A PRELIMINARY DESCRIPTIVE EPIDEMIOLOGICAL STUDY ON ANGULAR LIMB DEFORMITIES IN A SAMPLE OF COMMERCIAL NEW ZEALAND THOROUGHBRED FOALS.

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The work presented in this thesis is original and is the product of a study carried out across North Island Thoroughbred Stud Farms.

The work in this thesis does not incorporate any material previously submitted for another degree in any university. To the best of my knowledge this work is entirely my own and contains no material previously published or written by anyone else except where references are made.

Abstract

A prospective observational study was carried out to provide descriptive epidemiology of angular limb deformities (ALD) at several predetermined time-points in a sample of Thoroughbred foals born during the 2013/14 breeding season across five commercial North Island Thoroughbred stud farms. The stud farms selected were a convenience sample based on geographical location, annual foal crop and their willingness to partake in the study. Data were collected for foals scored at birth, foal heat (2 weeks), 6 weeks, and weaning age (approximately 5 months). Foals were examined for the presence of angular deviations at the carpal, tarsal and fetlock joints; these were graded on a scale ranging from 1-5 in severity between 0° and 20°, which was quantified using an ALD measuring limb protractor designed for the study. Foals were also examined for the presence of offset carpal joints and rotational deformities of the cannon and pastern regions. A total of 230 foals were scored for the presence of ALD at birth. Overall, 78% (180/230) were recorded to have one or more ALD at birth. This was significantly more than at foal heat (71%; 39/55), six weeks (29%; 18/55), and weaning age (12%; 30/257) ($p < 0.001$). A total of 363 ALD were recorded at birth, 66% (239/363) were recorded as severity score 2. Angular limb deformities with severity scores 3 and 4 were recorded less frequently (31%; 112/363); there were no ALD with severity score of 5 recorded throughout the trial. There was no significant association of overall occurrence of ALD to gestation length, mare age and foal gender.

Inter-observer agreement on the presence and severity of ALD was strong between study personnel and fair between study personnel and stud staff, ($k = 0.75$, 95% CI) and ($k = 0.27$, 95% CI) respectively. The greatest source of disagreement was in the scoring of mild ALD, and ALD at the carpal joint. Disagreement was attributed to a low number of simultaneous scorings between study personnel and stud staff, and the dynamic effect that changes in stance and maturation of foals during the first days post-partum have on the perception of ALD and severity.

Data for the management of ALD were recorded for 27% (71/265) of the foals scored with ALD over the course of the trial. Management of ALD across all stud farms involved a period of conservative management before any surgical interventions. Confinement (39%; 86/222) and hoof trimming (28%; 62/222) were the most frequently recorded methods of early intervention. Surgical interventions (5%; 12/222) were reserved for foals with severe ALD and those with ALD

that had not responded to a period of conservative intervention. Across all stud farms treatments were tailored to individual foals, highlighting the dynamic nature of foal development.

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Table of Contents

List of Tables

Chapter 2

Chapter 3

Chapter 4

List of Figures

Chapter 2

Chapter 3

Chapter 4

CHAPTER 1

LITERATURE REVIEW

The New Zealand Thoroughbred industry

New Zealand bred Thoroughbreds are renowned for their quality, soundness and on-track performance around the world (Fennessy, 2010; NZTR, 2010). In 2007, New Zealand was the eighth largest producer of Thoroughbred progeny globally, producing an estimated 4,338 foals (Fennessy, 2010). Each year New Zealand exports more than 1,500 horses to country's such as Australia, Honk Kong, United Arab Emirates and Singapore, with export values of more than NZ$ 130 million (Fennessy, 2010; NZTBA, 2013). The success of New Zealand's Thoroughbred industry, in both breeding and racing, is attributed to the quality bloodlines of the stallions available to breeders, as well as the countries pasture quality and temperate climate (NZTM, 2013). New Zealand's temperate climate and the quality of pasture available to stud farms, allows stud masters to keep horses at pasture year round, minimizing the need for supplementary feeds and allowing adequate rates of free exercise (Rogers *et al*., 2007; Rogers *et al.,* 2012). The growth rates of young pasture fed horses in New Zealand are similar to horses in other countries that receive large quantities of energy rich grain feeds (Brown-Douglas & Pagan, 2005; Hoskin & Gee, 2004; Rogers *et al*., 2009). Time at pasture during early development, allowing for increased rates of free exercise, has been linked to improved musculoskeletal development, which could be linked to the widely proclaimed quality of New Zealand bred Thoroughbreds (Bell *et al*., 2001; Rogers *et al*., 2008; Rogers *et al*., 2012).

The New Zealand Thoroughbred industry consists of both racing and breeding sectors. Combined, these sectors contribute over 1% of New Zealand's gross domestic product (GDP), estimated to be NZ$ 1,100 million annually (Fennessy, 2010; Waldron *et al*., 2008). New Zealand Thoroughbred Racing (NZTR) oversees the running of approximately 3,000 races annually, involving in excess of 5,000 horses competing for prize money totaling more than NZ$ 50 million (NZTR, 2010; NZTBA, 2013; NZTM, 2013). The New Zealand racing industry is sustained by the country's export oriented breeding industry (NZTBA, 2013; Waldron *et al*., 2008). The New Zealand Thoroughbred Breeders Association (NZTBA) statistics reported an estimated 5,300 active broodmares were served by approximately 90 stallions (shuttle and resident) in the 2012/13 breeding season; with approximately 3,800 foals born across 75 commercial stud farms and smaller scale breeders (Bolwell *et al*., 2012; NZTBA, 2013; Rogers *et al*., 2009; Waldron *et al*., 2008). The primary goal for many of New Zealand's commercial Thoroughbred stud farms is to produce progeny for the annual yearling sales run by New Zealand bloodstock (Waldron et al., 2008). The sale of yearlings at the Karaka sales center attracts a large international customer base and the sale and subsequent export of yearlings is reported to be in excess of NZ$ 130 million annually (NZTBA, 2013).

Annually the New Zealand Bloodstock (NZB) yearling sales offer over 1,500 yearlings across three sales categories; Premier, Select and Festival. Yearlings are placed within their respective sales categories based on pedigree and conformation, which in turn has been shown to influence sale price (Bolwell *et al.,* 2012; Waldron *et al*., 2008). Purchase price of yearlings is reportedly based on stallion reputation (associated with progeny performance and service fee), physical conformation, the dams racing performance and the performance of her preceding foals (Eberhart, 2009; Waldron *et al*., 2008). These claims are supported by the growing trend of international buyers (Hong Kong, Singapore, Australia) preferentially purchasing progeny by well renowned expensive sires (NZB, 2013; Robbins & Kennedy, 2001). The yearling sales are followed later in the year by the annual ready to run sale of 2-year-olds where buyers can purchase horses ready to begin their 2-year-old racing careers, based on their conformation and a video of the horses breeze (gallop) over 200 meters (NZB, 2013). The sale and export of New Zealand bred bloodstock, and its continued international racing success, is what fuels the New Zealand Thoroughbred industry (Waldron *et al*., 2008).

Wastage

Wastage is a term used to describe loss of production; which in the racing sector takes the form of horses failing to train or race, as well as premature retirement of horses from racing due to injury or death (Jeffcott *et al*., 1982; Wilsher *et al*., 2006). Wastage causes significant financial loss and lack of return on the initial investment into horses bred to race (Olivier *et al*., 1997). Significant financial loss is accumulated during the pre-racing production period through stallion service fees, up keep of broodmares and young horses, medical treatments for injured horses and yearling preparation (Jeffcott *et al*., 1982; Perkins *et al.*, 2005). During racing wastage is often quantified or measured as days when horses fail to train; due to injury or illness (Bourke, 1995; Perkins *et al*., 2005; Dyson *et al*., 2008; Parkin, 2008). However, days lost is a measurement criteria limited to the racing component of the Thoroughbred industry and cannot be used when attempting to quantify production loss across the entire Thoroughbred production system. It is important when considering wastage within the Thoroughbred industry to account for all losses from the point of conception right up to and throughout horses racing careers (Jeffcott *et al*., 1982; Olivier *et al*., 1997; Bourke, 1995; Wilsher *et al*., 2006; Fennessy, 2010).

Wastage statistics indicate that approximately 50% of purpose bred Thoroughbreds fail to race, and of those that do, many never win a race (Jeffcott *et al.,* 1982; Bourke, 1995; Wilsher *et al*., 2006; Tanner *et al*., 2013). Growing interest in the variables associated with wastage in Thoroughbred breeding and racing has resulted in a number of publications across many racing jurisdictions. The appeal of a horse to potential buyers relies on multiple factors; including, pedigree, age, conformation, sex, and biomechanical attributes (Barneveld & van Weeren, 1999; Robbins & Kennedy, 2001; Waldron et al., 2008). The reduction of wastage therefore begins in the planning of the mating, care of the mare during gestation and subsequent management of progeny post-partum to ensure correct physical development in order to produce horses with great athletic potential. This in turn will influence the age at which horses enter training, record their first race start as well as the longevity of their racing careers.

Wastage in breeding

Thoroughbred horses have a low reproductive efficiency in comparison to other domestic livestock (Brück *et al*., 1993). This is due to a shortened commercial breeding season associated with the requirements for natural service. Compounding this, the Thoroughbred is bred for racing performance rather than for reproductive efficiency (Polge, 1978; Sanderson & Allan, 1984; Morley & Townsend, 1997; Rogers *et al*., 2009). Many breeders attempt to have mares foal as early in the season as possible in order to maximize growth and development of the horse for both yearling sales and early age related racing series (especially 2-year-old racing) (Eberhart, 2009; Robbins & Kennedy, 2001). Prior to the industry imposed breeding season, mares are manipulated using hormone and/or light therapy to ensure their oestrous cycles have resumed in order to enable mating earlier than the natural physiologic breeding season (Morris & Allen, 2002; Sanderson & Allan, 1984; Rogers *et al*., 2009). It has been speculated that the continued requirement of natural mating, as oppose to artificial insemination (AI), contributes to reduced reproductive efficiency in Thoroughbreds; due to stallions having to cover large numbers of mares in a short season, placing pressure on the management of both the mares cyclic activity and stallion fertility (Sanderson & Allan, 1984; Rogers *et al*., 2009).

Breeding efficiency is quantified by mare conception and foaling rates. A study of the British and Irish Thoroughbred industry (Jeffcott *et al*., 1982), reported an end of season conception rate of 78.1% and a subsequent foaling rate of 67.4%. Wastage was the result of mares unable to conceive (22.5%) and foals that were aborted or died after birth (10.1%). Another study reported the reproductive performance of Thoroughbred mares across 6 stud farms in south eastern Australia (Brück *et al*., 1993). Overall pregnancy and foaling rates were 83.9% and 69.3%, respectively and 54.7% and 43.1%, respectively when reproductive efficiency was assessed per served oestrus cycle (Brück *et al*., 1993). A similar study in New Zealand by Hanlon *et al*., (2012), reported per cycle pregnancy and foaling rates of 53.6% and 80.2% respectively, with losses accounted for by lost pregnancies (8.5%) and multiple pregnancies (Twinning) (12.9%). Reproductive efficiency in mares is reported to to be a factor of mare age, number of oestrus cycles served and mare reproductive status (maiden, barren, foaling) (Polge, 1978;Palmer, 1978; Sanderson & Allan, 1984; Morley & Townsend, 1997). As mares age their ability to conceive and carry a foal to term decreases as the quality of their eggs and uterine lining deteriorate, resulting in reduced reproductive efficiency (Brück et al., 1993). Improved conception and foaling rates are attributed to better management of mares and stallions on stud farms, and improved veterinary understanding and the use of interventions required (Brück et al., 1993; Nath *et al*, 2010)

Post-service loss, reported by Jeffcott *et al*., (1982), accounted for 32.6% of wastage recorded. Losses comprised barren mares (22.5%) and pre or post-natal deaths (10.1%) consisting of aborted twins, stillbirths and foals which died after birth. The United Kingdom General Stud Book reported that of 60-70% of mares which conceived; only 40-50% went on to produce live foals (Sanderson & Allan, 1984). A study summarizing the lifetime production of a population of broodmares in Australia reported that 110 mares yielded 711 foals; ultimately 7%(50) of the foals died after birth, 83%(593) were named and 69%(494) of those named, eventually raced (Bourke, 1995). At an industry level it was identified that it takes 1,000 mares to produce 300 horses that would eventually race (Bourke, 1995). Wilsher *et al*., (2006) examined similar records from a sample of 1022 foals from the 1999 Thoroughbred foal crop. In all, 52% (537) of those foals entered training at 2 years of age; the remainder were exported, entered other disciplines, died or entered training at age 3. Fennessey *et al.,* (2010), reported similar statistics in New Zealand, with 44% (1928/4000) of a foal crop entering training with a registered trainer as 2-year-olds. These results suggest that there are underlying factors other than breeding efficiency that contribute to wastage within the Thoroughbred production industry. The common factors contributing to wastage after birth are reported to be foal death, export, kept as stores and lack of ability (Bourke,1995; Jeffcott *et al.*, 1982; Wilsher et al., 2006).

Wastage in training and racing

Horseracing places significant strain on the musculoskeletal system of the equine athlete. Sometimes these stresses overcome the ability of the musculoskeletal system to withstand the forces involved in racing, resulting in injury (Perkins et al., 2005b). Wastage, as a result of musculoskeletal injury or illness negatively affects the Thoroughbred racing industry through a reduction in racing stock, inability to fill race fields, negative perception and lack of attraction from the betting public and subsequently a high horse turnover for owners, suddenly faced with low financial return on their investment (Olivier *et al*., 1997; Stover, 2003). The most common causes of wastage reported by trainers from various Thoroughbred racing jurisdictions are lameness due to musculoskeletal injury, followed by respiratory illness and infection (Bourke, 1995; Jeffcott *et al*., 1982; Wilsher et al., 2006).

Wastage studies rely on the trainers to report the training and racing activity of their horses. As mentioned, lameness, respiratory problems and illness are the most common reasons for horses failing to train or race (Bailey *et al*., 1997; Jeffcott et al., 1982; Perkins *et al.,* 2005a, Rossdale *et al.,* 1985). Lameness was reported as the most common cause of wastage across all studies ranging between 45% and 79% (Bailey *et al*., 1997; Jeffcott et al., 1982; Lindner & Dingerkus, 1993; Perkins et al., 2005a; Wilsher et al., 2006). In a study of wastage in the English and Irish

Thoroughbred industry, Jeffcott *et al.,* (1982), symptoms of lameness resulted in horses failing to train or race 49% of the time. Trainers involved in the study reported dorsometacarpal disease (DMD) or shin soreness (15%), problems of the hoof (15%), and carpal damage (12%) as the most common reasons for lameness (Jeffcott et al., 1982). A survey of 40 trainers in Sydney, Australia, found that lameness resulting in failure to train or race was reported most often; lameness was mostly the result of shin soreness (60% on 2-year-olds), whilst joint problems and foot problems were also reported commonly (Bailey *et al*., 1997). Within in the New Zealand Thoroughbred industry, Perkins *et al*., (2005a), reported musculoskeletal injury to be responsible for 79% of missed training days or races. Musculoskeletal injuries reported were unspecified cause (51%), shin soreness (27%) and tendon and ligament injury (13%). Wilsher *et al*., (2006), reported wastage statistics from 1,022 Thoroughbred foals in their 2 and 3 year-old racing preparations. Lameness was responsible for missed training days 45% of the time in 2-year-olds and 32% in 3-year olds. Shin soreness was the most common source of wastage in 2-year-olds, while joint problems were more prominent in 3-year-olds (13%). The incidences of wastage are comparable across studies and the occurrence of lameness was shown to be related to horse age, with younger horses being more prone to interruptions (Stover, 2003; Wilsher et al., 2006).

Advances in the understanding of the equine athlete's musculoskeletal system have led to improved management procedures, which can potentially lengthen the athletic careers of horses by reducing the risk and occurrence of musculoskeletal injury (Rogers *et al*., 2012). Scientific evidence suggests that exercise during the early stages of development can potentially reduce the risk of musculoskeletal injury during training and racing by developing the structure and strength of the musculoskeletal system (Barneveld & van Weeren, 1999; Brama *et al*., 2002). Post-partum exercise in foals from birth to 5 months of age influences the development of the musculoskeletal system, as well as the kinematic characteristics of the equine gait (Barneveld & van Weeren, 1999). Comparisons at 5 and 11 months demonstrated that pasture based free exercise had greater beneficial effects on the musculoskeletal system than box confinement in conjunction with high intensity exercise, which resulted in lower quality articular cartilage and altered efficiency of the gait (Barneveld & van Weeren, 1999). In New Zealand, Rogers *et al*., (2008) subjected two groups of foals to different exercise treatments, pasture and pasture + conditioning. At 18 months of age, post-mortem examination of a subset of foals suggested early developmental free exercise was beneficial in stimulating the musculoskeletal system. Subsequent race training as 2 and 3-year-olds demonstrated there was no negative effect of the early high intensity exercise (Rogers *et al*., 2008).

Following maturation, articular cartilage loses the adaptive remodeling abilities that bone retains in response to exercise (Rogers *et al*., 2008). Dorsometacarpal disease (DMD), better known as shin soreness, has been reported to affect 70% of 2-year-old horses in early race training (Stover, 2003). An *in vivo* strain gauge study of racing Thoroughbreds showed that young horses (age 2 – 3) experienced far greater strains on the third metacarpal bone while galloping at race speeds as opposed to an older horse whose third metacarpal bone had adapted as a result of repeated loading during exercise (Nunamaker et al., 1990). The risk of shin soreness decreases with increasing age, which is attributed to older horses having been exposed to greater amounts of high-speed exercise (Cogger *et al* 2008; Perkins et al., 2005b). Early exposure to the appropriate training load is essential to prime the equine athlete for future strains encountered during its racing career (Verheyen *et al*., 2005). An investigation into 2-year-old training milestones and career longevity, (Tanner *et al.,* 2013), reported that 2 year-old training and racing activity had a strong association with an increased number of race starts, the likelihood of recording race wins or places and greater total career earnings.

The importance of exercise in the development of the equine musculoskeletal system is widely accepted throughout the Thoroughbred industry (Barneveld & van Weeren, 1999; Gibbs & Cohen, 2001; Rogers *et al*., 2008). Appropriate stimulation of articular cartilage and tendons during the early post-partum period (0-5 months) are essential in preparing the musculoskeletal system for the repetitive loading stresses associated with training and racing (Brama *et al*., 2002; Rogers *et al*., 2008). With respect to this, although there is no data from which a dose/response can be prescribed, it is clear that exercise early in life, particularly during the rapid growth phase, can produce more durable racehorses which in effect will reduce wastage in training and racing.

Angular limb deformities

Within the Thoroughbred market buyers have a preference for horses with straight limbs, due to the believed association this has on racing and soundness (Witte & Hunt, 2009). Biomechanical loading of the developing equine limb is known to influence adult conformation, particularly axial alignment, which impacts both performance and soundness of the equine athlete (Brama *et al*., 2002; Jansson & Ducharme, 2005; Santschi *et al*., 2006). In the neo-natal foal up to 2°-5° carpal valgus is considered acceptable conformation; allowing for physical maturation and widening of the chest which rotates the limbs inward (Greet, 2000; Levine, 2011). A proportion of foals are born with abnormally angulated conformation of the limbs known as Angular Limb Deformities (ALD) (Greet, 2000). Angular limb deformities are defined as axial deviations of the limb as seen from the frontal plane (Levine, 2011). The limb can deviate outward (valgus) and inward (varus) distal to the carpal, tarsal and fetlock joints and are often associated with a certain degree of rotation, making them identifiable by splay footed and pigeon toed postures (Auer, 2012; Bramlage & Auer, 2006; Santschi *et al*., 2006). Deviations originate from the cuboidal bones of the carpus or tarsus and the physeal and diaphyseal regions of the longbones (Auer, 2012). Angular limb deformities are split into either congenital or acquired deformities depending on their cause (Levine, 2011; Smith, 2010). Congenital deformities are the result of interruptions to gestational processes, which can lead to incomplete ossification of carpal and tarsal bones, laxity of periarticular structures or aberrant intrauterine ossification (Auer, 2012). Foals with congenital ALD are generally born with normally developed physes and ALD are a combination of poor posture and uneven growth between the lateral and medial aspects of the physeal plate during gestation (Bramlage & Auer, 2006). Acquired ALD develop post-partum, often as a result of mismanaged dietary intake and exercise (Auer, 2012; Smith, 2010). Excessive loading and repeated trauma of an immature skeletal system causes ALD by inducing disproportionate growth at the physis and in extreme cases crushing of physeal plate known as a Salter-Harris type V or VI fractures (Auer, 2012; Levine, 2011).

Commercial Thoroughbred stud farms put significant effort into producing progeny with desirable conformation (Bramlage, 1999; Santschi *et al*., 2006). Management of the foals conformation begins during gestation by providing the mare with the correct dietary management to optimize foal development, with a particular focus on carbohydrate and trace mineral content, both of which have been linked with the occurrence of Developmental Orthopedic Disease (DOD) in the form of osteochondrosis, physitis, flexural deformities and ALD (Auer, 2012; Floyd, 2007; Hoskin & Gee, 2004). Floyd, (2007), highlighted the importance of carbohydrate and nutrient content, to fuel growth of the foal from a fetus right through to yearling age, stating carbohydrate supply must be adequate to fuel the growth, but not in excess, as this has been proposed to be associated with DOD.

The temperate New Zealand climate provides Thoroughbred breeders the ability to keep mare and foal at pasture year round (Rogers *et al*., 2007); scientific evidence shows that adequate growth rates are maintained despite seasonal variation in pasture quality and quantity and changes in stocking density (Hoskin & Gee, 2004). Regardless, many stud farms supplement mares with formulated feeds with increased trace mineral content (calcium, phosphorus, copper and zinc) during the third trimester of gestation (Barneveld & van Weeren, 1999; Rogers *et al*., 2007). Supplementation of minerals (particularly copper) during the third trimester is often provided for correct development of the skeletal system in foals (Auer, 2012; Barneveld & van Weeren, 1999; Floyd, 2007; Gibbs & Cohen, 2001; Hoskin & Gee, 2004; Ott & Johnson, 2001). Copper is of particular importance as it supports collagen production, a key structural component of bone and cartilage, and when supplemented in a mares diet during gestation has been indicated to reduce the occurrence and severity of ALD in foals (Barneveld & van Weeren, 1999; Floyd, 2007; Ott & Johnson, 2001).

Neo-natal foals can appear to have ALD due to poor posture associated with muscular weakness, regardless of endochondral ossification (Auer, 2012; Santschi et al., 2006; Witte & Hunt, 2009). Some veterinary practitioners advise that foals should not be allowed free exercise until the level of ossification has been assessed by dorspalmar radiographs, particularly in foals born premature, as excessive trauma may crush the cuboidal bones leading to abnormal ossification and permanent ALD (Auer & von Rechenberg, 2006; Auer, 2012; Floyd, 2007; Jansson & Ducharme, 2005; Levine, 2011; Smith, 2010). If radiographic images show incomplete ossification, many studies suggest foals should be confined to a stall and have the limb externally supported with a cast or a brace to allow ossification under even axial alignment (Bramlage & Auer, 2006;

Jansson & Ducharme, 2005; Smith, 2010). Provided adequate ossification has taken place, ALD are often the result of unequal growth at the physis (Auer & von Rechenberg, 2006; Auer, 2012; Bramlage & Auer, 2006).

The literature surrounding ALD describes a well-established method for assessing foal conformation. The foal should be viewed from the front and back respectively and each limb should be viewed perpendicular to the frontal plane of the limb, this enables the clinician to distinguish between axial rotation and angular deviation (Auer, 2012; Bramlage & Auer, 2006; Witte & Hunt, 2009). Foals can also be viewed whilst walking toward and away from the clinician on a level surface, this allows the clinician to view the limb flight and gauge the straightness of the limb (Levine, 2011; Smith, 2010). Assessment of foal conformation is described as subjective in study methodologies throughout the literature (Anderson *et al*., 2004; Santschi *et al*., 2006; Witte & Hunt, 2009). Anderson & McIlwraith, (2004), described the assessment of conformation as subjective and largely based on experience or opinion. Radiographic imaging techniques can be used to gain more clinically accurate assessments of where ALD originate (Auer & von Rechenberg, 2006; Levine, 2011; Smith, 2010). Despite methods for assessing conformation being well published, no standardized scoring systems for quantifying ALD severity are published within the literature; both Santschi *et al*., (2006) and Jansson & Ducharme, (2005), graded ALD severity using a simplistic descriptive scale of severity from mild, moderate to severe.

With regard to treatment of ALD, both conservative and surgical interventions are discussed throughout the literature. Jansson & Ducharme, (2005), state that mild and moderate ALD predominantly correct on their own within 4 weeks of life, and that foals should not be confined to a stall as this hinders musculoskeletal strengthening and development. Contrary to this, other studies recommend confinement in combination with regular hoof trimming as the most effective form of treatment for mild and moderate ALD (Auer & von Rechenberg, 2006; Auer, 2012; Bramlage & Auer, 2006; Levine, 2011). A period of controlled exercise in conjunction with stall rest and hoof trimming has also been suggested as an effective means of conservative intervention in order to facilitate muscular development and ALD correction (Greet, 2000; Smith, 2010; Witte & Hunt, 2009). In the case where excessive hoof trimming is required for moderate to severe ALD, lateral or medial hoof extensions are suggested as an effective means of conservative intervention, whilst reducing the distortion to the hoof capsule (Auer & von Rechenberg, 2006; Floyd, 2007; Witte & Hunt, 2009).

Surgical intervention is generally reserved for foals with severe ALD or those for which conservative interventions are not having the desired effect (Jansson & Ducharme, 2005; Levine, 2011). Surgical intervention can correct ALD by growth acceleration via hemicircumferential periosteal transection and elevation (HCPTE), and growth retardation by transphyseal bridging (TPB) or a combination thereof (Auer & von Rechenberg, 2006; Greet, 2000; Jansson & Ducharme, 2005; Smith, 2010; Witte & Hunt, 2009). Hemicircumferential periosteal transection and elevation, often referred to as stripping, involves transecting the periostium proximal to the distal physis of the radius which stimulates bone growth by increasing the production of signaling molecules which induce the production of parathyroid hormones (PTH) and accelerate physeal growth (Auer & von Rechenberg, 2006). Alternatively, transphyseal bridging temporarily fuses the convex aspect of the physis allowing the concave side to catch up (Jansson & Ducharme, 2005). The recurring theme within the literature surrounding surgical intervention was deciding when it is appropriate. The decision is based around, the severity of ALD, the age of the foal, and closure of the physeal growth plates (Auer, 2012; Jansson & Ducharme, 2005; Levine, 2011; Smith, 2010). Jansson & Ducharme, (2005), summarized that the age at which foals are treated surgically influences their prognosis due to the reliance on residual growth remaining in the long bones. Treatment in older foals (4-6 months), may not achieve the desired amount of correction due to closure of physeal growth plates (Auer & von Rechenberg, 2006; Smith, 2010). Alternatively, treatment in foals too young may result in unnecessary intervention for ALD that may have corrected naturally (Jansson & Ducharme, 2005). Common management protocols reported involve the assessment of foals within 2 weeks of birth and subsequently every 2-3 weeks, and ideally not resorting to surgical intervention prior to attempting a period (2-3 months) of conservative intervention (Auer, 2012; Levine, 2011). Emphasis is also placed on an awareness of the time-point at which physeal closure occurs and the associated exponential increase in the difficulty and reduced success of intervention following their closure (Smith, 2010).

The prognosis for foals suffering ALD and their potential for future athletic endeavors are reported in several studies. One study reported the percentage of foals that went on to athletic careers was approximately 60% following treatment of ALD using HCTPE (Bertone *et al*, 1985). Alternatively, another study reported 80% and 27.3% of foals went on to have athletic careers after being treated using transphyseal bridging techniques at the carpal and metacarpal/metatarsal joints, respectively; the difference was associated with earlier closure of the physeal growth plate at the distal cannon bone region, which may result in insufficient correction (Fretz and Donecker, 1983). The prognosis for foals suffering ALD of the tarsal joints was less favorable in all cases in comparison to those suffering ALD at the carpal joint (Dutton *et al*., 1999; Jansson & Ducharme, 2005). Witte & Hunt, (2009), reported an increase in pelvic fracture and flexor tenosynovitis associated with tarsal valgus in National Hunt horses

While the potential for athletic endeavor following the correction of ALD is well published, studies reporting the racing performance of foals following corrective intervention are limited. One study reported fewer starts as 2-year-olds following HCTPE, however there was a high level of uncertainty with the results due to a lack of recorded incidences of HCTPE among yearlings that went to sale (Mitten *et al*., 1995). Other studies, including Morgan *et al*., (2005), reported that horses with straight legs had no advantage over horses with carpal or fetlock deviations on the racetrack, while Anderson *et al*., (2004) reported that slight carpal valgus was deemed to lessen the risk of carpal fracture whilst racing.

Summary

This review of the literature highlighted the significance of angular limb deformities (ALD) within Thoroughbred production systems, and the perceived effects conformation have on the viability and desirability of progeny at sale. Despite the amount of literature regarding ALD, there is no information on the prevalence of ALD among New Zealand Thoroughbreds. Therefore, there is a need for epidemiological studies on the prevalence of ALD across New Zealand Stud farms. The literature review identified a well-established and reliable method of assessing foal conformation, but subsequently labeled the assessment of ALD as subjective and largely reliant on scorer experience. Several studies identified many factors that result in inaccurate identification ALD and estimation of the associated severity score. There is need therefore to develop a standardized ALD severity scoring system that can produce accurate repeatable results when used by scorers of varying experience. On-going research has highlighted methods by which management of mares during gestation can reduce the occurrence and severity of ALD. Whilst the literature generally agrees on the treatment options available to treat ALD, there is a lack of information regarding the preferred treatment options of foals with ALD across New Zealand Thoroughbred stud farms. Therefore, there is need to summarize the most common and the most effective treatment methods used to treat ALD across the New Zealand Thoroughbred production system. The lack of information regarding the extent of ALD and the subsequent correction within the New Zealand Thoroughbred industry has led to the development of the following aims of this thesis.

AIMS

- To provide descriptive epidemiology of angular limb deformities (ALD) in a sample of the 2013/2014 New Zealand Thoroughbred foal crop and document the interventions administered and the respective improvements in foal conformation.

- To develop a standardized grading system that can be used to collect data on the angular limb deformities in Thoroughbred foals in New Zealand.

CHAPTER 2

DESCRIPTIVE EPIDEMIOLOGY OF ANGULAR LIMB DEFORMITIES IN A COHORT OF THOROUGHBRED FOALS

INTRODUCTION

There appears to be significant leakage or wastage from within the Thoroughbred racing production system. Within the United Kingdom it is estimated that only 50% of Thoroughbreds born in a given year will be registered with trainers; of these, only 30% may win a race during their careers (Wilsher *et al.*, 2006). These data are similar to findings in New Zealand with 33% of the 2001/02 foal crop failing to register with trainers and 55% never starting in a race (Tanner *et al.,* 2013).

Ideal conformation, particularly of the forelimbs, is considered critical in the selection of racing prospects by buyers at yearling sales due to the perceived effects it can have on racing performance and soundness once the horse is subjected to race training (Santschi et al., 2006). Inadequate conformation therefore contributes to wastage due to potential buyers' aversions to purchasing poorly conformed horses, as a perceived minimization of risk. Within the Thoroughbred industry, due to the substantial financial investments associated with preparing a yearling for its racing career, buyers are more likely to purchase better conformed racing prospects rather than spending money on horses with a greater risk of providing a poor return on investment (Eberhart, 2009).

Angular limb deformities (ALD), both congenital and acquired, are a major cause of inadequate conformation in young horses (Auer, 2012). During the latter stages of gestation, maturation of the equine skeleton by endochondral ossification of cartilaginous structures to bone occurs through a series of processes whereby the cartilage degenerates, calcifies and is replaced by bone (Bramlage & Auer, 2006). Interruptions to the intrauterine environment of the mare during gestation can negatively affect endochondral ossification which takes place during late gestation, leading to incomplete or abnormal ossification of the skeletal system (Floyd, 2007). An incompletely ossified skeletal system lacks structural integrity, which, with prolonged periods of uneven loading associated with the poor posture of newborn foals, leads to angular deviation of the poorly developed limbs (Auer, 2012). Furthermore, unbalanced dietary energy intake (resulting in excessive weight gain), as well as excessive exercise during the initial post-partum period can result in disproportionate growth at the physes and excessive trauma to the physes respectively, both of which result in acquired ALD (Auer, 2012; Levine, 2011).

The primary focus of commercial Thoroughbred stud farms is to produce drafts of well-developed yearlings to present at yearling sales each year (Waldron *et al*., 2008). In order to maximize sales returns, foals with ALD receive significant attention from stud masters, farriers and veterinarians in order to correct them for presentation as yearlings (Santschi et al., 2006; Waldron *et* al., 2008). Anecdotal reports from stud staff indicate that all foals are born with some degree of mild angular deviations of their limbs, which was supported by the study of Anderson & McIlwraith, (2004). ALD present at birth are predominantly postural and improve as foals strengthen (Auer, 2012). Further straightening of the limb occurs by way of natural physeal growth that works by way of intermittent loading during ambulation which stimulates physeal growth leading to straightening of the limb and consequently results in more even loading of the physis (Auer, 2012; Bramlage, 1999). In some cases angular deviations do not resolve naturally and can become worse during the rapid growth phase of newborn foals; in this case intervention is needed to correct the ALD (Bramlage & Auer, 2006). During early development foals go through developmental phases during which the growth plates in the limbs close at predetermined time-points, making identification and correction of ALD crucial early on in order to achieve the desired conformation (Bramlage & Auer, 2006).

Whilst the proposed causes and available treatments of ALD are reported throughout the literature, there is a lack of information regarding the prevalence of ALD in New Zealand Thoroughbreds and the treatments most commonly used within the industry. The aim of the current study is to provide the descriptive epidemiology of ALD in a population of New Zealand bred Thoroughbred foals born during the 2013/14 season.

MATERIALS AND METHODS

A prospective observational study was carried out whereby foals born during the 2013/14 season were assessed, at birth, for the presence of congenital ALD. A convenience sample of five North Island commercial Thoroughbred stud farms were selected based on geographical location, annual foal crop and their willingness to partake in the study. The stud farms were invited to be involved in the study prior to the commencement of the Southern Hemisphere breeding season. During the preliminary visit the stud masters, veterinary practitioners and staff were provided an overview of the project and details of data collection prior to their participation.

Foals were to be assessed for the presence of ALD at several pre-determined time-points: birth, foal heat at approximately 2 weeks, 6 weeks and at weaning age of 5 months. The aim was to assess as many foals as logistically possible at each time point, with stud staff availability in mind and also minimizing the studies impact of stud farm operations, the greatest effort was achieved by stud staff and study personnel at the time of foaling. Foals were then reassessed at every opportunity during stud farm visits by study personnel. Foals were examined from the front and back, ensuring each limb was viewed perpendicular to the frontal plane. In situations where personnel were available the foal was also assessed whilst walking toward and away from the scorer/s. Angular limb deformities were subsequently scored for their severity using a standardized scoring system. If a treatment or intervention was used to improve the ALD then foals were additionally scored each time their progress was assessed following treatment. Throughout the season, regular visits were made to the farms by study personnel. During these visits foals were scored by the study personnel and stud staff/or practitioners to generate data for inter-observer agreement.

Angular limb deformities were scored for their severity using a five point grading system. Foals were allocated a grade relative to the degree of angular deviation (Table 1). In accordance with common industry practice, the severity score of 1 was associated with limbs considered 'clean', as 0° to 5° angular deviation is deemed acceptable conformation in young foals (Bramlage & Auer, 2006; Smith, 2010).

Table 1. Summary of severity scores in relation to degree of deformity.

SEVERITY SCORE	ASSOCIATED ANGLE OF DEVIATION
1	0°-5°
2	5°-10°
3	10°-15°
4	15°-20°
5	20°+

The degree of angular deviation was quantified using a custom made limb protractor designed for the project (Figure 1). To use the ALD measuring limb protractor the scorer stood approximately five meters in front of the foal, perpendicular to the frontal axis of the limb being assessed. At this distance the joints (carpal, tarsal and fetlock) of the limb aligned with the Points A and B of the protractor (Figure 1) allowing for estimation of the angle of deviation by rotating the protractor to align the central axis to that of the limb. This technique is reciprocated for the hindlimbs.

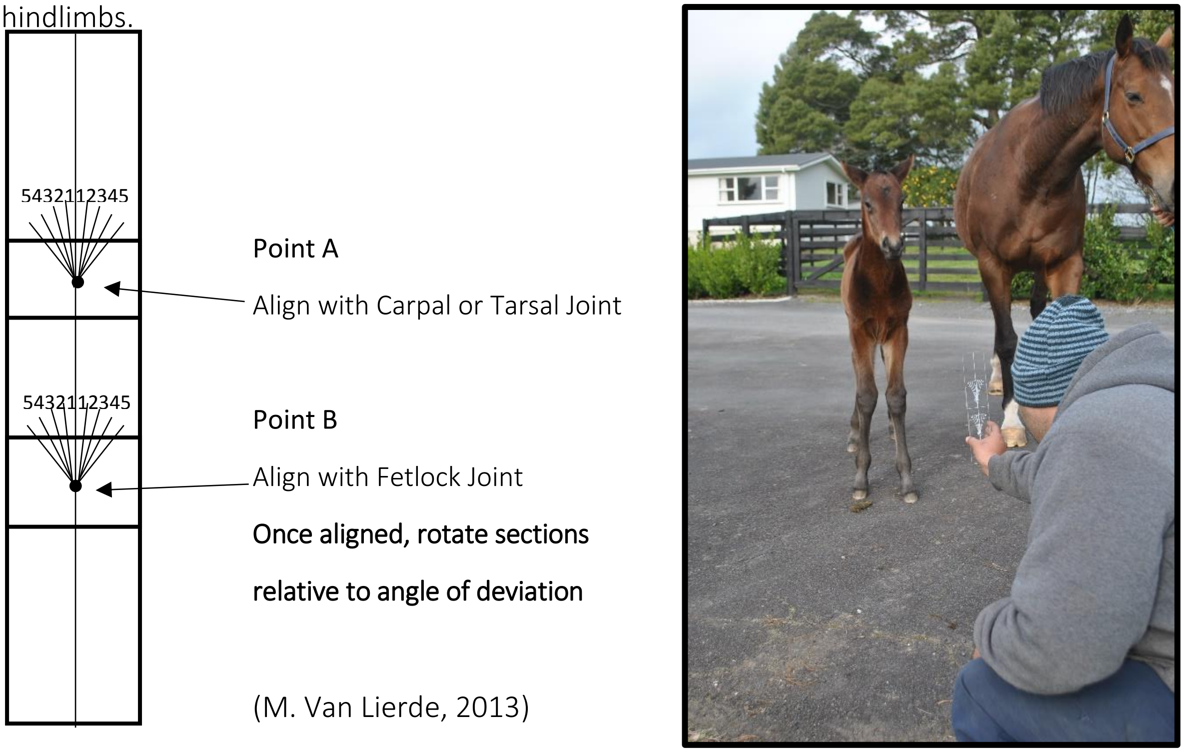


Figure 1: A - Diagram of limb protractor for measuring ALD (left) B- photo of the protractor in use (right)

Foal conformation was recorded on *pro forma* score sheets that incorporated the scoring system for angular limb deformities on all distal limb joints (Appendix A). The score sheets included identification information about each foal such as dam, sire, foal ID (color, sex), date of birth, the name of person scoring, and date of scoring. Angular limb deformities were split into three categories, angular deviations, rotational deviations and offset or bench knees, all of which were recordable on the *pro forma* scoring sheet. Angular deviations, in accordance with industry standards were recorded when a deviation was greater than 5° (Score 2-5) (Auer, 2012). Rotational deformities and offset knees were assessed subjectively, and were recorded as 'In' or 'Out' and 'Yes' or 'No', respectively. To reduce the scoring time for each foal three basic criteria were listed at the top of the scoring sheet:

1. Does this foal have an angular deviation score >1 in any limb? Yes No
2. Does this foal have rotation in any limb? Yes No
3. Does this foal have offset knees? Yes No

Only if the scorer circled Yes to any one of the criteria would they need to identify the location and severity of the limb deformity. Alternatively, if the foal received 'No' for each of the three criteria that foal was considered 'clean' and would only need to be scored again if it developed ALD at a later stage. The reverse side of the score sheets allowed for the recording of treatments administered for each deformity as well as comments on the progress of the treatment (Appendix A).

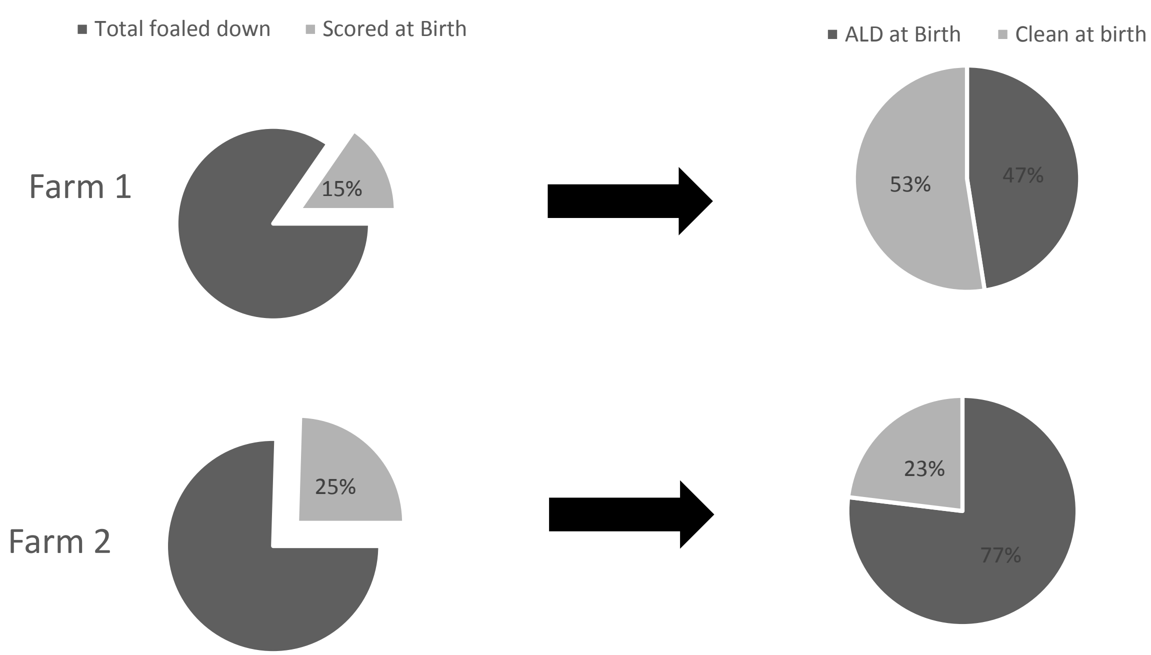
Statistical Analysis

Data were manually entered in a database designed specifically for this study (Microsoft Access, Microsoft Corporation Redmond, Washington, USA). For each foal assessed during the trial, information pertaining to the type of deformity, the location, the associated severity scores, the date of scoring, and the name of the scorer were entered. Subsequently, the treatments administered for each ALD were entered into the database. If information regarding a foal's conformation was not recorded (e.g. a severity but not a deviation direction or vice versa) the information was entered as missing. If a foal's conformation was not assessed at birth but was later recorded as having ALD, its birth scoring was entered as missing. Repeated cross checks were carried out following data entry to eliminate entry errors that may have occurred. The effect of stud farm, length of gestation, dam age, and foal gender on the observation of ALD were tested using Chi squared analysis and unpaired t-test, with the level of significance set at $p < 0.05$.

RESULTS

Sample Population

Of the six stud farms initially contacted, five stud farms completed the trial providing an estimated sampling population of 831 foals. In all, 230 foals were assessed at birth for the presence of ALD. A combined 78% (180/230) of the foals scored across stud farms were recorded to have one or more ALD at birth with a severity score of 2 or greater. Across all stud farms the mean percentage of the foal crop scored at birth was 32% (15% - 38%); the occurrence of ALD varied between stud farms ranging from 47% to 97% of all foals scored on each farm ($p < 0.001$) (Figure 2).



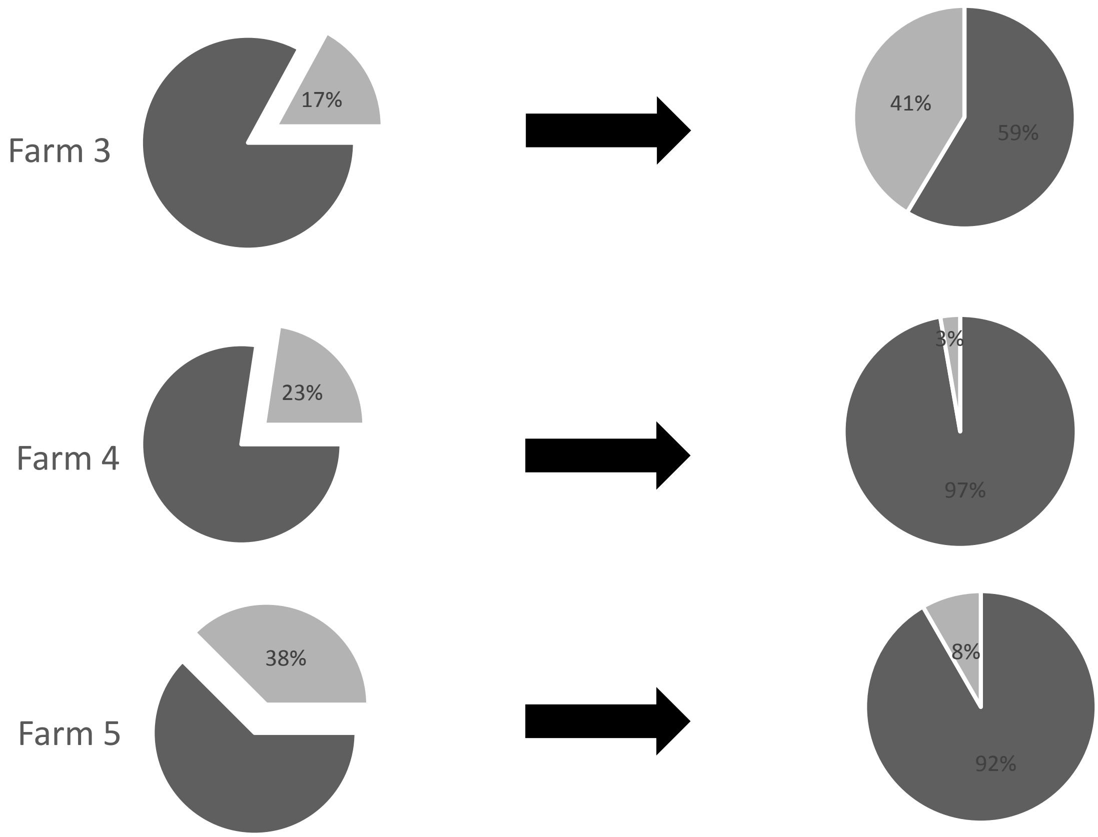


Figure 2: Pie charts representing individual stud farm foal scoring efforts; the first pie chart represents the percentage of foals scored at birth of the total number of foals foaled down per stud farm. The second pie chart represents the percentage of foals scored with ALD and the percentage of foals born clean; of the foals scored at birth.

Of the 599 foal scoring events throughout the season, most foals were scored at birth and weaning age (230 and 257, respectively) (Figure 3). There was a significant difference between the percentage of foals scored with ALD at birth (78%; 180/230), foal heat (71%; 39/55), six weeks (32%; 18/57), and weaning age (12%; 30/257) ($p < 0.001$). Furthermore, foals predominantly presented with more than one ALD at each time-point. The proportion of foals scored in comparison to limb deformities at specific joints and time-points is presented in tables 2.1 and 2.2. The percentage of limb deformities recorded at birth on the joints of the forelimbs (excluding offset carpal joints) (67%; 442/661), was significantly greater than the percentage of limb deformities recorded on the hind limbs at birth (33%; 219/661) ($p < 0.001$).

Table 2.1. Distribution and orientation of limb deformities across joints and pre-determined time-points (Forelimbs).

Forelimbs	ALD	Birth	Foal heat	6 weeks	Weaning (5 months)
Fetlock	Varus	4	-	1	-
	Valgus	38	5	5	-
	Direction of deviation missing	21	7	0	9
	Rotation (Out/In)	78/4	1/0	2/0	-
Carpus	Varus	19	1	3	-
	Valgus	150	37	26	-
	Direction of deviation missing	31	18	2	21
	Rotation (Out/In)	90/7	11/0	2/0	-
	Offset Carpus	113	19	0	-
	Number of foals with ALD	180	68	53	30

Table 2.2. Distribution and orientation of limb deformities across joints and pre-determined time-points (Hindlimbs).

Hind limbs	ALD	Birth	Foal heat	6 weeks	Weaning (5 months)
Fetlock	Varus	6	1	0	0
	Valgus	40	2	0	0
	Direction of deviation missing	5	1	0	0
	Rotation (Out/In)	42/4	2/3	0	0
Tarsal	Varus	13	4	1	0
	Valgus	24	4	1	0
	Direction of deviation missing	12	2	1	0
	Rotation (Out/In)	67/7	3/0	0	0
	Number of foals with ALD	180	68	53	30

Of the total number of foals scored (230), 323 rotational deformities, and 132 offset carpal joints were also recorded. Rotation of either the cannon or fetlock joints were predominantly 'out' (298/323, 92%).

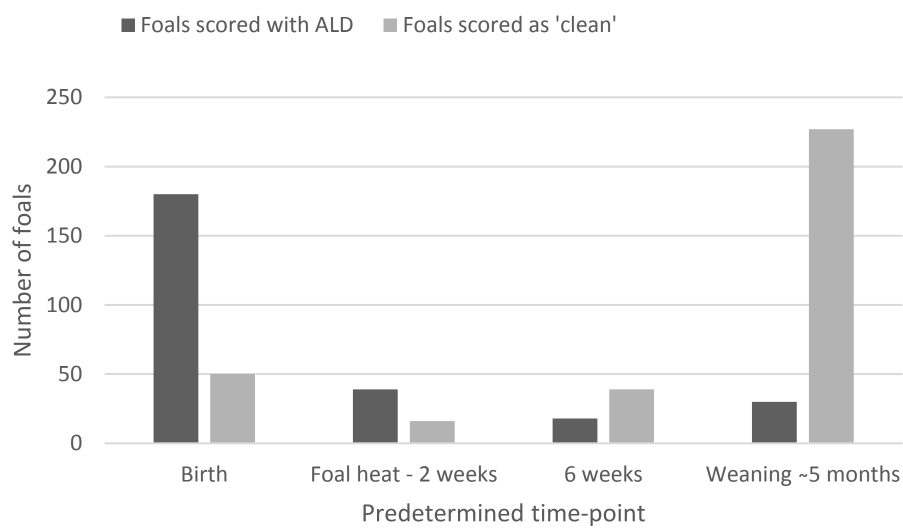


Figure 3: Histogram showing the proportion of foals scored both clean and with ALD across the predetermined time-points.

The greatest range in ALD severity score was recorded at the early developmental time-points, birth and foal heat, while the smallest range was recorded at 6 weeks and weaning (Figure 4). Of the 180 foals scored with ALD at birth, the majority (81%; 146/180) were recorded to have more than one ALD. A total of 363 angular deformities were recorded at birth. Of the 363 ALD, 66% (239/363) were recorded as mild severity (severity score 2). Similarly at foal heat the majority of ALD recorded were of a mild severity (79%; 38/48). Angular limb deformities with severity scores 3 and 4 were recorded less frequently at birth (31%; 112/363) and foal heat (21%; 10/48); there were no severity scores 3 and 4 recorded at the time-points 6 weeks and weaning. There was a significant difference between the number of ALD recorded at the time-points birth and weaning, 88% (363/413) and 12% (30/257) ($p < 0.001$).

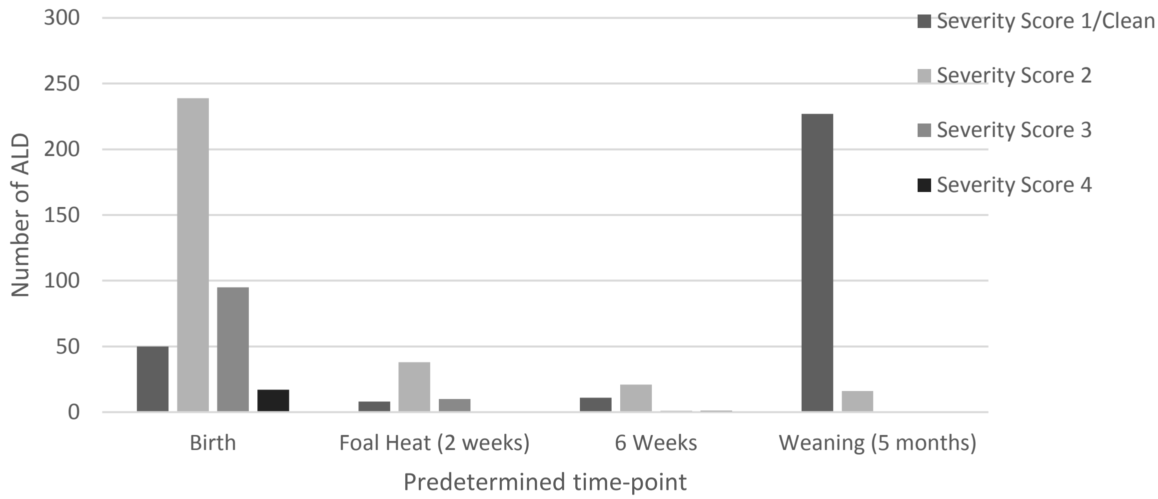


Figure 4: Histogram showing ALD severity recorded at each of the predetermined developmental time-points.

Overall, Carpal Valgus was the most commonly recorded ALD throughout the study, across all predetermined time-points. The majority of these deformities were mild in severity (Severity Score 2)(Figure 5)

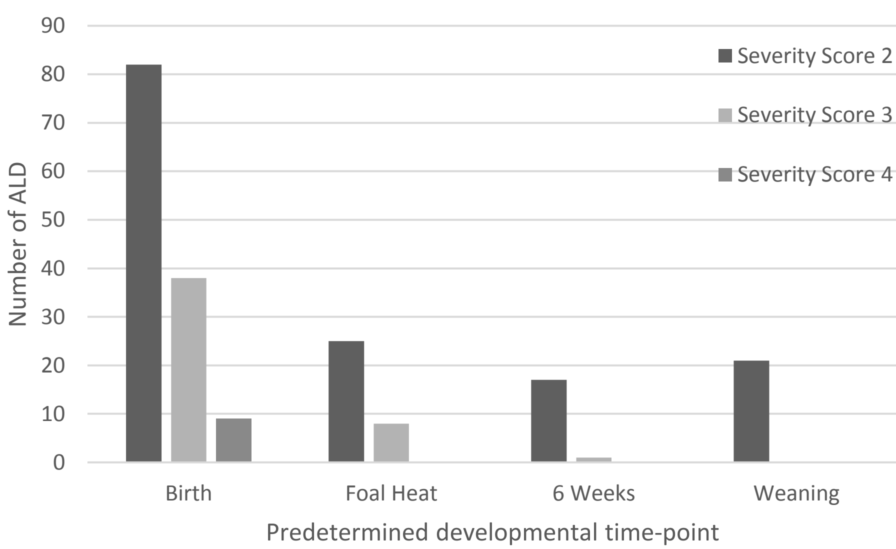


Figure 5: A histogram showing the number of Carpal Valgus ALD and associated severity across predetermined time-points

Gestation length

The mean gestation length for the 230 foals included in the study was 346 days (± 9 days). The mean gestation length for foals scored with ALD and foals scored clean at birth was 346 days (± 8 days) and 347 days (± 9 days) respectively. There was no significant association between gestation length and the occurrence of ALD in the foals scored (p= 0.45) (Figure 6).

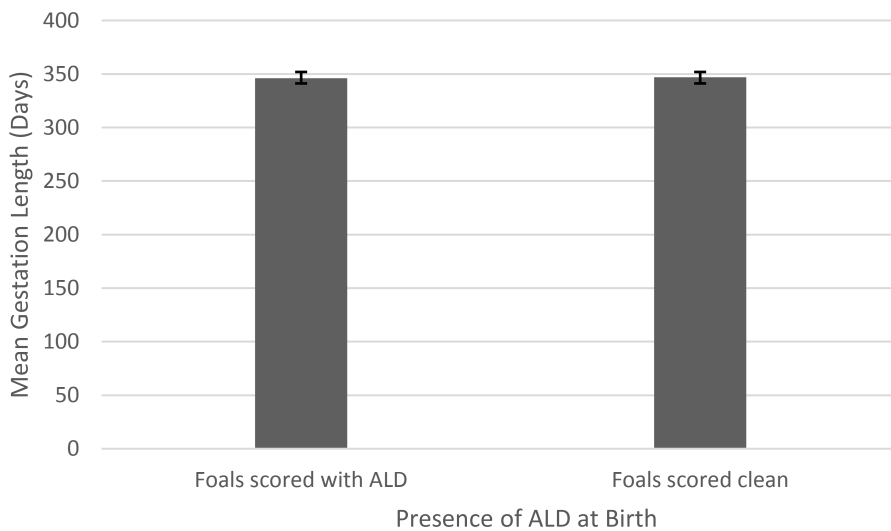


Figure 6: Histogram showing mean gestation length versus the presence of ALD at birth.

Dam age

Across all stud farms younger mares (≤ 12 years) made up a significantly greater proportion of the broodmare population (p < 0.001). Foals from younger mares represented 78% (180/230) of foals scored for the presence of ALD at birth. The mean age of mares was 9.5 ±4 years (min 3, max 23). There was no significant difference in the occurrence of ALD between foals from younger mares (78%; 137/176) and those from older mares (79%; 43/54) (p= 0.78) (Figure 7).

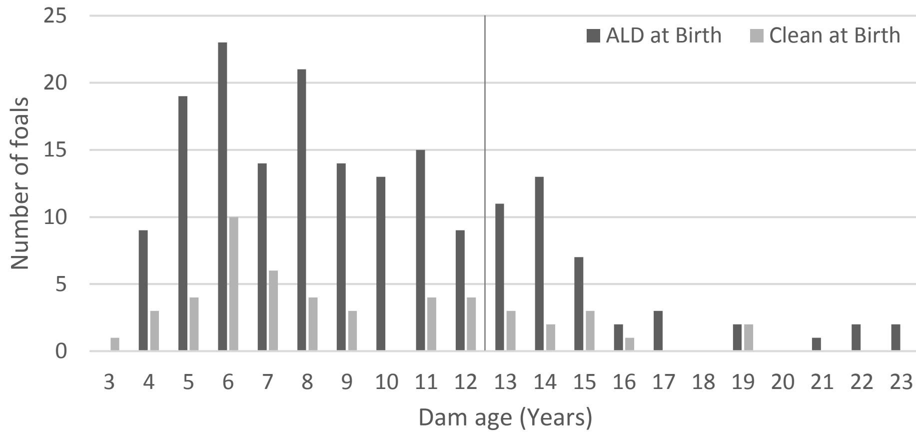


Figure 7: Histogram of dam age at last day of service (ldos) versus the presence of ALD at birth

Foal Gender

Foal gender was evenly distributed, with 116 colts and 114 fillies scored for ALD at birth. There was no significant difference in the occurrence of ALD at birth between colts and fillies ($p = 0.95$) (Figure 8).

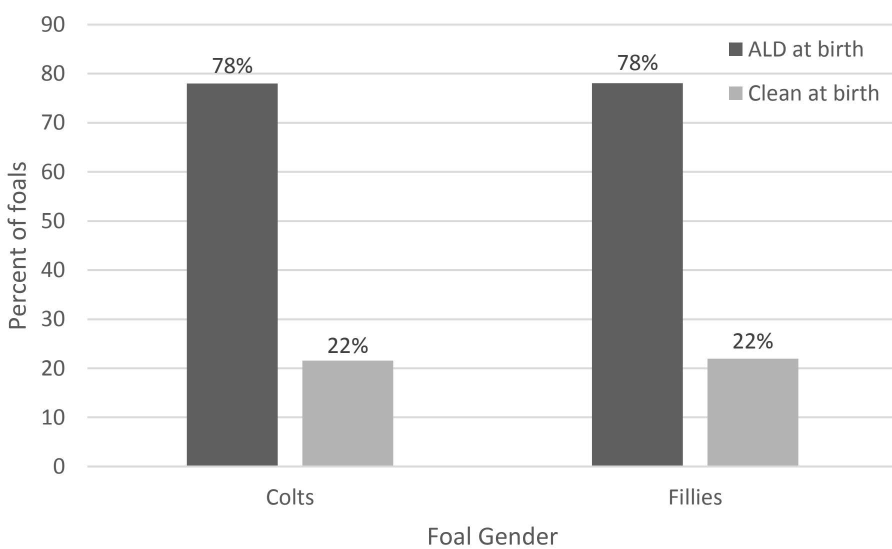


Figure 8: Histogram showing the occurrence of ALD at birth with regard to foal gender.

DISCUSSION

The aim of this study was to collect data on the prevalence of angular limb deformities at discrete developmental time-points in a sample of New Zealand Thoroughbred foals. The sampling frame for this study included five major commercial Thoroughbred stud farms, considered as leaders within the New Zealand Thoroughbred production system, based on the number of mares per farm and the number of resident and shuttle stallions standing (Rogers *et al.,* 2007). This sample frame provided a large foal population and was believed to provide an accurate representation of ongoing practices within the New Zealand Thoroughbred industry. The intention was for all foals born on the enrolled stud farms during the 2013/14 breeding season to be scored at birth for the presence of ALD. Unfortunately, in accordance with the original concerns expressed by stud staff involved in data collection, time constraints and personnel availability led to sporadic and often biased selection of foals being included in data collection. Throughout the season, regular communication and effective co-operation between study personnel, stud masters, staff and practitioners enabled study personnel to make regular visits to stud farms and collect data alongside stud staff.

Approximately a quarter of the foals across the enrolled stud farms were scored for the presence of ALD between the time-points birth and weaning. This gave rise to the assumption that foals were preferentially selected for scoring by stud farm staff based on the presence of ALD. The data indicated approximately 75% of foals scored had one or more ALD present at birth, which is similar to the findings reported by Visser *et al.,* (2012), where 81% of foals with data had one or more limb deformity at birth. It is believed that the high percentage of foals reported with ALD is associated with postural weakness seen in neo-natal foals and that this is not an accurate representation of true prevalence. Stowers *et al.,* (2010), reported approximately 20% of Standardbred were born with one or more ALD. This adds strength to the assumption that foals were preferentially selected for ALD and foals born clean were not scored by stud farm based staff.

The sampling frequency across all stud farms reflected the seasonal time constraints and personnel availability. The largest number of foals were scored at birth and subsequently at weaning (5 months of age). There were limited data on the occurrence of ALD at both foal heat and 6 weeks of age. On-farm observations suggested stud staff and practitioners had greater opportunity to score foals at birth due to foals being kept in either stalls or small foaling paddocks in close proximity to farm foaling units to enable foals to strengthen whilst being assessed for any possible problems or treatments required. The opportunity to score foals at foal heat and 6 weeks were less as they were exclusively done by study personnel during fortnightly farm visits. These scorings were either carried out when foals were brought in for assessment by stud staff, practitioners and/or farriers or out at pasture around the farms.

Regardless of sampling effort, the occurrence of ALD was higher among foals scored at the early developmental time-points. These findings concur with the literature stating that most foals are born with a certain degree of angular deviation; the majority of which resolve as the foal strengthens (Auer, 2012). The initial post-natal period whereby foals are kept in stalls or small foaling paddocks is thus justified in allowing the foal to strengthen and be properly assessed for any conformational issues (Smith, 2010). Data regarding the associated severity of ALD scored showed that moderate to severe ALD (severity score 3 & 4) were only present at early developmental time-points (birth & foal heat). As a result of foals natural physeal straightening mechanisms and interventions used during the first few months post-partum (Jansson & Ducharme, 2005); follow up scorings found few ALD were still present at 6 weeks and weaning age, and any ALD still present were of mild severity (score 2). The data described in other studies show that correction of most ALD occurred naturally prior to the end of the rapid growth phase at 4-6 months of age (Auer & von Rechenberg, 2006; Jansson & Ducharme, 2005).

Gestation length was considered to be a biological factor linked to the presence of ALD, particularly in the early stages post-partum (Auer, 2012). Interruptions to endochondral ossification during the latter stages of gestation as well as premature foaling are associated with incomplete ossification of the carpal and tarsal bones (Auer & von Rechenberg, 2006). Incomplete ossification does not represent an ALD, however it can lead to ALD forming as a result of uneven loading of the soft precursor cartilage associated with the postural abnormalities in newborn foals (Smith, 2010). We did not find a significant association between gestation length and the occurrence of ALD. It is unlikely that gestation length should predispose foals to ALD in the present Thoroughbred production industry due to the stringent management of mare reproductive processes and radiographic techniques, which can detect the level of ossification in the neonate (Auer & von Rechenberg, 2006; Rogers et al., 2007). It was policy on a number of stud farms to confine foals to a stall for several days to allow for proper assessment prior to allowing the foal unrestricted access to pasture.

There were far fewer foals from older mares (>12 years) scored for the presence of ALD across all stud farms. This led to the hypothesis that dam age may increase the occurrence of ALD. However, the data showed no significant difference in observed ALD between foals from younger mares and older mares. Within the Thoroughbred production system, a broodmares value is not only associated by the success of her progeny, but also her potential future earnings by way of foal production (Maynard & Stoeppel, 2007). As a mare ages however, the quality of her eggs deteriorates, as does the quality of the uterine lining and vital components related to pregnancy, effectively making pregnancies more strenuous and less likely to go to term; this makes the mare less financially viable for commercial stud operations (Brück *et al*., 1993; Jeffcott *et al*., 1982.; Morley & Townsend, 1997). Additionally, a broodmares taxable value is generally nullified by the age of 12 and there is a tendency for older mares to be sold, thus skewing the broodmare population towards younger mares (Aubrey, 2006; Turner, 2010; Waldron *et al.,*2011). The full effects of mare age on the occurrence of ALD therefore could not be quantified in the current study population.

Foal gender did not influence the occurrence of ALD. However, a study investigating the effects of dam age, month of birth and foal gender on growth rates of Thoroughbreds reported that colts were on average heavier at birth and remained heavier throughout development (Hintz *et al*., 1979). Ott & Johnson (2001) similarly reported that colts were heavier as yearlings also. If ALD is present, excess weight could lead to ALD worsening rapidly under uneven axial loading, therefore it is hypothesized that under ideal study conditions colts may present with ALD for a greater period of time than fillies.

Within the current study a greater frequency of ALD was reported at birth irrespective of gestation length, dam age, and foal gender compared to later developmental time-points (foal heat, 2 weeks of age, 6 weeks of age and weaning age). The majority of ALD scored were of mild severity and severe ALD were only recorded at the early developmental time-points birth and foal heat. Any ALD recorded at later developmental time-points (6 weeks and weaning) were only of mild severity (Severity score 2). This study therefore highlights that most of the ALD recorded appear to fit within the normal range of angular deviation present at birth, and a combination of physical development and proper management allow for the correct development of foals through latter developmental time-points.

CHAPTER 3

VALIDATION OF A GRADING SYSTEM

INTRODUCTION

Angular limb deformities (ALD) are a common cause of poor conformation in young Thoroughbreds (Auer, 2012). Poor conformation can make Thoroughbred yearlings undesirable as potential athletes (Eberhart, 2009); which in turn limits financial returns from sales and contributes to the wastage often associated with the Thoroughbred breeding industry (Santschi et al., 2006; Tanner *et* al., 2013). The rapid and effective correction of congenital ALD is therefore of great importance to breeders. It is proposed that the greatest response to, and efficacy of, any intervention is during the early developmental neo-natal stages of growth. Therefore most breeders attempt to correct ALD within the first few weeks post-partum with the end goal of producing correctly conformed horses with athletic potential (Anderson *et al.*, 2004; Santschi et al., 2006).

The treatments for ALD are widely discussed within the literature (Auer & von Rechenberg, 2006; Jansson & Ducharme, 2005), however, the scoring systems for measuring and quantifying ALD are both limited and basic (Santschi et al., 2006). Furthermore, the employment of on-farm veterinarians and farriers by stud farms results in variation in the classification and grading of ALD severity between stud farms (Witte & Hunt, 2009). There is currently no 'gold standard' for what is considered 'normal' equine limb conformation for new born foals. However a slight outward deviation at the carpus (carpal valgus), between 2°-5°, has been reported as acceptable to allow for widening of the chest during maturation (Levine, 2011; Smith, 2010).

Scoring of ALD is subjective and based largely on personal experience of the scorer; various external factors such as the posture of the foal and the surface it is standing on can also influence the appearance of ALD (Anderson & McIlwraith, 2004). Current scoring systems described by both Santschi *et al.,* (2006) and Jansson & Ducharme (2005) used simple semi-qualitative scoring systems with a four point scale where the affected limb was defined to have valgus or varus deformities of a mild, moderate or severe nature. Semi-qualitative categorical scoring systems are commonly used in veterinary medicine. In general it is relatively straight forward for scorers to distinguish between mild or severe categories. However it is difficult to differentiate between mild and moderate scores, even with clear criteria, and thus acceptable repeatability is generally only obtained by experienced clinicians (Keegan *et al.,* 2010).

In an attempt to improve the subjective scoring of juvenile radiographic findings, Lepeule *et al.,* (2013), proposed and tested a radiographic severity scoring system which weighted the score based on the location and severity of the lesion. Severity scores of 1, 2, 4, and 8 were given to radiographic findings based on the size, position, associated complications and interference with joint range of motion. The overall agreement on the presence and severity of radiographic findings between three experienced veterinarians was good, with most disagreement arising from the scoring of the carpal and fetlock joints of the forelimb, particularly the mild severity scores 1 & 2. The study of Lepeule, (2013) demonstrated that a more objective and weighted scoring system is still limited in its repeatability at the lower end of the scale. This observation of poor agreement on mild severity cases reflects the difficulties reported in the literature with the evaluation of foal conformation (Denoix *et al.,* 2013). The introduction of a standardized ALD severity scoring system with associated treatment options would be beneficial in reducing inter-observer bias and permit comparison of data between studies reported for different populations.

Whilst there is inconsistency within the literature regarding severity scoring systems for ALD; methods for assessing foals for the presence of ALD are well documented and seemingly uniform. In all cases the foal should be examined from the front and back and each limb should be viewed perpendicular to the frontal plane not just from the front or back of the foal itself as rotation of the joints can present the false appearance of angular deviations (Auer, 2012). Physical manipulation of the joint and having the foal walk toward and away from the observer further aids in the assessment of ALD by helping identify the location of the angulation and the axial alignment of the joints respectively (Bramlage & Auer, 2006; Greet, 2000; Santschi et al., 2006; Levine, 2011). Radiographs of the affected limb can also be used in identifying the source of deformity at particular joints (Auer, 2012; Greet, 2000; Trumble, 2005). Given these well described methods of assessing ALD, an increase in the accuracy and repeatability of identifying and scoring of ALD would result in an overall improvement in the reliability of reporting of ALD.

An ALD severity scoring system would form a standardized system by which uniformly 'normal' foal conformation could be described, whilst recording change through time as correction takes place and also obtaining repeatable accurate data on the prevalence of ALD in the New Zealand Thoroughbred industry. The data obtained by the scoring system could be compared between different stud farms, years and countries. The aim of the current study was to assess the level of inter-observer agreement using a standardized ALD severity scoring system to collect data on the prevalence of ALD in New Zealand Thoroughbred foals.

MATERIALS AND METHODS

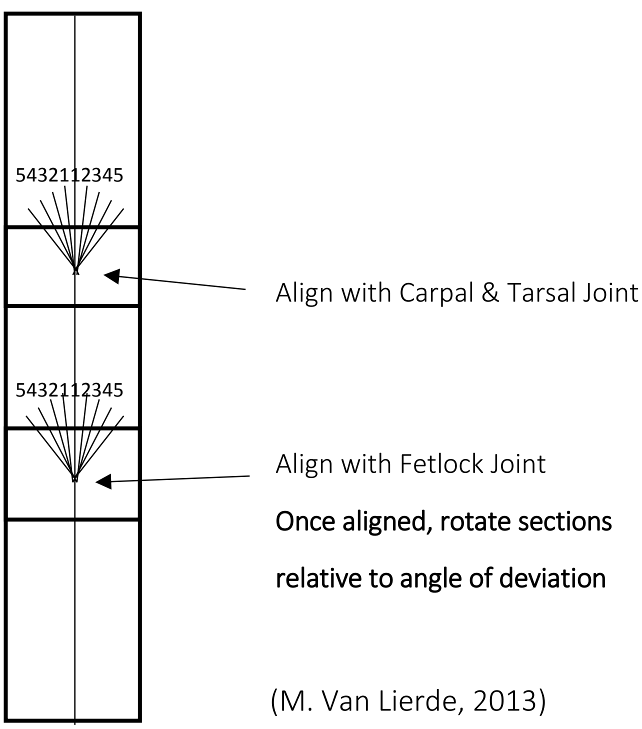
Study population

The descriptive epidemiology of ALD in New Zealand bred Thoroughbred foals was investigated in a sample of foals born during the 2013/14 Southern Hemisphere breeding season. Details of the enrollment of stud farms involved were reported in Chapter 2. Briefly a convenience sample of five North Island Thoroughbred stud farms were selected to take part. Stud farms expressing their interest were visited and explained the details of the study prior to their commitment. Foals born during the 2013/14 breeding season were assessed for the presence of ALD primarily at birth, and subsequently at foal heat (2 weeks), 6 weeks, and weaning age (5 months).

Data collection

Details of the assessment of foal conformation and the measurement of ALD severity were outlined in Chapter 2. Briefly, foal conformation was assessed following published techniques whereby the foals were examined from the front and back, ensuring each limb was viewed perpendicular to the frontal plane. If facilities allowed, the foal was also viewed walking toward and away from the scorer. Angular limb deformity severity was estimated using a custom made ALD measuring limb protractor (Figure 1). Instructions on the use of the limb protractor were outlined in Chapter 2. Briefly, by aligning the two points of rotation on the limb protractor with the carpal and fetlock joints from approximately 5 meters away and rotating the individual sections to match the angular deviation of the limb; the associated severity score (1-5) was indicated by the protractor. The limb protractor was functional on all joints affected by ALD, thereby eliminating the need for multiple scoring systems to collect data.

Angular limb deformities and any treatments prescribed were recorded on *pro forma* recording sheets. Each limb joint was identifiable alphabetically by the letter printed beside it on this scoring sheet, the letter for each deformed limb could then be transcribed onto the treatment sheet for recording the treatment of each ALD (Appendix A). Additional severity score assessments of the identified ALD were made throughout a foal's development until treatment was deemed complete or the foal left the farm. Foals were assessed by study personnel, stud staff and/or practitioners to generate data for inter-observer agreement in order to test the reliability of the severity scoring system.



(M. Van Lierde, 2013)

(Figure 1: A - Diagram of ALD measuring protractor (left) B- photo of the protractor in use (right))

Statistical analysis

Data were manually entered into a customized database, as described in Chapter 2 (Microsoft Access, Microsoft Corporation Redmond, Washington, USA). Details of data entry were outlined in Chapter 2. Briefly, individual ALD, their limb and joint location, the associated severity scores, the date of scoring and the name of the scorer were entered into the database for each time a foal was assessed. The data were cross-checked to identify and remove any errors that may have occurred during data entry. In order to assess the level of inter-observer agreement, the data were sorted to display entries with two or more scores from different observers on the same occasion. The level of agreement achieved using the ALD severity scoring system was determined by calculating the kappa statistic (*k*). The kappa statistic measures the degree to which the experimental agreement exceeds the agreement expected to occur by chance (Sim, & Wright, 2005). Kappa statistics were interpreted according to the suggestions of Landis and Koch (1977), where 0.20 or less indicated poor agreement, 0.21 to 0.60 indicated fair agreement, and to 0.61-1 indicated strong agreement. A *k* value of 1 indicates perfect agreement, a *k* value of 0 indicates no agreement beyond that expected by chance, and a negative *k* value indicates less agreement than would be expected by chance alone (Menzies-Gow *et al*., 2010).

RESULTS

ALD Severity Scoring System

Over the course of the trial there were 599 individual foal scoring events. A total of 514 angular deviations were identified and scored. Using the ALD measuring limb protractor, scorers identified and scored the ALD with severity scores ranging from 1-4; no ALD received a severity score of 5. Figure 2 below shows examples of ALD which were given severity scores of 4 through 1 respectively.

Figure 2: Examples of various ALD severity scores at the carpal joint (Limb indicated by arrow). From left to right; severity score of 4, severity score of 3, severity score of 2, severity score of 1 (normal).

Agreement

Of the 514 ALD recorded throughout the trial, 198 were scored simultaneously by study personnel and stud farm staff and/or practitioners. The majority of these scorings occurred at the time-points birth (59%; 351/599) and 22+ days (31%; 183/599). The overall level of agreement between study personnel across all time-points was strong (k = 0.75). Overall agreement between study personnel and stud farm staff was fair (k = 0.27). The least agreement between scorers was encountered with the scoring of mild ALD (score 1 & 2), as seen in table 1. Inter-observer agreement varied between the carpal, tarsal and fetlock joints. Agreement in the severity scoring of ALD at the carpal joint was fair (k = 0.28), whilst agreement was strong for both tarsal and fetlock joints (k = 0.60 and k = 0.63, respectively).

Table 1.
A comparison of scores allocated by study personnel and scores from stud staff. The values in each cell represent number of respective scores for each value. Values in bold on the diagonal indicate agreement in score.

		Others (Stud staff and/or Practitioners)			
		ALD Severity 1	ALD Severity 2	ALD Severity 3	ALD Severity 4
Study Personnel	ALD severity 1	**5**	4	3	0
	ALD severity 2	3	**136**	9	0
	ALD severity 3	0	2	**24**	8
	ALD severity 4	0	0	0	**4**

DISCUSSION

The ALD severity scoring system used in the current study was based on the quantitative measurements obtained using the ALD measuring limb protractor. The use of the ALD measuring limb protractor was intended to reduce the opportunity for variation in the interpretation of the ALD severity between scorers. There was good agreement between study personnel; however this agreement was not seen with the data collected by the stud farm staff. Few repeated measurements of foals were recorded from which to obtain on-farm staff repeatability values. The methodology intended for data to be collected in a manner which allowed us to identify whether lower agreement values were driven by differences in interpreting the ALD and the use of the limb protractor, or due to the effect of time and differences in stance and perspective when viewing the foals.

The variability that arises in the assessment of ALD between scorers has been a consistent limitation within the literature (Greet, 2000; Santschi et al., 2006). Prior to data collection, visits were made to participating stud farms to explain and demonstrate the method of measuring the degree of angular deviation using the custom made ALD measuring protractor. This was intended to reduce the inter-observer variation in scores by providing consistency in the way measurements were made. It is probable that the poor agreement results between study personnel and stud farm staff was due to stud farm staff neglecting to use the ALD measuring protractor for the duration of data collection but rather relying on their personal experience.

Although there were a large number of foals assessed by stud farm staff, particularly at birth, few assessments were made in conjunction with study personnel. This was due to differences in the times that stud staff and study personnel saw the foals. Similarly, there were very few simultaneous scoring events made between the time-points 3 days and 21 days, which reduced the opportunity for the data to display change through time as foals gained strength in the first days post-partum. This was a result of study personnel visiting stud farms fortnightly, in an attempt to reduce disruptions to stud operations, which further reduced scoring opportunities between stud staff and study personnel.

Due to the nature of on-farm data collection, the different times at which stud farm staff assessed new born foals (this constituted 51% of the agreement data), as opposed to study personnel, resulted in an inherent temporal effect in the data. Compounding this, many of the ALD scored at the time-point birth were of mild severity (score 2). In other studies, deformities at the lower end of the grading spectrum have also provided the greatest variation in opinion between scorers (Lepeule et al., 2013). The lower than expected agreement level between scorers may be due to a combination of mild ALD and differences in the time of scoring on the first day post-partum. During the first day or days post-partum there can be variation in foal limb conformation as new born foals strengthen and thus improve their posture. This temporal effect can result in differences in limb conformation assessment between both scorings (Auer, 2012; Jansson & Ducharme, 2005). Scoring of ALD is semi-objective and as a result there will always be variation in opinion between multiple parties based on personal experience and opinion.

Mild ALD (severity score 2), and ALD at the carpal joints, had the lowest level of agreement between study personnel and stud staff. Angular limb deformities at the carpal joint and ALD of severity score 2 were recorded most frequently throughout the trial and both had the lowest inter-observer agreement respectively. The frequency at which carpal deviations of mild severity (score

2) were recorded suggest that foals with a knock kneed posture (carpal valgus) might be considered normal. This hypothesis was formed in accordance with publishing's in the literature suggesting carpal valgus of between 2°- 5° is normal foal conformation (Santschi et al., 2006; Witte & Hunt, 2009). Whilst agreement is affected by the proportion of subjects within each category, a greater number of events within a category can also increase the chance for disagreement (Brennan & Silman, 1992). Several explanations for poor inter-observer agreement have been proposed in the literature, including the circumstances under which the foals may have been scored i.e. the surface on which foals were scored at stud farms (pasture, pavement, shavings and gravel), which could have altered ALD severity depending on how the foal was standing on the limb (Greet, 2000). Secondly, due to normal conformation of a neo-natal foal exhibiting slight carpal valgus, varying scorer experience level may have led to disagreement between ALD and foals with normal conformation (Greet, 2000; Santschi et al., 2006). Lastly, direct observations and communication with stud farm staff confirm that scorers estimated ALD severity based on personal experience as opposed to using the ALD measuring limb protractor provided.

The kappa statistic for agreement is affected by the proportion of subjects within each category (Altman, 1991; Sim & Wright, 2005), and thus few scores or multiple categories will limit the ability of the kappa to test agreement. This is a problem with the current dataset as there were limited multiple scoring events, bias towards mild cases and lack of spread in ALD severity across the range. Therefore some caution must be applied to the lower kappa values as these lower scores are a reflection of the bias in the data and do not necessarily mean a lack of validity in the scoring system itself.

In order to validate the ALD severity scoring system, future studies should increase the number of scorings between study personnel and stud farm staff, along with veterinary practitioners and specialized practitioners would help to strengthen the validity of the present study and further test the reliability of the ALD severity scoring system. In order to achieve this, further studies are needed wherein a method of data collection incorporates significantly more stud farm visits to score a greater amount of foals alongside stud farm staff and/or practitioners, not only at birth, but also at subsequent developmental time-points.

CHAPTER 4

INTERVENTIONS AND THEIR DEGREE OF SUCCESS

INTRODUCTION

In order to produce sound racing prospects and maximize sales returns, stud masters in association with veterinary practitioners and farriers pay particular attention to foal conformation and the correction of any angular limb deformities (ALD) that may be present (Bramlage, 1999; Santschi et al., 2006). Both pre and post-natal factors contribute to ALD in foals, and details of these factors have been described in Chapter 2. Briefly, interruptions during the the latter stages of gestation such as placentitis, metabolic disease, parasites or colic can result in perinatal ALD; symptoms include incomplete ossification of the carpal and tarsal bones, laxity of the periarticular structures and abnormal intrauterine ossification (Auer, 2012). The combination of muscular weakness, poor posture and improper management of ALD post-partum, means ALD can worsen quickly and become debilitating within 2 weeks following birth (Auer, 2012; Smith, 2010). In cases where normal gestation and adequate ossification of the skeletal system has taken place, ALD in newborn foals are merely postural; proper management of a foals nutrient intake and exercise will see the foal strengthen and the natural physeal growth mechanisms will act to straighten the limbs (Auer & von Rechenberg, 2006; Bramlage & Auer, 2006).

In more severe cases of ALD, the natural physeal straightening mechanisms fail, and the rapid growth rate of a neo-natal foal can quickly worsen ALD, thus requiring intervention to achieve the desired conformation (Bramlage, 1999). Both conservative and surgical intervention methods can be used to correct ALD depending on the cause, location and severity (Auer & von Rechenberg, 2006; Greet, 2000). Conservative interventions straighten ALD by indirectly manipulating the physeal growth plates in the limb (Smith, 2010). Interventions commonly used include confinement, splints and casts, hoof trimming and hoof extensions, altering exercise regimen and managing nutrient intake (Auer & von Rechenberg, 2006; Auer, 2012; Smith, 2010; Witte & Hunt, 2009). Confinement, splints and casts are the most commonly used treatments for foals suffering incomplete ossification or periarticular laxity following premature birth (Witte & Hunt, 2009). These interventions facilitate ossification and strengthening under even axial alignment (Auer, 2012). Provided adequate ossification of the cuboidal bones has taken place, hoof trimming and extensions are used to correct mild valgus and varus deformities by altering the load bearing surface of the foot which indirectly creates even loading of the physes (Auer & von Rechenberg, 2006; Smith, 2010). In the case of valgus deformities, the medial aspect of the hoof will experience more wear, thus the lateral aspect is trimmed with a rasp in order to better balance the foot and encourage even loading; the opposite is true for varus deformities (Smith, 2010; Witte & Hunt, 2009). In more severe cases of ALD, excessive trimming may distort the hoof capsule, thus extensions are applied that provide greater manipulation of the load bearing surface of the hoof (Auer & von Rechenberg, 2006; Auer, 2012; Jansson & Ducharme, 2005).

Should conservative interventions not achieve the desired amount of correction within 4 to 6 weeks, surgical interventions can be used in order to correct ALD prior to the predetermined closure of the physeal growth plates (Jansson & Ducharme, 2005). Surgical intervention directly manipulates the physes, altering the rate of bone growth to effectively straighten the limb (Smith, 2010). Manipulation of bone growth occurs by acceleration or restriction of growth at the growth plates (Witte & Hunt, 2009). Growth acceleration is achieved by hemicircumferential periosteal transection and elevation (HCPTE) (Auer, 2012; Jansson & Ducharme, 2005). Hemicircumferential periosteal transection and elevation is performed on the concave side of the limb (lateral side for valgus deformities) and the proposed mechanism stimulates bone growth by up regulating signaling molecules (Indian Hedge Hog (Ihh)), which reach the physis via afferent blood vessels where they up regulate parathyroid hormones (PTH) that accelerate the physeal growth locally; effectively straightening the limb (Auer & von Rechenberg, 2006; Smith, 2010). Alternatively, growth restriction temporarily halts bone growth on the convex side of the physis by artificially fusing the growth plates enabling the concave side to catch up (Auer & von Rechenberg, 2006). Methods of growth restriction include: transphyseal stapling, transphyseal bridging and single transphyseal screws; which artificially fuse the growth plate by inserting the staple or bridge on either side of the physis or inserting the screw through the growth plates respectively (Auer & von Rechenberg, 2006; Smith, 2010; Witte & Hunt, 2009). When using bridging techniques, the limb must be checked regularly and the bridge must be removed when the level of correction desired is achieved in order to prevent over correction occurring and creating an opposing angular deviation (Witte & Hunt, 2009). More recently extracorporeal shock wave therapy (ESWT) has also been used to inhibit growth in a less invasive manner by effectively decreasing chondrocyte viability (Smith, 2010). Rather than surgically inserting, staples or screws, ESWT involves administering cycles of electrical stimulus (2000 x 15Hz at 3 bar) at weekly intervals until correction is complete (Auer & von Rechenberg, 2006; Bathe *et al.,* 2006; Smith, 2010).

In all cases of severe angular limb deformities, the need for early diagnosis is emphasized, in order to treat deformities using the least invasive interventions possible prior to closure of physeal growth plates (Auer, 2012; Smith, 2010). The success of an intervention is based largely on what is considered acceptable conformation by stud masters and veterinary practitioners. The literature contains several publications reporting on the effectiveness of various treatments, which also provide recommendations for the time periods at which different interventions are most effective; however there is a lack of information regarding the degree of success one intervention may have over another. The aim of the current study is to describe the range of conservative and surgical interventions commonly used to treat ALD in Thoroughbred foals in the New Zealand breeding industry and define the point at which each intervention is considered successful by individual participating stud farms.

MATERIALS AND METHODS

Study population

In conjunction with data collected on the prevalence of ALD in a sample of New Zealand Thoroughbred foals; data regarding the interventions used to treat ALD were also recorded. Details of the enrollment of stud farms were reported in Chapter 2. Briefly, during the 2013/14 season, a convenience sample of 5 North Island Thoroughbred stud farms elected to take part. During the course of the study, all foals were scored, at birth, for the presence of ALD; they were subsequently scored again at several predetermined developmental time-points (foal heat, 6 weeks and weaning). Specific details on the location and severity of ALD were recorded on *pro forma* scoring sheets. Treatments administered for ALD were recorded and foal progress was monitored until treatment was deemed complete by stud masters and/or veterinary practitioners.

Data Collection

Details of the treatments administered were recorded on the reverse side of the *pro forma* recording sheets provided (Appendix A). The treatment sheets allowed the stud farm staff, or veterinary practitioner, to identify the specific limb and deformity being treated by way of the alphabetical identification system; each joint was represented by particular letter printed beside it on the scoring sheet (Appendix A). Furthermore, stud staff provided details on the treatment administered, the date of treatment, supplementary comments, perceived improvements since the foal was last monitored, and whether or not treatment was complete.

Data recording and analysis

Data regarding the treatments administered for ALD were manually entered in a database designed specifically for this study (Microsoft Access, Microsoft Corporation Redmond, Washington, USA). Information pertaining to the treatments administered for each individual ALD was also entered into the database including, the date of treatment, any improvements since the last monitoring and whether or not the treatment was complete. If nothing was recorded in the way of improvements or completion of treatment, this was entered into the database as missing. The data were cross-checked multiple times to eliminate any errors which may have occurred during data entry. The data were arranged to show the range of treatments administered and the frequency at which they were recorded. Subsequently, the data was analyzed to assess which treatments were used to treat ALD of varying type and severity. Chi squared analysis was used to compare the occurrence of conservative and surgical interventions, as well as the effect of ALD severity on the use of surgical intervention. The level of significance was set at p= 0.05.

RESULTS

Treatment Record

Over the course of the trial, 265 foals were scored with one or more ALD across all developmental time-points. Treatments administered by stud masters and/or veterinary practitioners were recorded for 27% (71/265) of the foals scored with ALD. The resulting data showed 222 treatments were administered for 167 different ALD. The range of treatments used and the frequency at which they were recorded are presented in Figure 1. Both confinement and hoof trimming were recorded most often across all stud farms (86/222 and 62/222 respectively). It was noted that all stud masters and veterinary practitioners employed a precautionary confinement period for all foals immediately after birth to allow foals to strengthen and have their conformation thoroughly assessed. Throughout their development all foals underwent regular hoof trimming regardless of conformation to ensure their feet were balanced correctly to ensure even axial loading (Witte & Hunt, 2009).

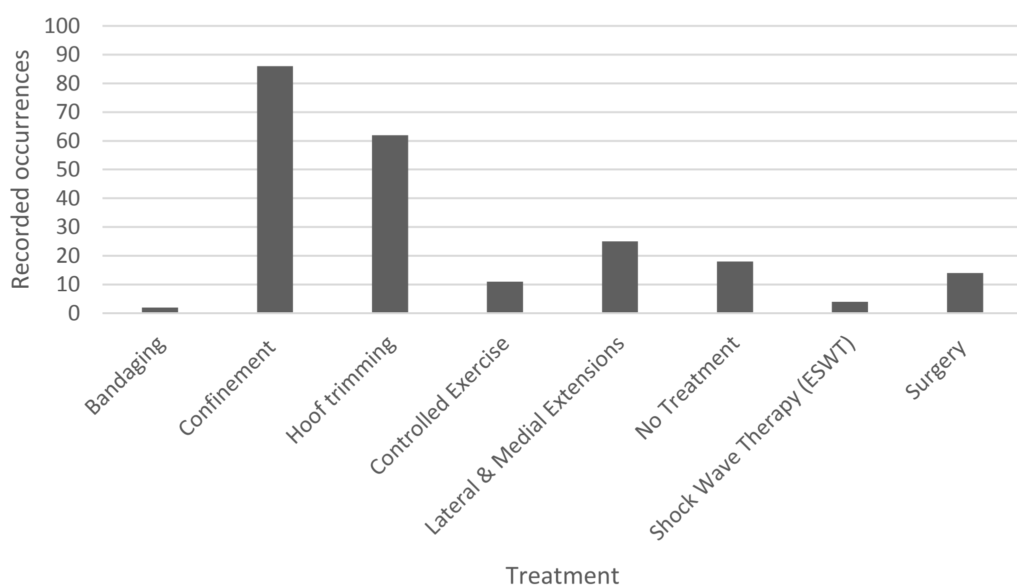


Figure 1: Bar graph showing the frequency at which different interventions were recorded across all stud farms throughout the trial.

The type of treatment used was similar for all variations of limb deformity (angular deviation, rotational deformity & offset knees) (Table 1). The frequency at which treatments were administered also reflected the frequency at which the different types of deformities were recorded. Overall, confinement (39%; 86/222) was the most common treatment recorded by all stud farms. Hoof trimming (18%; 62/222) and hoof extensions (11%; 25/222) were also common treatment methods recorded.

Table 1.
Distribution of recorded treatments used across stud farms per individual ALD.

TREATMENT	ANGULAR DEVIATION	ROTATIONAL DEFORMITY	OFFSET KNEES
BANDAGES	2	-	-
CONFINEMENT	47	17	22
CONTROLLED EXERCISE	4	3	4
LATERAL & MEDIAL EXTENSIONS	22	-	3
NO TREATMENT	5	8	5
ESWT (SHOCKWAVE THERAPY)	4	-	-
GROWTH ACCELERATION SURGERY	11	-	-
GROWTH RESTRICTION SURGERY	1	-	-
HOOF TRIMMING	58	3	1

(“-“ refers to no recorded incidences)

**Please note some horses may have received multiple treatments for the correction of a single ALD.

Conservative interventions were exclusively used within the first 3-4 weeks post-partum. Their use declined at 4-6 weeks and plateaued at a consistent rate throughout the remainder of the trial period (Figure 2). There were no records of surgical intervention within the first 3 weeks post-partum. The number of recorded surgical interventions was significantly lower than conservative interventions throughout the trial ($p < 0.001$).

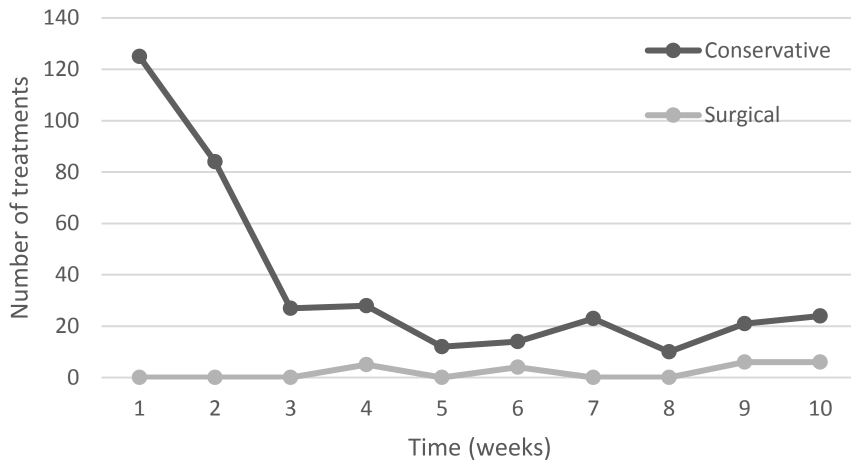


Figure 2: Line graph showing the occurrence of conservative and surgical interventions with respect to time after birth.

The earliest recorded incidence of surgical intervention was at 25 days post-partum (Table 2.). The median number of days at which surgical intervention was recorded was 38 days (IQR 25-64). The results in table 2 below indicate that a number of foals underwent more than one surgical procedure for ALD present on multiple limbs and each procedure was considered a single entity.

Table 2.
Number of days since birth against the frequency of foals that underwent surgery and the frequency of surgical procedures to treat angular limb deformities.

DAYS SINCE BIRTH	FREQUENCY (FOALS)	FREQUENCY (SURGERIES)
0-25	0	0
25-50	5	7
50-75	2	4
75-100	1	1

A greater proportion of severe angular limb deformities (ALD severity Score 4) had surgical intervention compared to ALD of lesser severity (p= 0.042) (Table 3). A number of foals with mild and moderate ALD (severity score 2 & 3) also underwent surgical intervention to correct ALD.

Table 3.
Frequency of varying ALD severity before treatment and the proportion of which required surgical intervention.

ALD SEVERITY SCORE	NUMBER OF FOALS	NUMBER HAVING SURGERY (%)
4	8	3 (37.5%)
3	15	3 (20%)
2	40	6 (15%)

A lack of follow-up scoring resulted in insufficient data regarding the point at which treatments were complete and/or successful at treating ALD.

DISCUSSION

The aim of the current study was to describe the range of conservative and surgical interventions used to treat ALD in the New Zealand Thoroughbred breeding sector and subsequently define the point at which intervention was deemed successful in achieving the desired conformation across all participating stud farms. The study methodology intended for the recording of all treatments administered to treat ALD on the *pro forma* recording sheets, as well as any comments or improvements seen each time a foal was reassessed. Unfortunately, there was limited compliance in part a result of an already large workload throughout the foaling season, time constraints and personnel availability resulting in sporadic recording of treatment data.

In agreement with a previous study of New Zealand Thoroughbred stud farm management (Rogers *et al.*, 2007), confinement of all foals to stalls or small foaling paddocks during the first few days post-partum was common practice across all farms. It is believed this allowed stud masters and veterinary practitioners to assess the degree of endochondral ossification of the cuboidal bones using radiographic imaging techniques as well as assessing the conformation of a foal, whilst also allowing the foal to strengthen prior to being allowed free exercise at pasture with other mares and foals. If a foal with ALD or an immature skeletal system is allowed unlimited exercise at pasture, fatigue and continued compression of an unevenly loaded physis may lead to the foal developing ALD or increase in the severity of existing ALD (Jansson & Ducharme, 2005; Witte & Hunt, 2009). Regular hoof trimming was recorded for all foals across all stud farms and stud farm staff indicated that this practice continued as the foals developed into a yearling. The goal of hoof trimming is to create a level point of contact between the hoof and the ground so as to encourage even physeal loading (Greet, 2000). A combination of restricted exercise (confinement) and regular hoof trimming was reported across all farms, the data collected in the current study in conjunction with the literature suggest that mild and moderate ALD respond well to this treatment approach (Witte & Hunt, 2009).

Surgical intervention is generally regarded as an aggressive form of treatment and its popularity has fluctuated over the years due to both the ethical issues surrounding conformation altering procedures and the effect on the horses subsequent athletic potential (Bramlage, 1999; Bramlage & Auer, 2006). When deciding between conservative or surgical interventions, stud masters and veterinary practitioners must weigh up both the cost and potential risk associated with surgical procedures with the potential benefits to sale price of the foal and subsequent athletic potential (Floyd, 2007; Smith, 2010; Witte & Hunt, 2009). It is highly probable that, given the large foal populations on the commercial farms followed and the cumulative cost of surgery and post-surgical care requirements, there was a preference for conservative interventions across the stud farms involved. Surgical interventions rely on sufficient remaining longitudinal bone growth at the time of treatment in order for the interventions to be most effective (Jansson & Ducharme, 2005). Therefore, the stud masters and veterinary practitioners initially implement conservative interventions during the first 4-6 weeks, and subsequently switch to surgical interventions before predetermined physeal growth plate closure occurs (Smith, 2010).

A lack of recorded surgical interventions made it difficult to identify trends in the management of severe ALD among stud farms involved; however, of those recorded, surgical intervention was not carried out before approximately one month of age, depending on the severity and response to conservative measures. It was assumed that the lack of recording had resulted from stud farm staff preferentially recording only the more severe cases of ALD being treated in order to provide a snapshot of management practices. Anecdotal observations during stud farm visits supported these assumptions as a number of older foals with evidence of surgical procedures on the distal joints of the limbs were observed with no record of their treatment provided. The data indicated surgical intervention was used to correct severe ALD only after conservative interventions had failed to show any improvement over a period of 4-6 weeks. This belief was supported by comments from stud masters and/or veterinary practitioners when discussing the data provided. This approach often resulted in treatment records showing surgical intervention used to correct moderate ALD as opposed to the severe ALD originally present. Following surgical intervention, in agreement with the literature, foals were restricted to stalls or small paddocks to reduce excessive loading of the physis (Jansson & Ducharme, 2005). In all cases foals received continual hoof trimming or had hoof extensions applied in order to continue correct development.

Although the literature differs as to the optimal time for surgical intervention, there is strong agreement that early diagnosis is paramount as treatment becomes less effective and more invasive as growth slows down and physeal growth plates close at predetermined developmental time-points (Auer, 2012; Jansson & Ducharme, 2005; Smith, 2010; Witte & Hunt, 2009). For stud masters and veterinary practitioners, the preparation of yearlings which will be selected by clients based on potential racing ability begins at birth when stud masters and veterinary practitioners assess foal conformation and implement individual foal management regimens; however, there is currently no standard protocol for every foal (Santschi et al., 2006). The question remains as to what is considered successful when correcting ALD. Correct conformation of young Thoroughbreds involves a certain degree of carpal valgus (2°-5°) which corrects itself as the foal gains strength and the chest expands (Bramlage & Auer, 2006; Greet, 2000). The data regarding the success of interventions was incomplete. It was assumed that this was the result of stud farm staff discontinuing the recording of information on a foal once treatment was observed to be effective and they failed to comment further on the success of the treatments administered. We therefore suggest that the latter interventions recorded for foals were successful in achieving the conformation desired by stud masters and veterinary practitioners.

A lack of detailed recording of the interventions used throughout the season across the stud farms prevented comparison of efficacy across treatment programs. As suggested in the work of Witte and Hunt, (2009), the data captured suggested that the majority of mild and moderate ALD responded well to a period of controlled exercise and regular hoof trimming. Similarly surgical intervention should be and was seen to be reserved for foals displaying severe ALD (15°+ or ALD severity score 4) and foals not responding to conservative interventions (Bramlage & Auer, 2006; Witte & Hunt, 2009). Due to the complex nature of foal development and the number of variables which can influence foal conformation, no single treatment may be better than another. The recurring theme within the literature is that early identification and intervention with ALD is vital and provides a better prognosis for young Thoroughbreds destined for athletic careers, by giving the practitioner time to fully assess the situation and decide whether treatment is needed or the deformity will correct itself (Bramlage & Auer, 2006; Jansson & Ducharme, 2005). Lastly it is important to note that regardless of the location, severity and cause of any ALD, its treatment is a dynamic undertaking and must be tailored to each individual case.

CHAPTER 5

FINAL DISCUSSION

This thesis presents the findings of an epidemiological study into the prevalence and subsequent management of Angular Limb Deformities (ALD) in a sample of New Zealand Thoroughbred foals. The aims of the study were to determine the prevalence of ALD at discrete developmental time-points, and document the interventions used in the management of ALD across several commercial Thoroughbred stud farms.

Angular limb deformities not only present a significant problem for stud masters and veterinary practitioners in the Thoroughbred production industry, they also contribute to wastage, which places the Thoroughbred racing industry under scrutiny around the world (Anderson *et al.,* 2004; Santschi *et al*., 2006). Quantifying the prevalence of ALD, as well as the subsequent management practices among Thoroughbred stud farms is an important step toward reducing wastage and ensuring the sustainability of the industry. The data presented in Chapter 1 indicated that 78% of foals scored presented with one or more ALD at birth. In comparison, a similar study on New Zealand Standardbred foals, Stowers *et al.,* (2010), reported a prevalence of 19%. Analysis of the data from the current study prompted the assumption that stud farm staff had preferentially recorded foals with ALD, as opposed to all foals born as intended. This led to an estimation of what the true prevalence of ALD might be, by comparing the number of foals recorded with ALD to the remainder of the foals on the stud farms involved, which were assumed to be clean at birth. The estimated true prevalence was calculated to be 21%, a result which closely resembles the reported prevalence of 19% in New Zealand Standardbred foals (Stowers *et al.*, 2010). Regardless of the prevalence of ALD, there was no significant association of the occurrence of ALD with gestation length, mare age and foal gender.

The ALD severity scoring system when used in accordance with well-established protocols for assessing conformation of the equine limb, appeared to be robust and yielded reliable, repeatable data. Inter-observer agreement was strong between study personnel (k=0.75). Conversely, inter observer agreement between study personnel and stud farm staff was only fair (k=0.27), possibly due to a limited number of simultaneous scorings throughout the season, as a result of time constraints and personnel availability. The measure of agreement using the kappa statistic largely relies on the number of subjects within each category (Altman, 1991). Therefore, the inability of stud farm staff to adequately collect data individually and alongside study personnel, due to large workloads, represents a major limitation in the data collected during this study.

A lack of detailed recording of the interventions used to treat ALD made it difficult to identify any one treatment as better than another at treating ALD. However, in accordance with the literature, the data showed a common trend for conservative interventions being used exclusively in the first four weeks postpartum regardless of ALD severity (Floyd, 2007; Jansson & Ducharme, 2005). The most common form of conservative intervention was a period of restricted exercise, coupled with regular hoof trimming. If ALD were not showing improvement following a period (4-6 weeks) of conservative management, regardless of severity, surgical interventions were implemented whilst significant longitudinal growth potential remained (Witte & Hunt, 2009). In light of the work by Auer & von Rechenberg, (2006), this current study shows how the approach to management of ALD has shifted to a 'wait and see' approach rather than aggressive intervention immediately after diagnosis which often results in foals receiving unnecessary treatments for ALD which would otherwise correct naturally. This requires a significant understanding of growth plate physiology and pathophysiology, and highlights the ongoing scientific efforts to improve the Thoroughbred production system (Witte & Hunt, 2009).

The current study provides significant scope for improvements with future studies on the prevalence of ALD. Firstly, in order to establish the true prevalence of ALD, entire foal populations should be included in a sample. The experiences gained from this study indicate this could be achieved by either defining a set sample population of a size that would provide sufficient statistical power, or alternatively increasing the on-farm study personnel presence and frequency of farm visits. The latter would provide greater opportunity for simultaneous scoring of foals by study personnel and stud staff and/or veterinary practitioners in order to better test the agreement achieved with the severity scoring system. Observations from this study suggest it would be possible to increase the on-farm study personnel presence provided communication with stud masters and staff is consistent and an effective working relationship is formed between the two parties. Reducing the sample size would further reduce the statistical power of the data collected, which is valuable in terms of drawing epidemiological inferences from the results (Banarjee & Chaudhury, 2010). Furthermore, the frequency of follow up scorings whilst foals are undergoing treatment to correct ALD would provide potential insight to the rate of correction being achieved and allow for the determination of the most effective treatment with respect to the foals stage of development. This could be achieved by increasing the study personnel presence on farm so they can track foals progress through their treatment regimes.

Finally, future studies should focus on not only the prevalence of ALD in the current foal sample as they are prepared for yearling sales, but also the influence any ALD and interventions used have on the sales category foals are placed in and the subsequent sale price. Foals should also be followed, to the greatest extent possible, to their two year-old racing careers to assess the impacts that ALD and interventions may have on athletic function and racing performance.

Appendix A

Dam Sire Foal ID DOB Scored By on / /

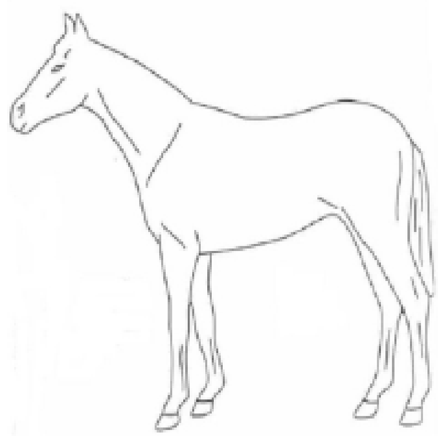
FLEXURAL DEFORMITIES

Does this foal have a laxity scoring >1 in any limb? Yes No

Does this foal have a contracture scoring >1 in any limb? Yes No

If yes, please fill in the appropriate section(s) of this form below.

LAXITY



A *Right Fore*

Hoof
1 2 3 4

B *Left Fore*

Hoof
1 2 3 4

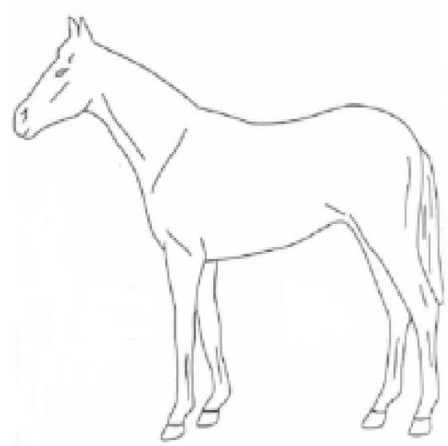
C *Right Hind*

Hoof
1 2 3 4

D *Left Hind*

Hoof
1 2 3 4

CONTRACTURE



E *Right Fore*

Hoof
1 2 3

Joint
1 2 3

F *Left Fore*

Hoof
1 2 3

Joint
1 2 3

G *Right Hind*

Hoof
1 2 3

Joint
1 2 3

H *Left Hind*

Hoof
1 2 3

Joint
1 2 3

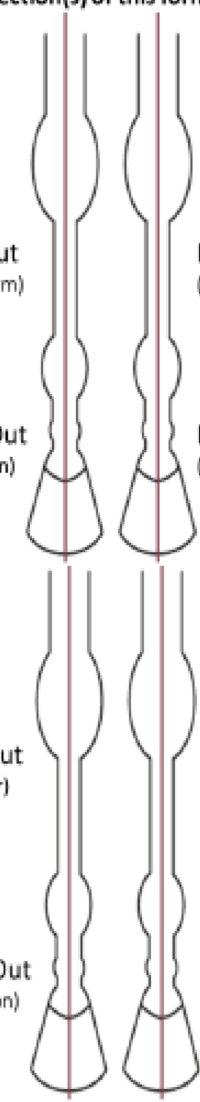
ANGULAR DEFORMITIES

Does this foal have an angular scoring >1 in any limb? Yes No

Does this foal have rotation in any limb? Yes No

Does this foal have offset knees? Yes No

If yes, please fill in the appropriate section(s) of this form below.



Right Fore

I In Out 1 2 3 4 5
Offset knee Y N

Rotation In Out
(cannon relative to forearm)

K In Out 1 2 3 4 5
Rotation In Out
(pastern relative to cannon)

Left Fore

J In Out 1 2 3 4 5
Offset knee Y N

Rotation In Out
(cannon relative to forearm)

L In Out 1 2 3 4 5
Rotation In Out
(pastern relative to cannon)

Right Hind

M In Out 1 2 3 4 5

Rotation In Out
(cannon relative to femur)

O In Out 1 2 3 4 5
Rotation In Out
(pastern relative to cannon)

Left Hind

N In Out 1 2 3 4 5

Rotation In Out
(cannon relative to femur)

P In Out 1 2 3 4 5
Rotation In Out
(pastern relative to cannon)

Date ___________

Deformity (A-?)	Treatment	Comments/Other treatments	Showing improvement?	Treatment complete? Reason?
	Confine, Bandages Exercise, Wedges Physiotherapy, Shoeing Oxytet/Engemycin, Splints Trimming, Casts Heel extensions, Swimming Toe extensions, Shockwave Medial extensions, Surgery Lateral extensions, Euthanasia		Yes No Same	Yes No
	Confine, Bandages Exercise, Wedges Physiotherapy, Shoeing Oxytet/Engemycin, Splints Trimming, Casts Heel extensions, Swimming Toe extensions, Shockwave Medial extensions, Surgery Lateral extensions, Euthanasia		Yes No Same	Yes No
	Confine, Bandages Exercise, Wedges Physiotherapy, Shoeing Oxytet/Engemycin, Splints Trimming, Casts Heel extensions, Swimming Toe extensions, Shockwave Medial extensions, Surgery Lateral extensions, Euthanasia		Yes No Same	Yes No
	Confine, Bandages Exercise, Wedges Physiotherapy, Shoeing Oxytet/Engemycin, Splints Trimming, Casts Heel extensions, Swimming Toe extensions, Shockwave Medial extensions, Surgery Lateral extensions, Euthanasia		Yes No Same	Yes No

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