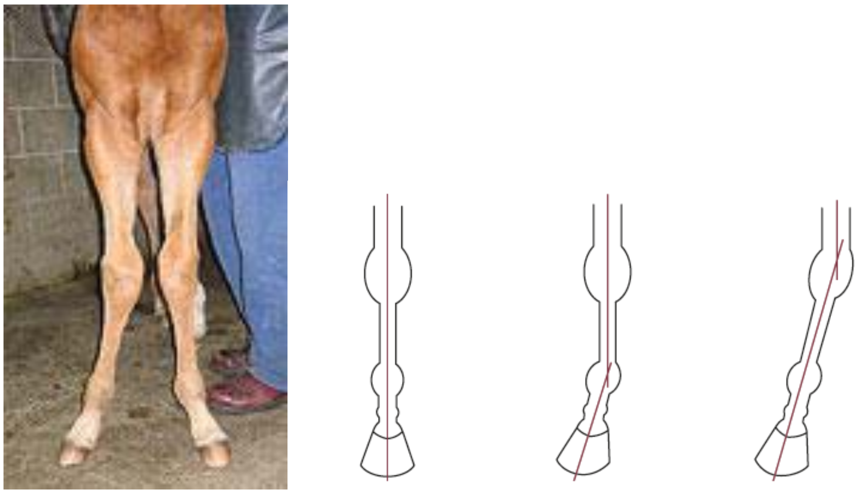


Figure 1.3: Carpus varus in a newborn foal

The most common angular limb deformities in new born foals are carpal or tarsal valgus and fetlock varus (Trumble 2005). A carpal or tarsal valgus deformity is defined as a lateral deviation of the limb distal to the carpus or tarsus, respectively, in relation to the limb proximal to the carpus or tarus (Trumble 2005). A fetlock or carpal varus is a medial deviation of the limb distal to the fetlock or carpus, respectively, in relation with the limb proximal to the fetlock or carpus (Trumble 2005).



(a) (b)

Figure 1.4: (a) Carpal Valgus in a newborn foal (b) Normal, carpal and fetlock valgal deformities.

Correct conformation of the new born foal is not the same as that of an adult horse. A normal carpal conformation for a neonatal foal is considered to be 2 – 5 degrees of carpal valgus (Greet 2000). In these cases, by the time the foal is approximately 8-10 months old, the limb will have usually self-corrected as the horses chest expands and the limbs elongates (Smith 2010) and due to the self-correcting nature of this conformation, required management of these deformities is minimal (Trumble 2005).

RISK FACTORS

Knowledge of the risk factors for congenital angular limb deformities in foals are limited (Sirin & Alkan, 2010). It is believed that possible risk factors include: musculoskeletal immaturity, epiphyseal/physeal dysplasia, incomplete ossification of cuboidal bones of the carpus or tarsus, uterine positioning, and ligamentous laxity (Santschi 2003). However, whether or not the mineral status of the mare or other environmental influences are associated with these types of deformities in foals is unknown.

MANAGEMENT

It is important to evaluate angular conformation in the foal as early as possible so the deformities can be more easily treated (Smith 2010). Angular limb deformities are usually treated by manipulation of the growth plates of the limb (Smith 2010). The treatment of various angular limb deformities is dependent on the origin and severity of the deviation, the age of the foal (Table 1.1; 1.2), the cause of the deviation and, other associated limb pathology (Santschi 2003; Trumble 2005).

Table 1.1: Severity of limb deformity and suggested treatment

Degree of angular limb deformity	Suggested treatment
0 to 3°	No treatment/corrective treatment
4 to 6°	Corrective trimming/Extensions/ECSWT
7 to 10°	ECSWT/periosteal transection
11 to 15°	Transphyseal bridging
>15°	Transphyseal bridging/radical intervention

ECSWT Extracorporeal shockwave therapy

(Table extrapolated from Smith 2010)

If a deformity can be manually corrected i.e. Manipulated physically back to the correct position (Figure 1.5), conservative treatment is usually possible (Auer 2006). Irrespective of what method of manipulation is used, it is usually targetted at direct intervention at the metaphyseal end of the physis as that is where most of the longitudinal growth occurs (Smith 2010).

Table 1.2: Various treatment options for Angular limb deformities in the foal

Age range for intervention					
	Corrective trimming	**Hoof extensions**	**Periosteal transection**	**Transphyseal bridging**	**Age of closure of the physis (growth plate)**
Fetlock	≥ 2 weeks	2 weeks – 10 months	4-6 weeks	1-3 months	6 months
Carpus	≥ 2 weeks	2 weeks – 10 months	3-6 months	7-16 months	20-24 months
Tarsus			3-6 months	6-15 months	17-24 months

Stall rest and corrective farrier treatment are the most commonly used conservative treatment for angular limb deformities (Greet 2000). Corrective trimming is often used for both varus and valgus deformities. Varus deformities result in excessive wear of the lateral aspect of the hoof (Smith 2010) and the medial side of the hoof is therefore trimmed to produce an even solar conformation (Greet 2000). Conversely, with valgus deformities there is usually excessive wear on the medial aspect of the hoof and the lateral side is trimmed (Greet 2000). Extension shoes are sometimes used to alter the loads placed on the limb (Smith 2010) and this encourages more axial weightbearing and load through the physis (Greet 2000). For a varal deformity, a lateral extension is used and for a valgus deformity, a medial extension is used.

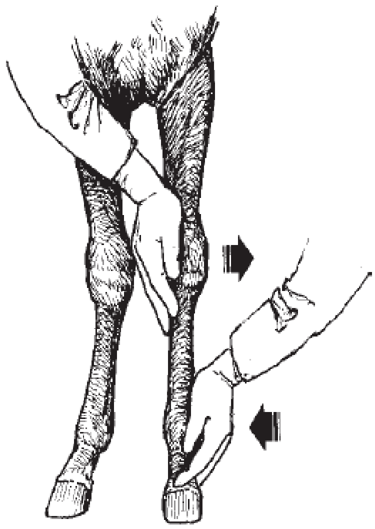


Figure 1.5: Applying manual pressure to the medial aspect of the carpal region of a foal with bilateral valgus deformity, correcting the deformity temporarily (Auer 2006).

Where deformities appear to relate to the physis (growth plate), manipulation of the physis may result in correction of the deformity (Greet 2000). This can be achieved through growth acceleration by use of periosteal transection (Figure 1.6) ("Periosteal strip") or through growth retardation which can be achieved by temporary transphyseal bridging (Figure 1.7) (Auer and Stick 1999). Periosteal transection is a surgical technique for angular limb deformities of the lower radius and tibia. During the surgery, an inverted T-shaped incision is made just above the growth plates on the shorter side of the bone and then peels away the periosteum from the bone at the site to encourage growth. Periosteal transection works on the principle that tension in the periosteum is released stimulating the physis to grow more rapidly on the concave side of the bone (Greet 2000). Transphyseal bridging attempts to retard growth by creating compression on the more active side of the physis (Greet 2000).

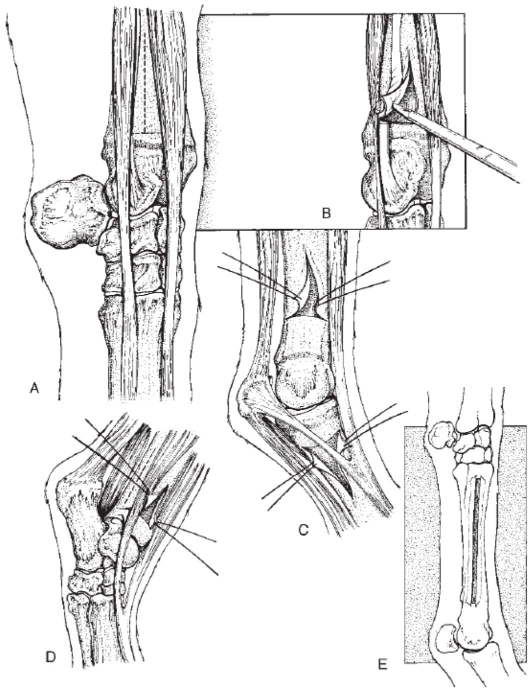


Figure 1.6: Correction of angular limb deformities using periosteal transaction to accelerate growth (Auer 2006).

Limited studies have investigated the association between surgical correction and subsequent racing performance (Baker *et al.* 2011; Mitten *et al.* 1995). One study reported a decrease in racing performance of horses treated with periosteal transection (Mitten *et al.* 1995). However, Baker *et al.* (2011) found the success of horses treated with transphyseal bridging was not significantly different to their sibling (controls) that had no limb deformities (Baker *et al.* 2011). The distinct lack of research in this area, highlights the importance of further investigation into the effect of treatments for limb deformities on sales and racing performance.

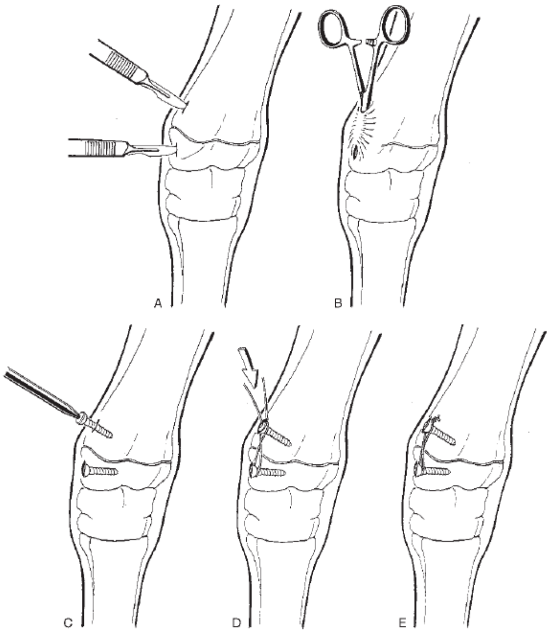


Figure 1.7: Correction of angular limb deformities by transphyseal bridging (Auer 2006).

Splints and casts can also be effective in the management of foals with angular limb deformities if the foal has incomplete ossification of the carpal or tarsal regions (Figure 1.8) (Auer 1992). If the foot is incorporated in the splint and the splint is applied correctly, the splint will allow the foal to strengthen the periarticular soft tissues while maintaining a correct vertical limb axis and limb loading (Leitch 1985).

Figure 1.8: The application of splints for the correction of severe angular limb deformities (Auer 2006).

Congenital flexural limb deformities

OVERVIEW

Flexural deformities are a common condition amongst growing horses in which the joint is held in an abnormally flexted position (Figure 1.9; 1.10) (Kidd and Barr 2002). Flexural limb deformities are those being viewed from the saggital plane (side of the horse) and affect soft tissue structures (Kidd and Barr 2002; Trumble 2005). Flexural limb deformities consist of hyperextensive ("tendon laxity") and contractural deformities ("contracted tendons") (Trumble 2005).

Contractural deformities are often referred to as 'contracted tendons', implying there is a defect in the tendon itself (Kidd and Barr 2002). There is, however, no evidence that tendons are shorter or contracted with respect to the bone (Trumble 2005; Wagner and Watrous 1990). Contractural deformities are common in foals and can be either bilateral or unilateral (Trumble 2005). They most commonly affect the metacarpophalangeal joint or the carpus (Kidd and Barr 2002). Rarely, the tarsus, metatarsophalangeal joint, and distal and proximal interphalangeal joint are also affected (Kidd and Barr 2002).

Figure 1.9: Contractural deformities in a new born foal

New born foals may also present with hyperextension, which results in a weakness of the flexor tendons because of dysmatureity or prematurity, causing foals to have a general lack of muscle tone, (Embertson 1994) or due to insufficient cross-linking of collagen fibrils in the flexor tendons (Barnard *et al.* 1982). The fetlock joint is most commonly affected, and foals generally rock back onto the caudal portion of the hoof wall and heel bulbs. As a result, the pastern hyperextends, the fetlock drops and the toe flips upwards (Figure 1.10) (Trumble 2005).

Figure 1.10: Hyperextension of the fetlock joint in a newborn foal

RISK FACTORS

Little evidence exists about the origin of flexural deformities (Auer 2006). It has been speculated that nutrition of the mare during pregnancy (Allen *et al.* 1996; Arndt and Eversfield 2002; Hintz 1996), bone or joint malformation, or other physiologic causes such as intrauterine malpositioning may result in flexural deformities (Arndt and Eversfield 2002; Embertson 1994; McIlwraith 2004). Intrauterine malpositioning, a commonly reported cause of the problem, can occur rarely in an abnormally large foal relative to the size of the mare, where intrauterine crowding leads to development of the problem.

MANAGEMENT

Whether or not the foals leg can be corrected manually is a good indicator of the prognosis of the foal with a flexural deformity, and can help in the decision of whether to treat a foal (Auer 2006). If manual correction is easily obtained the animal can usually be treated successfully with splint or cast application (Auer 2006). However, it is important that splints are applied correctly as they exert a large amount of tension of the soft tissues, and can have deleterious effects if applied incorrectly (Santschi *et al.* 2006). Where manual correction is not easily obtained, the decision will depend on the severity of the deformity and economic implications associated with treatment and management of the foal.

Congenital flexural deformities can be classified as severe (rarely correctable), moderate (correctable with therapy), or mild (self-correctable) (Santschi 2003). Mild contractural deformities can result in an upright conformation to the limb, but the foal is able to weight bear and load the flexor structures (Santschi 2003). The limbs in these cases can be manually corrected and foals are generally managed by restricting exercise, through box rest or stall confinement, and do not require any specific veterinary treatment (Auer 2006; Santschi 2003). Moderate contractural deformities make it difficult to bear weight on the limb and load the flexor structures and ligaments (Santschi 2003). In these cases, often foals cannot rise to suckle, and the lack of weight bearing increases the severity of the deformity (Santschi 2003). Treatment of moderate contractural deformities is directed at achieving a normal limb orientation, so the foals' weight can stretch the flexor structures as soon as possible post-partum (Santschi 2003). Splints are often applied, but require attention to detail as the splints exert an extreme amount of tension on the soft tissues (Figure 1.11) (Santschi 2003).

Figure 1.11: (a) A foal with severe contractural deformity (b) The application of splints to enable the foal to suckle (Santschi et al. 2006).

Oxytetracycline is routinely administered to foals presenting with congenital flexural deformities (Kidd and Barr 2002; Santschi 2003). The mechanism of action is unknown, however, it appears to exert its effect by relaxing the soft tissues (Santschi 2003). Surgery for congenital flexural limb deformities is uncommon and foals rarely respond favourably to it (Santschi 2003). The most common surgical procedure performed on foals with congenital flexural limb deformities is the inferior check ligament desmotomy (cutting or division of the ligament) for fetlock or coronopedal flexural deformities (Santschi 2003).

Prevalence of congenital limb deformities in horse populations

Crowe and Swerczek (1985) reported the prevalence of flexural limb deformities in a population of newborn foals to be around 20%. Other studies carried out in the northern hemisphere indicated the prevalence of congenital limb deformities to be 10% (Couroucé-Malblanc *et al.* 2006; Wohlfender *et al.* 2009). To date, the prevalence of congenital limb deformities in New Zealand horse populations is yet to be quantified but a preliminary study carried out in New Zealand Standardbred foals found that 19% of foals were born with some form of LD (Stowers *et al.* 2010).

Influence of limb deformities on racing success and injury

Within the racing community, there is a perceived negative association between limb deformities and racing success (Weller *et al.* 2006). Limb deformities have been associated with a greater risk of injury and interruptions to training due to injury (Anderson *et al.* 2004; Weller *et al.* 2006). In a recent study, horses with congenital angular limb deformities were 24 times less likely to be acceptable for sale than those born without congenital angular limb deformities (Yates 2010). A preliminary study of Standardbred foals in New Zealand found that foals with congenital limb deformities (LD) at birth were 1.5 (95% CI 1 – 2.4) times less likely to qualify for racing before the age of four, than those without congenital LD (Stowers *et al.* 2010).

Conformation may be an indicator for racing success (Love *et al.* 2006). If foals that have specific conformational problems could be identified as not being viable for racing, time and money could be saved on these foals and instead resources could be better utilised on foals with racing potential. Forelimb conformation from the carpus distally has received the most attention from veterinarians and horse breeders due to the perceived impact on performance and lameness (Anderson and McIlwraith 2004). A study comprising data from around 4,000 Thoroughbred yearlings, destined for flat racing (Love *et al.* 2006), demonstrated that horses with conformational defects/limb deformities had less chance to race than horses with more correct conformation. It has been demonstrated that there is an increased risk of injury in horses with limb deformities, specifically an increase in the angle of the metacarpophalangeal joint and carpal valgus (Weller *et al.* 2006b). However, these results are controversial, and Anderson *et al.* (2004a) found this conformation to have a protective effect. The risk of pelvic fracture has also been demonstrated to increase with an increase in tarsal valgus and decreased with an increase in the coxofemoral angle (Weller *et al.* 2006b).

CONCLUSIONS, OBJECTIVES OF THE RESEARCH AND THESIS CONTENT

This review of the literature highlighted the current position of the New Zealand standardbred industry and current knowledge surrounding the effects of limb deformities in foals and subsequent racing success. It described the normal growth and development in the equine and the associations between Developmental orthopedic disease (DOD) and congenital limb deformities. It also identified the known prevalence of limb deformities in overseas populations under northern hemisphere conditions, and highlighted the need for research into the prevalence of limb deformities under New Zealand management conditions as well as the percieved association between limb deformities and subsequent racing success.

This study therefore aimed to:

- Describe the prevalence of congenital limb deformities on two large Standardbred stud farms in New Zealand.

- Investigate potential mare and farm level risk factors associated with the prevalence of congenital limb deformities.

- Investigate the association between limb deformities and subsequent racing success.

The following thesis is written in the style of two individual papers that will be submitted for publication.

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CHAPTER 2 – THE PREVALENCE OF CONGENITAL LIMB DEFORMITIES IN A POPULATION OF NEW ZEALAND STANDARDBREDS AND ASSOCIATED RISK FACTORS

ABSTRACT

There is limited knowledge of the prevalence of congenital limb deformities in New Zealand horse populations. Risk factors under New Zealand management conditions have not been identified to date. The objectives of this study were therefore to describe the prevalence of congenital limb deformities at birth on two commercial Standardbred stud farms in New Zealand and investigate associated risk factors.

A historical cohort study of 1,189 foals was conducted on two commercial Standardbred stud farms over two breeding seasons (2005/06 and 2006/07) in the Canterbury region of New Zealand. A visual, clinical inspection was conducted on all foals for congenital limb deformities by one experienced clinician. The presence and types of limb deformities were determined.

Thirty four percent (404/1,189) were born with a limb deformity (LD). Contracted tendons were the most commonly reported LD at birth (26%) and tendon laxity (20%) and angular limb deformities (19%) were also commonly reported. The prevalence of congenital limb deformities varied between farms and seasons ($P<0.001$). At the multivariable level farm, season and birth month were significantly associated with the prevalence of limb deformities at birth ($P<0.05$).

A high proportion of foals in this study were born with some form of LD. Farm, season and birth month were all identified as risk factors for the presence of limb deformities, indicating nutrition and management factors may be associated with congenital limb deformities. Future investigation should focus on identifying risk factors for congenital limb deformities under New Zealand management conditions and describe current management techniques.

INTRODUCTION

Congenital limb deformities are a significant problem for racehorse breeders worldwide (Jeffcott 2004). There is an industry bias for purchasing foals with good conformation as racing and breeding prospects, due to the perceived association between correct conformation and the duration and success of racing careers (Weller *et al.* 2006). Horses born with limb deformities are more likely to be unacceptable for sale than those born without limb deformities (Yates, unpublished data, 2010). Due to the percieved association between congenital limb deformities and an increased rate of musculoskeletal injury later in life, horses born with limb deformities are further scrutinised as successful racing prospects (Santschi *et al.* 2006). In another study, congenital abnormalities were the most common cause of death of foals during the first 12 months post-partum (Galvin and Corley 2010).

In a preliminary investigation, Stowers et al (2010) reported that the prevalence of congenital limb deformities in a population of New Zealand Standardbreds was 19%. This is higher than the prevalence reported in similar studies carried out in Thoroughbred foals overseas (10-15%) (Odonohue *et al.* 1992; Wohlfender *et al.* 2009; Yates 2010). However to date, there have been limited investigations in limb deformities in Standardbreds and under New Zealand management conditions (Stowers *et al.* 2010).

The management of foals with limb deformities may influence the conformation and success of the racehorse later in life. There is limited data available on the current management practices for foals under New Zealand management conditions (Rogers *et al.* 2007; Stowers *et al.* 2009). These investigations have focused on overall management of foals between farms and not on the management of limb deformities in detail. There is some indication that unidentified horse and management associated risk factors may increase the risk of a foal being born with limb deformities (Allen *et al.* 1996; Arndt and Eversfield 2002).

However, to date, risk factors for limb deformities in New Zealand foals have not been investigated. Due to the high prevalence of limb deformities in the preliminary study, which utilised data from the same breeding farms as the current study from the 2004/05 and 2005/06 breeding season (n=1379 foals) (Stowers *et al.* 2010), further investigation was carried out over two breeding seasons to investigate risk factors for congenital limb deformities in New Zealand Standardbred foals. The present study investigated the prevalence of congenital limb deformities over the 2005/06 and 2006/07 breeding seasons and associated horse and farm level risk factors.

MATERIALS AND METHODS

Limb deformity data collection

At the completion of the 2005/06 and 2006/07 breeding seasons, the two Standardbred stud farms provided access to their clinical records. A visual, clinical inspection of the LD status of all foals (n=1,189), within one day after birth, was conducted on both farms by the same experienced equine clinician. The foals' front and hind legs were recorded as normal, flexural deformity (contracted tendons or tendon laxity), angular deformity (Varus or valgus), rotational deformity or other. The management of all foals that required veterinary attention for limb deformities was recorded (n=390). Conservative treatments were only recorded for some (n=14) foals. Data were provided as Microsoft Excel[1] extracts, with chronological records of each foal, which were then transcribed to a customised Microsoft Access[1] database.

Statistical analysis

Horse (foal gender, date of birth, horse name, sire, mare) level data were collected and checked against the official records provided by Harness Racing New Zealand (HRNZ). Data were screened for errors and outliers by simple descriptive statistics including cross tabulation and scatter plots.

The exposures investigated were sex, mare age, parity, farm, season, birth month and sire. Logistic regression was used to examine the effect of these exposures on the binary outcome of the presence of limb deformities at birth. Variables were considered for inclusion in the final multivariable analysis if $P<0.35$ in the univariable analysis. Univariable screening of exposures was carried out using backwards selection and exposures remained in the final multivariable model if $P<0.05$. Data analysis was conducted in Intercooled STATA 11 and the critical probability for assigning statistical significance was set at $P<0.05$.

Descriptive analysis was carried out to investigate the above exposures and the associations with congenital limb deformities. Continuous outcomes (birth month) investigated were described as medians and interquartile ranges (IQR). Date of birth data were categorised into birth months, with November being the reference month. Because there were few (n=4) foals born in February, January and February were combined for analysis.

RESULTS

Descriptive statistics

Thirty four percent (404/1,189) of foals born had some form of congenital LD. Only 29% (117/404) foals were categorised as a specific type of deformity. Of these foals, 26% were born with contracted tendons, 20% were born with tendon laxity, 19% were born with angular limb deformities (varus or valgus), 4% had rotational deformities, 9% were classed as "other" types of deformity and 21% had multiple types of LD at birth (Table 2.1). There was a significant association between farm and congenital limb deformities ($P<0.05$). Fifty five (219/396) % of foals on farm 1 were born with congenital limb deformities whilst only 23% (182/793) of foals on farm 2 were born with limb deformities. The prevalence of limb deformities also varied between season ($P<0.05$). In season 1, 25% of foals were born with LD whilst 41% in season 2 were born with LD. There was also a higher prevalence of LD in January than any other month (Figure 2.1) and this was significantly greater than the prevalence of LD in November (reference month) ($P<0.05$).

Table 2.1: Proportion of limb deformities by type

Type of limb deformity	**n**	**% of total limb deformities**
Contracted tendons	87	26
Tendon laxity	68	20
Angular limb deformities	64	19
Rotational limb deformities	14	4
Other limb deformities	32	9
Multiple limb deformities	75	22

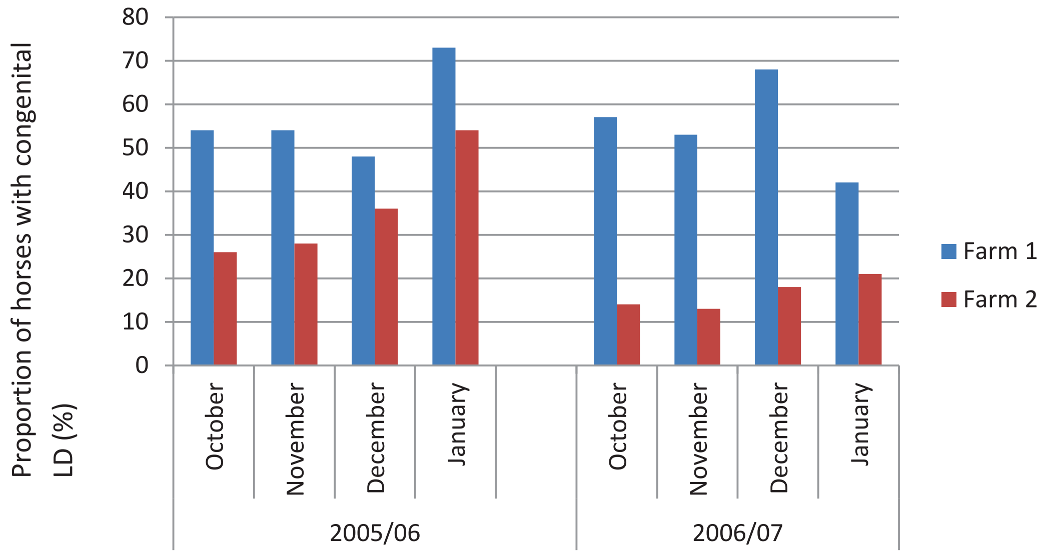

Figure 2.1: Proportion of horses with congenital limb deformities born in the 2005/06 and 2006/07 breeding seasons on farms 1 and 2.

Mare age and parity were highly correlated (r^2 = 0.84) and had similar distributions on both farms and across both seasons (Table 2.2), therefore mare age was used for logistic regression.

Table 2.2: Descriptive statistics by farm

Variable		Median	IQR	P value
Mare age				
	Farm 1	10	7-14	
	Farm 2	10	7-14	0.13
Parity				
	Farm 1	3	2-6	
	Farm 2	4	2-6	0.42
Correlation		0.84		

Logistic regression

Table 2.3 shows the associations between farm and mare level risk factors and congenital limb deformities in the foal. At the univariable level, farm, season and birth month were significantly associated with LD at birth (P<0.05). Sex and mare were also associated (P<0.35) and were considered for inclusion in the final multivariable model. In the final multivariable analysis only farm, season and birth month were significantly associated with a foal being born with LD (P<0.05) (Table 2.4).

Table 2.3: Univariable logistic regression for outcome limb deformities

Variable	Odds ratio	95% confidence interval	Wald test P value	LRT P value
Sex				
Female	1(ref)			
Male	1.15	0.90-1.46	0.26	0.26
Sire	1.00	1.00-1.01	0.23	0.20
Mare age				0.30
>5 years old	1(ref)			
6-8years old	0.67	0.42-1.06	0.09	
9-14 years old	0.94	0.68-1.29	0.70	
>14 years old	1.10	0.81-1.50	0.53	
Parity	0.99	0.96-1.03	0.76	0.76
Farm				<0.0001
1	1(ref)			
2	0.24	0.19-0.31	<0.0001	
Season				<0.0001
2005/06	1(ref)			
2006/07	2.13	1.66-2.74	<0.0001	
Birth month				0.03
November	1(ref)			
September	1.07	0.55-2.10	0.84	
October	0.87	0.63-1.19	0.38	
December	1.29	0.94-1.76	0.11	
January/February	1.75	1.14-2.69	0.01	

Horses born in January were 1.8 times (1.2-2.7) more likely to be born with congenital limb deformities than those born in November (P=0.01). No other birth months were significantly associated with an increased or decreased incidence of congenital LD (P>0.05). Horses born in season two were also 2.1 (1.7-2.7) times more likely to be born with congenital limb deformities than horses born in season one (P<0.001). The goodness of fit test was non-significant (P=0.18). The model was therefore assumed to be a good fit.

Table 2.4: Multivariable logistic regression model for limb deformities

Variable	Odds ratio	95% confidence interval	Wald test P value	LRT P value
Farm				<0.0001
1	1(ref)			
2	0.26	0.20-0.34	<0.0001	
Season				<0.0001
2005/06	1(ref)			
2006/07	1.75	1.34-2.29	<0.0001	
Birth month				0.02
November	1(ref)			
September	1.36	0.67-2.78	0.40	
October	0.93	0.67-1.31	0.69	
December	1.29	0.92-1.80	0.14	
January	2.01	1.26-3.19	0.003	
February	2.09	0.18-23.80	0.55	

DISCUSSION

The current study investigated the LD status in a population of 1,189 foals, over two breeding seasons on two Standardbred stud farms in New Zealand, representing approximately one quarter of the Standardbred foal population per season (IER 2004). The sample population was a convenience sample of stud farms that had staff and clinicians with a high level of commitment to the project. While this restricted the data collection to a particular geographical region, the farms surveyed were two of the larger farms in the Southern hemisphere and have management practices similar to other Standardbred farms in New Zealand (Dicken, 2012). Another limitation of the study was the absence of continuity with and incompleteness of the data collection, so all information regarding LD was not always available for every foal. As this study was based on a historical cohort, future studies would benefit from being prospectively based. Further studies should also investigate not only the incidence of limb deformities at birth but also the change of foals' limbs over time and the management of these diseases.

The aetiology of congenital limb deformities in horses is multifactorial and limited studies have identified specific risk factors for these diseases (Allen *et al.* 1996; Arndt and Eversfield 2002). If risk factors could be identified under specific management conditions, efforts could be made to minimise the incidence of these diseases in racehorse and other horse populations.

The high proportion of foals born with some form of LD on these farms is high (34%). Other studies carried out overseas have indicated that the prevalence of limb deformities is between 10-15% (Marshall *et al.* 2010; Yates 2010). Large variation also exists between different production systems (countries) and the two farms in this study, as well as potential variation between the two farms. There were no differences in mare age or parity between farms 1 and 2 (Table 1). The higher prevalence of LD seen on farm 1 compared with farm 2 is therefore not due to differences in the characteristics of the underlying broodmare population. It is likely that differences seen could be due to differences in management and nutritional factors affecting the broodmare during gestation as well as other factors like genetics, which were not considered this study. Marshal et al (2010) found that the incidence of DOD on a stud in Australia to be 50% whilst only 14% on a similar stud in Ireland despite similar genetics of the foals. Some of the variation between studies could be due to different scoring systems as currently there is no standardised system employed by stud farms or researchers around the world. Differences could also exist due to differences in management and nutrition of the mare during pregnancy and of the foal after birth on different farms and in different production systems.

The finding in the current study that horses born in January (late in the breeding season) are more likely to be born with limb deformities than foals born early in the season, suggests that differences in nutrition and/or management of these mares from the time of conception until the time of birth are contributing to the high prevalence of limb deformities in these foals. Other potential factors like birthweight of foal were not considered in this study but could also have an effect on the incidence of LD.

The variation of the prevalence of limb deformities between seasons is in agreement with other studies (Marshall *et al.* 2010). Marshall et al., found that between two consecutive seasons, as in the current study, there were differences of up to 33%. As the management of mares between season didn't differ, this further suggests that varaition in the nutrition of the broodmares may be associated with the increased prevalence of LD. In Canada, a syndrome has been reported characterized by hyperplasia of the thyroid gland and concurrent musculoskeletal deformities (TH-MSD) (Allen *et al.* 1994). It has been argued that the incidence of this syndrome may be exposure related and nutrition may be an important factor, as no breed or sex differences were seen in horses with this syndrome.

Mares on farms 1 and 2 were not supplemented with any form of concentrate during pregnancy and this suggests that the potential association between nutrition and the prevalence of limb deformities, on these farms is due to changes in the nutrient composition of pasture. As the primary food source for broodmares during pregnancy on most farms in New Zealand is pasture this may have important implications for future management decisions on New Zealand farms.

CONCLUSIONS AND POTENTIAL RELEVANCE

The prevalence of congenital limb deformities observed in this study was higher than has been reported in similar previous studies carried out overseas. Future investigations should focus on the identification of risk factors and different treatment options used for limb deformities in New Zealand foals.

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CHAPTER 3 - THE INFLUENCE OF CONGENITAL LIMB DEFORMITIES ON RACING SUCCESS IN A POPULATION OF NEW ZEALAND STANDARDBRED FOALS

ABSTRACT

There is limited knowledge on the associations between congenital limb deformities and future racing performance. The objectives of this study were therefore to describe the associations of congenital limb deformities on early training and racing milestones, and future performance.

A historical cohort study of 627 foals was conducted on two commercial Standardbred stud farms in New Zealand during the 2006/07 breeding season. A visual, clinical inspection was conducted on all foals for congenital limb deformities. The 2006/07 born foals' records were then combined with racing performance data up to the completion of their 3-year-old season.

Forty one percent of foals (259/627) presented with some form of LD at birth. At the multivariable level, horses born with contractural deformities ("contracted tendons") were significantly less likely to trial than those born without contractural deformities. Horses born with Hyperextension ("tendon laxity") were more likely to trial and race by the age of 2-years-old than those born without hyperextension. Horses born in January had significantly less total race starts and total stakes at the completion of their 3-year-old season than those born in November.

Congenital limb deformities may be associated with a decreased likelihood of horses reaching important training and racing milestones and may also influence future racing performance. Further studies should investigate the associations of specific deformities, and the management of these, on racing success.

INTRODUCTION

Limb deformities are a major problem for horse breeders worldwide (Jeffcott 2004; Weller *et al.* 2006). Within the racing community, there is a perceived negative association between limb deformities and racing success (Weller *et al.* 2006). Limb deformities have been associated with a greater risk of injury and interruptions to training due to injury (Anderson *et al.* 2004; Weller *et al.* 2006). In a recent study, horses with congenital angular limb deformities were 24 times less likely to be acceptable for sale as yearlings at auction, than those born without congenital angular limb deformities (Yates 2010). A preliminary study of Standardbred foals in New Zealand identified a negative association between congenital limb deformities and subsequent racing success (Stowers et al. 2010). This study highlighted found that foals with congenital limb deformities (LD) at birth were 1.5 times less likely to qualify for racing before the age of four than those without congenital LD (Stowers *et al.* 2010). The current study involved a subpopulation of horses within this cohort (2006/07 born foals) to investigate the effects specific limb deformities and other risk factors had on early training and racing milestones and racing performance.

There is an increased focus within the racing industry in New Zealand, and throughout the world, for horses to commence their racing careers as two and three year olds. Emphasis is therefore on horses to meet this niche within the racing market, and as a result breeders invest a significant amount of resources into foals to ensure they provide a marketable product that is perceived as suitable for racing. However, from birth to the time of racing a horse goes through significant conformation changes (Santschi *et al.* 2006). Limited studies have focused on the effect of congenital limb deformities and their associations with racing performance (Anderson *et al.* 2004; Weller *et al.* 2006). Horses born with congenital LD could also be managed differently than those born without congenital LD. This could have an influence on the success of the horse in its racing career. However while we have a broad understanding of the management of foals and young stock within the New Zealand production system (Rogers *et al.* 2007; Stowers *et al.* 2009), we have limited data on the management of the foal with congenital limb deformities.

This study aimed to describe the associations of congenital limb deformities from a subset of the population of foals in Chapter two (n=627) on early training and racing milestones, and future performance. We hypothesised that horses with congenital limb deformities would be less likely to reach early training and racing milestones, and have less successful racing careers as 2- and 3-year-olds than those born without limb deformities.

MATERIALS AND METHODS

A historical cohort study of 627 foals was conducted on two commercial Standardbred stud farms in New Zealand during the 2006/07 breeding season. The study used a convenience sample based on the willingness of the farms to participate and the co-operation and enthusiasm of the clinician based on these farms. All foals born on the two farms during the 2006/07 breeding season were included in the study.

Limb deformity data collection

At the completion of the 2006/07 breeding season, the farms provided access to their clinical records. A visual, clinical inspection of the LD status of all foals, within one day after birth, was conducted on both farms by the same experienced equine clinician. The foals' front and hind legs were recorded as normal, flexural deformity (contracted tendons or tendon laxity), angular deformity (Varus or valgus), rotational deformity or other. Data were provided as Microsoft Excel[1] extracts, with chronological records of each foal, which were then transcribed to a customised Microsoft Access[1] database.

Racing performance data collection

Racing performance data were obtained for all foals enrolled in the study (n=627). Data on trainer registration, trialling and racing were obtained up to the completion of the 3-year-old season (1st September 2010) in a Microsoft Excel[1] extract, provided by Harness Racing New Zealand (HRNZ). These data were then combined with stud farm data in the customised Microsoft Access database.

Statistical analysis

Data provided by the farms (foal gender, date of birth, horse name, sire, mare) were checked against the official records obtained from Harness Racing New Zealand. The distribution of the data was assessed using a Shapiro Wilk test, and screened for outliers using simple descriptive statistics and scatter plots.

The main exposures investigated were the presence of congenital limb deformities, contracted tendons and flexor tendon laxity at birth. Other exposures investigated were mare age, foal sex, farm and birth month (categorised into: September, October, December, January, February; November – reference month). Logistic regression was used to examine the effect of these exposures on the binary outcomes registered with a trainer and exported (n=627 horses). Horses that were never registered with a trainer (n=215 horses) were excluded from the racing analysis dataset (n=412 horses).

Logistic regression was used to investigate the effect of the above exposures with: (i) Trialled, (ii) Raced, (iii) Registered with a trainer by 2-years- old, (iv) Trialled by 2-years-old (v) Raced by 2-years-old. Linear regression was used for continuous measures of success, namely: natural log transformation of (a) total race starts and (b) total stakes. Variables were considered for inclusion in the final multivariable analysis if $P<0.35$ in the univariable analysis. Univariable screening of exposures was carried out using backwards selection and exposures remained in the final multivariable model if $P<0.05$. The main exposures were forced into the multivariable model if they were not significant at the $P<0.35$ level. Data analysis was conducted in Intercooled STATA 11 and the critical probability for assigning statistical significance was set at $P<0.05$.

RESULTS

Descriptive analysis

Limb deformity data were recorded for 627 foals, of which 309 (49%) were females and 318 (51%) were males. Farm one recorded data for 360 foals, and farm two recorded data for 267 foals. More foals were born in November (n=227) than any other month. The median dam age was 9 (IQR 7-14) years old.

Of the 627 foals born, 259 (41%) were categorised as presenting with some form of LD. The most common were flexural deformities (54%, 184/627), consisting of either tendon laxity (53%, 97/184) or contracted tendons (47%, 87/184). Angular LD accounted for 18% (47/627) of limb deformities. Multiple LD categories were recorded for 19% (119/627) of foals, and for 8% (50/627) of foals the type of LD was not recorded. Thirty-four percent (215/627) of foals were never registered with a trainer, and of these 45% (96/215) had a LD at birth. In total 163 foals were born with some type of congenital LD and forty percent (66/163) of these horses never trialled and 39% (63/163) never raced.

Logistic regression

Univariable logistic regression results are listed in Tables 3.1 and 3.2. All final multivariable models are provided in Table 3.3. At the univariable level, limb deformities, contracted tendons, sex, birth month and mare age were all considered for inclusion in the final multivariable analysis for being registered with a trainer (P<0.30). After adjusting for other variables, males were more likely to be registered with a trainer than females. At the univariable level; sex, mare age, limb deformities and farm were associated with a horse being registered with a trainer by 2 years old. After adjusting for other variables, mare age was the only variable associated with a horse being registered by the age of 2-years old (P<0.05).

Table 3.1: Univariable logistic regression of exposures on early milestones (Registered with a trainer, trialled, raced) of Standardbred racehorses born in the 2005/06 breeding season up to the completion of their 3-year-old racing season.

Variable		Odds ratio	95% Confidence interval	Wald test p-value	LRT P Value
Registered with a trainer					
Limb deformities					
	No	1(ref)			
	Yes	0.81	0.58-1.13	0.22	0.22
Contracted tendons					
	No	1(ref)			
	Yes	0.69	0.43-1.09	0.11	0.12
Flexor tendon laxity					
	No	1(ref)			
	Yes	1.09	0.69-1.73	0.71	0.71
Sex					
	Female	1(ref)			
	Male	1.33	0.96-1.85	0.09	0.09
Farm					
	1	1(ref)			
	2	1.05	0.75-1.46	0.79	0.79
Birth month					0.25
	November	1(ref)			
	December	0.87	0.56-1.37	0.55	
	January	0.64	0.34-1.19	0.16	
	September	1.28	0.82-2.02	0.28	
	October	0.72	0.29-1.83	0.50	
Mare age (years)					
	≤5	1(ref)			0.02
	6-8	1.89	0.96-3.72	0.07	
	9-13	1.27	0.58-2.18	0.72	
	≥14	0.79	0.41-1.55	0.50	
Trialled					
Limb deformities					
	No	1(ref)			
	Yes	1.09	0.63-1.87	0.76	0.76
Contracted tendons					
	No	1(ref)			
	Yes	0.64	0.31-1.32	0.22	0.24
Flexor tendon laxity					
	No	1(ref)			
	Yes	2.61	1.01-6.77	.05	0.03
Sex					
	Female	1(ref)			
	Male	1.16	0.69-1.97	0.58	0.58

Farm				
1	1(ref)			
2	0.95	0.56-1.62	0.86	0.86
Birth month				0.66
November	1(ref)			
December	1.47	0.73-2.99	0.29	
January	1.41	0.62-3.22	0.41	
September	1.43	0.87-2.35	0.16	
October	0.44	0.14-1.41	0.17	
Mare age (years)				
≤5	1(ref)			
6-8				
9-13				
≥14				
Raced				
Limb deformities				
No	1(ref)			
Yes	0.82	0.55-1.24	0.35	0.35
Contracted tendons				
No	1(ref)			
Yes	0.62	0.34-1.12	0.12	0.12
Flexor tendon laxity				
No	1(ref)			
Yes	0.78	0.45-1.33	0.36	0.36
Sex				
Female	1(ref)			
Male	1.07	0.72-1.60	0.73	0.73
Farm				
1	1(ref)			
2	0.90	0.60-1.35	0.62	0.62
Birth month				0.99
November	1(ref)			
December	1.08	0.64-1.85	0.77	
January	1.01	0.45-2.28	0.98	
September	1.10	0.67-1.81	0.71	
October	0.94	0.29-3.00	0.91	
Mare age (years)				
≤5	1(ref)			0.02
6-8	1.89	0.96-3.72	0.07	
9-13	1.27	0.58-2.18	0.72	
≥14	0.79	0.41-1.55	0.50	

In the univariable analysis contracted tendons, tendon laxity and mare age were all associated with whether or not a horse trialled. At the multivariable level, only tendon laxity and mare age were associated with a horse trialling (P<0.05).

Table 3.2: Univariable logistic regression of exposures on early milestones (Registered with a trainer by 2yo, trialled by 2yo, raced by 2yo) of Standardbred racehorses born in the 2005/06 breeding season up to the completion of their 3-year-old racing season.

Variable	Odds ratio	95% Confidence interval	Wald test p-value	LRT P Value
Registered with a trainer by 2-years-old				
Limb deformities				
No	1			
Yes	0.94	0.63-1.40	0.76	0.76
Contracted tendons				
No	1(ref)			
Yes	0.74	0.41-1.34	0.32	0.32
Flexor tendon laxity				
No	1(ref)			
Yes	1.27	0.73-2.20	0.39	0.39
Sex				
Female	1(ref)			
Male	1.82	1.22-2.72	0.003	0.003
Farm				
1	1(ref)			
2	0.81	0.55-1.21	0.31	0.31
Birth month				0.40
November	1(ref)			
December	0.72	0.43-1.21	0.21	
January	0.49	0.22-1.07	0.07	
September	0.90	0.55-1.47	0.68	
October	0.89	0.28-2.84	0.84	
Mare age (years)				
≤5	1(ref)			0.30
6-8	1.16	0.58-2.32	0.67	
9-13	0.66	0.34-1.31	0.23	
≥14	0.41	0.20-0.81	0.01	
Trialled by 2-years-old				
Limb deformities				
No	1(ref)			
Yes	1.19	0.80-1.77	0.40	0.40
Contracted tendons				
No	1(ref)			
Yes	0.77	0.42-1.42	0.41	0.40
Flexor tendon laxity				
No	1(ref)			

Yes	1.58	0.93-2.69	0.09	0.09
Sex				
Female	1(ref)			
Male	1.61	1.08-2.38	0.02	0.02
Farm				
1	1(ref)			
2	0.85	0.58-1.27	0.43	0.43
Birth month				0.41
November	1(ref)			
December	0.85	0.51-1.43	0.54	
January	0.58	0.25-1.31	0.19	
September	0.79	0.49-1.28	0.34	
October	1.84	0.58-5.88	0.30	
Mare age (years)				
≤5	1(ref)			0.002
6-8	1.16	0.84-3.05	0.16	
9-13	0.66	0.64-2.34	0.55	
≥14	0.41	0.29-1.16	0.12	
Raced by 2 years-old				
Limb deformities				
No	1(ref)			
Yes	1.20	0.77-1.88	0.42	0.43
Contracted tendons				
No	1(ref)			
Yes	0.70	0.34-1.46	0.34	0.33
Flexor tendon laxity				
No	1(ref)			
Yes	1.72	0.98-3.03	0.06	0.06
Sex				
Female	1(ref)			
Male	1.31	0.84-2.05	0.24	0.24
Farm				
1	1(ref)			
2	0.69	0.43-1.08	0.11	0.10
Birth month				0.94
November	1(ref)			
December	1.10	0.61-1.96	0.76	
January	0.76	0.29-1.99	0.57	
September	1.13	0.64-1.94	0.67	
October	0.91	0.24-3.47	0.89	
Mare age (years)				
≤5	1(ref)			0.13
6-8	1.16	1.01	0.50-2.03	
9-13	0.66	0.76	0.37-1.56	
≥14	0.41	0.51	0.23-1.09	

In the univariable analysis tendon laxity, mare age and sex were associated with a horse trialling by 2 years of age. At the univariable level, limb deformities, contracted tendons, tendon laxity and mare age were associated with whether or not a horse raced. After considering other variables, mare age was the only variable associated with whether or not a horse raced. Tendon laxity, and mare age were associated with a horse racing by 2-years-old at the univariable level and after considering all other variables in the multivariable analysis (P<0.05). Foals from mares aged between 6- and 8-years-old were more likely to trial and race by the age of 2-years-old, and foals born with flexor tendon laxity were more likely to race by 2-years-old than those born without tendon laxity. Males were also more likely to trial by 2-years-old than females (P<0.05). Sex was the only variable significantly associated with export, with Males being 1.4 times more likely to be exported than females (P<0.05). Limb deformities as well as specific deformities (contracted tendons and laxity) didn't have any effect on the likelihood of horses being exported (P>0.05).

Table 3.3: Final multivariable linear regression model of exposures on early milestones (Trialled, trialled by 2yo) of Standardbred racehorses born in the 2005/06 breeding season up to the completion of their 3-year-old racing season.

	Odds ratio	95% confidence interval	Wald test P value	LRT P value
Trialled				
Mare age				0.003
≤5	1(ref)		1	
6-8	1.16	1.13-6.97	0.03	
9-13	0.66	0.71-3.84	0.24	
≥14	0.41	0.34-1.69	0.50	
Flexor tendon laxity				0.03
No	1(ref)			
Yes	2.68	1.02-7.01	0.04	
Trialled by 2				
Mare age				0.002
≤5	1(ref)			
6-8	1.66	0.87-3.20	.013	
9-13	1.25	0.65-2.40	0.51	
≥14	0.60	0.30-1.20	0.15	
Sex				0.02
Female	1(ref)			
Male	1.63	1.09-2.43	0.02	

Linear regression

At the univariable level, limb deformities, tendon laxity, and birth month were associated with total race starts (Table 3.4). After consideration of all other variables, limb deformities and birth month were significantly associated with total number of race starts (P<0.05). The final multivariable models for total race starts and total stakes are presented in Table 3.5.

Table 3.4: Univariable linear regression of exposures on ln(total starts) and ln(total stakes) of Standardbred racehorses born in the 2005/06 breeding season up to the completion of their 3-year-old racing season.

Variable	Coefficient	Standard Error	95% Confidence interval	Wald test P-value	LRT P-value
Ln(total starts)					
Limb deformities					
No	1(ref)				
Yes	-0.24	0.11	-0.47- -0.02	0.03	0.03
Contracted tendons					
No	1(ref)				
Yes	-0.0004	0.18	-0.36-0.35	0.98	0.98
Flexor tendon laxity					
No	1(ref)				
Yes	-0.17	0.16	-0.47-0.14	0.28	0.28
Sex					
Female	1(ref)				
Male	0.03	0.11	-0.18-0.25	0.76	0.76
Farm					
1	1(ref)				
2	0.01	0.11	-0.21-0.23	0.94	0.94
Birth month					0.01
November	1(ref)				
December	-0.028	0.14	-0.56-0.002	0.05	
January	-0.68	0.22	-1.11- - 0.24	0.002	
September	-0.04	0.13	-0.30-0.23	0.78	
October	-0.41	0.32	-1.05-0.23	0.20	
Mare age (years)					
≤5	1(ref)				0.13
6-8	1.16	1.01	0.50-2.03		
9-13	0.66	0.76	0.37-1.56		
≥14	0.41	0.51	0.23-1.09		
Ln(total stakes)					
Limb deformities					
No	1(ref)				
Yes	-0.20	0.25	-0.70-0.29	0.41	0.41
Contracted tendons					

No	1(ref)				
Yes	0.18	0.40	-0.60-0.96	0.65	0.65
Flexor tendon laxity					
No	1(ref)				
Yes	0.09	0.34	-0.59-0.76	0.80	0.80
Sex					
Female	1(ref)				
Male	0.46	0.24	-0.01-0.94	0.06	0.06
Farm					
1	1(ref)				
2	-0.10	0.25	-0.59-0.38	0.68	0.68
Birth month					
November	1(ref)				
December	-0.71	0.31	-1.33- -0.10	0.02	0.4
January	-1.41	0.48	-2.35- -0.47	0.003	
October	0.05	0.29	-0.53-0.63	0.87	
September	0.28	0.75	-1.19-1.75	0.71	
Mare age (years)					
≤5	1(ref)				0.3
6-8	1.16	0.58-2.32	0.67		
9-13	0.66	0.34-1.31	0.23		
≥14	0.41	0.20-0.81	0.01		

At the univariable level and after considering all other variables sex and birth month were associated with total stakes earned (P<0.05). In the final multivariable analysis horses born in or after December earned significantly less total stakes than those born in November (P=0.003), however there were no differences in stakes earned for horses born before November. At the multivariable level, males earned significantly more stakes than females (P=0.03).

Table 3.5: Final multivariable linear regression model for ln(total starts) and ln(total stakes) of ln(total starts) and ln(total stakes) of Standardbred racehorses born in the 2005/06 breeding season up to the completion of their 3-year-old racing season.

Variable	Coefficient	Standard Error	95% confidence interval	P value	LRT value	P
Ln(total starts)						
Birth month					0.01	
November	1(ref)					
December	-0.27	0.14	-0.56--0.01	0.06		
January	-0.67	0.22	-1.10--0.24	0.003		
October	-0.04	0.13	-0.30-0.22	0.78		
September	-0.45	0.32	-1.09-0.18	0.16		
Ln(Total stakes)						
Sex						
Female	1(ref)					
Male	0.53	0.24	0.06-0.99	0.03	0.06	
Birth month					0.006	
November	1(ref)					
December	-0.74	0.31	-1.35—0.13	0.02		
January	-1.43	0.47	-2.37—0.50	0.003		
October	0.09	0.29	-0.48—0.67	0.75		
September	0.19	0.74	-1.27-1.65	0.80		

DISCUSSION

A preliminary investigation conducted over two breeding seasons (2005/06 and 2006/07) identified a negative association between congenital limb deformities in a population of Standardbred foals and racing success (Stowers *et al.* 2010). The current study involved a subpopulation of horses within this cohort (2006/07 born foals) to investigate the effects specific limb deformities and other risk factors had on early training and racing milestones and racing performance, as more detailed limb deformity and management information was available for these foals.

The conformation of foals is believed to be an important factor in the success of a racehorse (Santschi *et al.* 2006; Weller *et al.* 2006). Anecdotally, foals with good conformation are deemed by breeders and purchasers within the racing industry to have a greater chance at racing and breeding success. Knowledge on the association between limb deformities and racing success under New Zealand management conditions is limited; however there is a perceived association between conformation and the duration and success of racing careers (Weller *et al.* 2006).

The sample population was a convenience sample of stud farms that had staff and clinicians with a high level of commitment to the project. While this restricted the data collection to a smaller geographical region, the farms surveyed were two of the larger farms in New Zealand and have management practices similar to other Standardbred farms in New Zealand (Dicken, 2012). Another limitation of the study was the lack of training and exercise information. These variables have previously been shown to influence the reaching of early milestones and racing success (Ely *et al.* 2010; Verheyen *et al.* 2009; Bolwell et al 2010). A major advantage of the study was the ability to have a single highly experienced equine clinician evaluate and categorise all the foals, and thus minimise the variation in grading of the limb deformities.

At the multivariable level, sex and birth month were the only variables that were significantly associated with a horse being registered with a trainer. The fact that males were 1.4 times more likely to be registered with a trainer and 2 times more likely to be exported than females, suggests an industry bias towards selecting males as racing prospects. This is in agreement with a larger prospective study of Standardbreds in New Zealand (Tanner *et al.* 2010) which identified a strong male bias in age of entering training and starting in either a race or trial. Perkins *et al.* (2005) also found that females had shorter careers in racing possibly due to their residual value as breeding stock, whereas geldings have fewer alternative options other than racing.

Tanner *et al.*, (Unpublished data, 2011) concluded a horse being registered with a trainer was potentially an important milestone for racing success. Bolwell *et al.* (2010) identified that trainers reported that trialling was an important milestone for future racing performance of Thoroughbred racing horses. There is also a growing body of evidence to suggest that exercise early in life is associated with greater orthopaedic health and longer racing careers (Barneveld and van Weeren 1999) (Barneveld and van Weeren 1999; Rogers *et al.* 2008a; Rogers *et al.* 2008b). The possible associations between early exercise and racing success and the industry-driven market to produce 2- and 3- year-olds for racing, means that breeders must produce foals that have the ability to start their racing careers early in life, to increase their chance of success. As horses born with congenital LD, specifically contracted tendons, may be less likely to reach these important milestones, they may be less successful than those born without congenital limb deformities.

As mare age increased, the likelihood of a horse trialling or racing by the age of two also increased, indicating perhaps that as mares become proven by successful progeny trainers may be more likely to trial and race these progeny earlier as future racing prospects.

There was a trend for horses born with tendon laxity to be more likely to trial and race by the age of 2-years-old, than horses born without tendon laxity. In contrast, other studies have identified a negative association between tendon laxity and subsequent racing performance. However, this could be due to the difference in study designs and the analysis carried out. Yates (2009) only focused on tendon laxity at the univariable level, and most previous studies have focused on LD as opposed to specifically flexor tendon laxity as a risk factor. Differences between these studies could also be due to the study population. In this study, horses were included from one breeding season and further investigation over more breeding seasons would increase the robustness of this kind of study. It could also be hypothesised that the positive trend with tendon laxity may be due to more intensive management of foals born with this deformity, which alters the trainer's impression of the 2-year-olds' ability to tolerate training. Further studies should, therefore, investigate not only the diseases but also the management of these in the foal.

In the final multivariable analysis, horses born with limb deformities and horses born in or after December (late in the season) had significantly less race starts at the completion of their 3-year-old season, than those born without limb deformities and those born in November (mid-season) respectively. Horses born in or after the month of December also earned significantly less stakes at the completion of their 3-year-old season, than those born in November (mid-season). This suggests the importance of having foals born earlier in the season to maximise their chance of success as a racehorse. There is also an industry perception that more horses are born with limb deformities later in the season (which is also supported by data in this study) and one possibility is that an increase in the proportion of foals with LD late in the season (Stowers, unpublished data, 2011) could be accounting for this reduced success. Previous studies have indicated that alterations in maternal nutrition may influence the incidence of limb deformities at birth (Arndt and Eversfield 2002; McIlwraith and James 1982). On both farms, the mares' primary feed source throughout gestation was pasture. The feed intake of mares throughout gestation, and potentially the incidence of limb deformities in foals, may, therefore, vary depending on time of year the mare was served.

CONCLUSIONS AND POTENTIAL RELEVANCE

Several variables including congenital limb deformities, sex, mare age and birth month were associated with early training and racing milestones and future racing performance. Horses born with congenital limb deformities, specifically contracted tendons, may be less likely to reach important training and racing milestones and may therefore be less successful as racehorses. Further studies should investigate the associations of specific deformities, and the management of these, on racing success. Birth month was significantly associated with racing performance. As birth month was associated with the prevalence of limb deformities, limb deformities may have an indirect effect on racing performance due to their association with birth month.

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CHAPTER 4 – GENERAL DISCUSSION, CONCLUSIONS AND FUTURE DIRECTIONS

GENERAL DISCUSSION

This thesis reports on the retrospective epidemiological findings of the prevalence of and risk factors for limb deformities in Standardbred foals, and the associations between limb deformities and racing success, on two studfarms in New Zealand.

Chapter 2 investigated the prevalence of and risk factors for limb deformities. Data were collected over two breeding seasons (2004/05 and 2005/06) for this study. A high proportion of foals (34%) were born with congenital limb deformities in both seasons. The prevalence of congenital limb deformities differed between, farm, season and birth month, indicating that management factors may be associated with the increased prevalence of limb deformities at birth.

Chapter 3 investigated the associations between congenital limb deformities and subsequent racing success up to the completion of the 3-year-old season. Several measures of racing success were investigated. When other variables were considered, limb deformities appeared to have minimal effects whether or not a horse was registered with a trainer, trialled, or raced. However limb deformities were associated with the total number of races a horse had started in and the total stakes they had earned at the completion of their 3-year-old season, indicating that limb deformities may have an effect on the ability of the horse to start in a number of starts over several seasons and this may therefore affect their ability to win money.

CONCLUSIONS AND FUTURE DIRECTIONS

Limb deformities are a major source of wastage for breeders worldwide and for studfarms included in this study. Intensive management of horses with limb deformities requires large capital and labour input on studfarms and this is associated with significant time and monetary costs. Some potential risk factors have been identified for congenital limb deformities under New Zealand based conditions but further investigation should focus specifically on mare level risk factors.

One limitation of this study included the retrospective nature of the collection of data. A further possible limitation was that the LD data collection was carried out by one clinician. Although this minimised the chance for variability between the scoring of foals, other studies conducted have indicated that there is a large amount of variation between scorers when using objective measures of conformation assessment. Therefore future studies should be conducted prospectively and inter- and intra-variability between and within scorers should be identified.

The identification of birth month, season and farm as risk factors for the prescence of limb deformities in birth, indicate variation in mare management and environmental factors during pregnancy may influence the growth and development of the foal. Future studies should also investigate specific management techniques used under New Zealand conditions as research into the efficacy of different treatment options is lacking.