AN EVALUATION OF GROWTH AND SYMMETRY IN THOROUGHBRED FOALS AND HOLSTEIN CALVES

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ABSTRACT

Holstein calves were photographed and measured over a period of 84 days to determine the feasibility of Image Analysis as a measurement tool. It was determined that the disparity between actual measurements and image analysis measurements decreased as the bone length increased, and that image analysis could be used to monitor growth successfully in large ungulates, using the length of certain bone.

Image analysis was then used to evaluate growth in Holstein calves on two weaning programs (weaned early at six weeks of age and weaned later at eight weeks of age). Calves were weighed and photographed over a period of 224 days to determine the effects of weaning on skeletal symmetry. Weaning time did have an affect on the skeletal symmetry of the calves, with calves weaned earlier found to be more asymmetrical. The extent to which skeletal symmetry is affected by a stress is determined by the nature and duration of the stress.

The growth and development of Thoroughbred foals was recorded and photographed for a period of 300 days and the relative asymmetry for bilateral traits was assessed. Thoroughbred foal growth correlated to statistics reported over the last twenty eight years. Asymmetry can be detected in growing foals using image analysis. Weaning stress produced some asymmetry that the foals were able to recover from. One can use highly correlated body weight and height measurements to produce a tool stud managers can used to monitor growth. In young training Thoroughbreds (between 18 and 24 months of age), no significant asymmetry was found in the forelimbs but the hind legs displayed asymmetry, which has interesting implications for training and for performance criteria in the racehorse.

Tools can be produced to monitor the growth and development of Thoroughbred foals destined to race, which can improve their management and the duration of their racing careers.

DECLARATION

I .... declare that:

(i) The research reported in this thesis, except where otherwise indicated, is my original research.

(ii) This thesis has not been submitted for any degree or examination at any other university.

(iii) This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from those persons.

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One can pay back the loan of gold, but one dies forever in debt to those who are kind.

~Malayan Proverb

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GLOSSARY OF TERMS

ACTH	Adrenocoticotropic Hormone
ADG	Average Daily Gain
ADF	Acid Detergent Fibre
ANOVA	Analysis of Variance
DE	Digestible Energy
DM	Dry Matter
DOD	Developmental Orthopaedic Diseases
EW/LW	Early Weaned/Late Weaned
EX	Exercised
FA	Fluctuating Asymmetry
Mc III	Third Metacarpal Bone
Mt III	Third Metatarsal bone
NDF	Neutral Detergent Fibre
NEX	Non-Exercised
RA	Relative Asymmetry

CHAPTER ONE
GENERAL INTRODUCTION

Any horse that is pedigreed and is typical of a particular breed can be “purebred”. The Thoroughbred horse is a breed that traces its development to three foundation sires from the 17^{th} Century. It is a high performance speed and endurance animal (Callery, 2003). The Thoroughbred is most commonly used in horse-racing, and the overflow from a relatively short racing career services other performance horse industries like eventing, dressage, showjumping, polo and polocrosse.

To produce a high quality animal of the calibre necessary to win races consistently is the cornerstone of the Thoroughbred breeding and racing industries in South Africa. Millions of rands are channelled into this lucrative industry. The average selling price for a two year old thoroughbred racehorse at the National Two Year Old Sale 2007 (ARO, 2007) was R 83 000 but the onus remains on the horse itself to produce the results. It is interesting that race records over the last 100 years have demonstrated 100 fold improvements in live weight gains and feed conversion efficiencies in production animals, but not so in the horse. Perhaps our pursuit of rapid output and return for investment has catapulted willing and gracious animals into trifectas, jackpots and handicaps, with a concomitant price that the horse has to pay, including asymmetrical growth.

Man displays idiosyncratic motor laterality in that we have a dominant writing hand, and in much the same way, researchers have been able to demonstrate that this capacity is not limited to man, and is in fact displayed by a number of animals. In addition, this laterality can be influenced through environmental intervention, and produces measurable asymmetries in animals.

Much of the work on smaller animals, like chickens, has strengthened the arguments that nutrition and stress can impact greatly on bilateral measurements of animals, and limited work has been done in large ungulates. The significance of a loss of symmetry may be lost in the pursuit of meat and milk production. In the horse, however, the productive aim of the animal is speed (Clayton, 2004), which can be greatly influenced by bilateral measurements and balance. It has been shown that horses also demonstrate an idiosyncratic motor laterality (Murphy *et al*., 2004) and in addition are subjected to heavy training regimes before closure of some major growth plates (of the radius and humerus Campbell (1981)). The timing of training and physis closure has been a matter of contention for many years, and again changes the racehorse from a companion to a production animal. Much of the training of these animals occurs more in circles, in one direction more than the other, and races run over 1200m in South Africa include a section of bend on a circle and then a straight.

Given the magnitude of the South African racing and sport horse industry, any study that seeks to understand the stress of training on a young horse, and seeks to discover whether this can be manifest physically, will indeed promote an improvement of training and hopefully of racing performance. It has been alluded to in the field, and in the literature, that training on the same rein (either clockwise or anti-clockwise) in a horse that is significantly left or right reined, can alter its efficiency in racing on that rein. Whether it is indeed possible to measure an effect of this in growing and training young Thoroughbreds was the subject of this thesis. Because the value of the Thoroughbred foals in the racing industry precludes the imposition of treatments *in situ* for the most part, Holstein calves were chosen as representatives of large ungulates and image analysis featuring Holstein calves platformed the more critical analysis of growth and symmetry in young Thoroughbred horses. This thesis explores means of obtaining symmetry data, and then determines the actual degree of symmetry or lack thereof in Thoroughbred foals and young horses.

CHAPTER TWO
GROWTH IN THE LARGE UNGULATES

2.1 GROWTH IN FARM ANIMALS

A juvenile horse under the age of six months (regardless of sex) is termed a foal, from six months to one year of age, it is called a weanling and between one and two years of age, a yearling. Thoroughbreds compete in races from the age of two. All Thoroughbred racehorses share a common "birthday", and in the southern hemisphere, all horses turn a year older on the 1st August. This date regulates the Thoroughbred breeding seasons, and is significant in that foals born before the 1st of August can conceivably be expected to race against animals that are older than them.

Most breeds of horses will have achieved 50 % of their mature body weight within the first six months of birth (Kohnke, 1998) and then achieve 90% of their mature weight by 18 months of age (Frape, 1986; Jackson & Pagan, 1993). At six months of age (weaning), 80% of the foal's mature height will been achieved and the foal will be at 95% of its mature height by 18 months of age (Hintz, 1978). This rapid growth occurs in the foal in the first 6 to 18 months of life (Kohnke, 1998; Jackson & Pagan, 1993) in stages with different segments growing at different rates in accordance with the availability of resources such as the horse's diet and exercise regime (Raub *et al.*, 1989; Thompson, 1995). In the horse, segmental growth is evident in wither height and tuber sacrale height (a foal will alternate, being higher at the tuber sacrale and then at the point of wither), and also in knee to pastern, hock to pastern, point of shoulder to pastern and width of chest measurements. Giorgetti *et al.* (1996) found that the cranio-dorsal regions of bull calves grew faster than the distal limbs, proximal hind limb and loin when they investigated the growth patterns of Chianina bulls fed two different diets.

The growth and development of these different parts of an animal is dependent on the nutrition, breed, sex and duration of development of the animal (Raub *et al.*, 1989).

2.2 DEVELOPMENTAL STABILITY/SYMMETRY

Plants and animals have copies of morphological structures, which are controlled genetically. Any deviations in two sides of a bilateral trait can be used as an indicator of disturbed development due to stresses (Leary & Allendorf, 1989). Developmental stability is the production of a phenotype under specific conditions, both environmental and genetic, and the capacity of the organism to develop and resist disturbances during the growth process. A highly stabilised development produces an ideal phenotype whilst developmental instability produces imperfect growth (caused by developmental errors) (Møller & Swaddle, 1997). Developmental instability may reveal itself as a variation among replicated or symmetrical organs (Rasmuson, 2002).

Both sides of a bilateral trait are developed as a consequence of the same genome, therefore random deviations from symmetry of these bilateral traits may reflect developmental instabilities under given environmental conditions (Palmer, 1996). "Asymmetries of bilateral traits enable the measurement of responses and adaptation at the phenotypic level to environmental insults" (Yalçin *et al*, 2001). By using deviations from perfect symmetry the degree to which the individual can buffer against stresses can be determined (Yalçin & Siegel, 2002).

When there is a reduction in the available nutrients and metabolisable energy for growth and other metabolic activities, there is an increase in the frequency of asymmetry for the expressed phenotypes (Møller & Swaddle, 1997). The developmental processes proceed most efficiently under optimal environmental conditions (Yalçin & Siegel, 2003) resulting in minimum levels of asymmetry (Møller *et al*., 1999). Any deviations from the optimal phenotype reflect a reduction in fitness because individual fluctuating asymmetry is negatively associated with growth performance, survival and mating success (Møller & Swaddle, 1997) and can be used as a measure of environmental and/or genetic stresses (Yalçin & Siegel, 2002; Yang *et al.*, 1997). The development of an organism can be influenced by stresses, which cause malfunctions and deteriorations in the repair mechanisms of cells (Yalçin *et al.* 2001). Developmental instability measures can provide easy, potentially useful, non-invasive tools for a range of animal breeding and animal welfare problems (Møller *et al*., 1999). Deviations from symmetry may reflect the inability of the individual to combat stresses of genetic or environmental origin (Yang *et al*., 1997).

Man's dominant hand is often larger than the non-dominant hand (Watson *et al.,* 2003). Throughout the ages, horsemen have noticed asymmetries in horses, such as the tendency for a horse to be stiffer on the left and softer on the right rein. Watson *et al*., (2003) found highly significant differences ($P< 0.0001$) in the length of the left and right third metacarpal bones. The growth of the third metacarpal bone has ceased by ten weeks of age and should therefore not be affected by training conditions after this age (Fretz *et al*., 1984). Any asymmetries found in the measurements of the third metacarpal bone are a result of the growing process or nutrition of the young racehorse (Watson *et al.,* 2003). The metaphyseal growth plate contributes about 89% (68.2 ± 4.1mm) of the length change (Fretz *et* al., 1984). The horse's long bones increase in diameter or thickness throughout their length, but there is no increase in the length of the shank (diaphysis) after birth. The increase in length occurs by the growth of the metaphyseal plate (the region of linear growth of the long bones between the epiphysis and the diaphysis) at the proximal and distal ends (Frape, 1986). Murphy *et al*., (2004) was able to reproduce this idiosyncratic motor laterality in horses, demonstrating again that horses will tend to favour one side of their bodies. Perhaps this can be manipulated by training.

Symmetry keeps the body in a state of stable equilibrium; asymmetry disrupts this equilibrium and requires energy to maintain a state of equilibrium. The relation between asymmetry and locomotion performance has a negative correlation and has been recorded in Thoroughbred flat-racing horses (morphological asymmetry and handicap rating), racing dogs (running speed and asymmetry) and chickens (asymmetry and gait quality) (Møller & Swaddle, 1997). Mass and acceleration result in force. Asymmetry will result in an uneven distribution across an axis and the force produced will be asymmetrical, resulting in a movement even if the force from both sides (left and right) is equal. This will cause a rotation in the body and a resulting correction will be required to maintain the body in a state of equilibrium. This correction will be at the expense of energy and a decrease in overall intrinsic performance and efficiency (Møller & Swaddle, 1997).

Morphological asymmetry and the three independent measures of welfare used in a trial (tonic immobility, tibial dyschondroplasia and quality of walking) were used to evaluate responses of chickens to sub-optimal environmental conditions (Møller *et al*., 1999). It was found that asymmetries found in the skeletal traits at early incubation had a tendency to decrease towards hatching. This is consistent with unpublished data that bilateral traits that occur during incubation converge at different rates to ensure a developmental stability prior hatching (Yalçin & Siegel, 2003). Foals born from “luxury” and “cramped” *in utero* environments will persistently differ through development and parturition in terms of linear measurements and body size, but the convergence toward symmetry was not evaluated in these foals (Allen *et al.,* 2004).

Broiler performance may be affected by stresses such as temperature, light, disease and parasites (Yalçin & Siegel, 2002). In a study by Yalçin *et al*.,(2001) it was found that there were differences in the face length among the stocks of chickens used with the differences depending on the age of the birds. It has been found in previous studies with chickens (Yang *et al.,* 1997) that bilateral asymmetry is a good indicator of developmental instability caused by genetic stresses (Nestor *et al.,* 2002). However bilateral asymmetry was not a good indicator of developmental stability in Japanese Quail in the trial conducted by Nestor *et al*., (2002).

Asymmetry increases the variability of the load (Alexander *et al.*, 1984) from a biomechanical point of view. The increased variability will increase pressure, stresses and strains and decrease performance of the animal. The forelegs of Thoroughbred flat-racing horses were measured and used to determine if there was any relationship between performance and asymmetry and none was found. However, the hind legs are more important in determining the speed produced and these were not measured (Manning & Ockenden, 1994). The handicaps placed on racehorses are determined from the horse’s performance in previous races. Therefore, horses that have done well will carry more weight than those that have performed poorly. A negative correlation between asymmetry and handicap was found in the work done by Manning & Ockenden (1994), where the different segments of the racehorses’ bodies was measured for asymmetry in relation to their handicap ratings, and the most asymmetrical horses received lowest handicap ratings (Table 1).

Table 1: Correlations between character asymmetry and handicap ratings (plus age allowance) of flat racing Thoroughbred horses (Manning & Ockenden, 1994).

Character	Rating	P	Rating + age	P
Elbow-knee	-0.15	0.19	-0.15	0.21
Knee-ergot	-0.05	0.65	-0.06	0.64
Knee thickness	-0.15	0.21	-0.24	0.03
Coronet band	-0.19	0.11	-0.22	0.06
Ear height	-0.10	0.40	-0.02	0.89
Incisor height	-0.21	0.07	-0.38	0.001
Incisor width	-0.12	0.31	-0.14	0.24
Nostril width	-0.22	0.06	-0.20	0.09
Cheekbone-ear	-0.04	0.72	-0.06	0.59
Cheekbone-mouth	-0.35	0.0027	-0.33	0.003
Overall mean asymmetry	-0.43	0.0002	-0.48	0.0001

The handicaps are also related to the age of a horse, as the older horses are believed to run faster and are therefore receive heavier handicaps. This increases the negative correlation between asymmetry and handicap (Møller & Swaddle, 1997). Asymmetries were found to decrease with age. This may be due to the selection bias against the most asymmetrical horses and the more symmetrical horses having longer racing careers (Møller & Swaddle, 1997). Dalin (1985) found that the performance (total earnings, races/ horse and race recordings - min/km) of Standardbred Trotters that were more asymmetrical (with respect to the hindquarters) were lower than the more symmetrical horses measured. Leleu *et al*., (2005) found that older horses had significantly higher earnings than the younger horses (five year olds earn significantly more than three year olds) and older horses were able to achieve significantly faster speeds than the younger horses. The more asymmetrical horses had difficulty performing at speed (Dalin, 1985). The more asymmetrical horses were found to have longer body lengths with greater chest circumferences. The differences in load distribution were found to be the main cause of asymmetries found in these horses. It also is possible that muscular development can compensate for the skeletal asymmetry that has developed (Clayton, 2004).

Determining if there are large differences in the third metacarpal bone length may assist a trainer in determining which races are suitable for an individual racehorse, as the differences in the long bone between the two sides of the body are likely to have subtle effects on the co-ordination and balance (Watson *et al.,* 2003). These differences may also have clinical significances in determining the cause and effect of unilateral injuries in all classes of horses (Watson *et al.,* 2003). Watson *et al.,* (2003) also identified that the ability to race and the soundness of racing around the turns may be affected by large differences between the left and right bones of the limbs of the racehorse. His study suggests that there may be selection against horses with large differences between the third metacarpal bones. When racing clockwise it has been found that horses with longer right third metacarpal bones have some advantage over horses with more symmetrical metacarpal bones.

The developmental stability of the foal during the growth period can be affected by a number of environmental factors, which can result in asymmetries forming between bilateral traits (e.g. in the limbs). Stress can be indicated in the asymmetrical development of skeletal structures, in particular bilateral structures. Symmetry of a bilateral trait is where both sides are equal in size and length and therefore if someone is asymmetrical their arms for example are not the same length and one is longer than the other. If one is asymmetrical the body would need to use more of its resources in order to achieve the same or similar results than horses that are perfectly symmetrical or closer to this. The effects of asymmetry can be seen in poorer race performances by horses that are more asymmetrical running against horses that are more symmetrical. It was found that there was less asymmetry in horses that are ending a long career on the race track than in the horses starting out. As horses are still growing (horses continue to grow for the first 3 years –the humerus is still growing at this point) one would then think that racing would help improve their symmetry but this is incorrect on two fronts. Firstly horses generally work one way around a track when training and this alone could produce asymmetries as working on one side will cause horses to be muscularly one sided and if they are still growing this could affect skeletal structure. Secondly there is less asymmetry in horses later in racing because these horses are more symmetrical at the start and achieve better results and therefore are retained in training for longer.

If during the growing phases in a foal's life the foal receives inadequate nutrition, incorrect exercise and/or experiences poor health etc., the foal will be at a disadvantage against the less affected ones. The nutritional requirements of a horse have been investigated in length over the last 100 years and further research is still continuing to determine the requirements of horses (growing, aging, all degrees of working or resting).

2.3 GROWTH AND CHANGES IN THE THOROUGHBRED FOAL

2.3.1 Growth

The development of the muscular skeletal system of a horse increases at a decreasing rate from birth for the first few years of life (van der Harst *et al.,* 2005). There has been very little change in the growth rates of Thoroughbred foals over the last twenty eight years (Green, 1969; Thompson, 1995; Hintz, 1979). Hintz *et al*., (1979) and Thompson & Smith, (1994) conducted trials on the skeletal growth patterns and found that there were no significant changes in the growth rates from 1958 to 1991. Growth rates from the trials run by Hoffman *et al*., (1996) were found to be similar to those reported by Hintz et *al*., (1979) and Thompson (1995).

The phases of general growth and development are seen in three-month periods, with the first three months of growth being the most rapid (particularly the first month), after which the average daily gain decreases. From zero to three months there is a high growth rate which slows in the next three months (three to six months of age), and slows further over the next three months (six to nine months of age). The growth periods between six and nine months and those between nine and twelve months proceed at roughly the same rate (Green, 1969). This can be seen by the gains of height and girth measurements which in the first three months are only slightly less than that of the next nine months. There is a linear trend in the body weight curve from birth to approximately eight to nine months of age and there is a marked reduction in the following thirteen to fourteen months (Jelan *et al.,* 1996). Foals of both horses and ponies follow the same pattern of growth even though they achieve different mature heights (Frape, 1986). By the time a foal has reached six months of age (time of weaning) it would have reached 85% of its mature height and approximately 50% of its mature body weight (Kohnke, 1998), therefore leaving the first six months important in regard to achieving optimal skeletal growth. At fourteen days of age, the body lengths of the Thoroughbred colts and fillies were roughly 53.4 % and 54.3 %, respectively, of the body length obtained at 588 days of age, which represent gains of 70.9 and 68.3 cm, respectively (Thompson, 1995).

Young foals fed for rapid growth may not maximise bone growth, as there is a smaller area of new bone growth (Thompson *et al.*, 1988a). By manipulating the weaning process, diet, feed intake and protein: energy ratio, the growth rates and skeletal development of a growing horse may be controlled (Thompson *et al.*, 1988b). In controlling the growth rate of young Thoroughbreds, one should be able to reduce the incidence of developmental orthopaedic disorders and therefore potentially improve symmetrical growth and ultimately improve the performance life of a Thoroughbred horse.

2.3.1.1 Average Daily Gain (ADG)

There are four phases in the ADG of a foal in the first twenty months of life. The phases are: birth to one month (where the most intense growth occurs), one to twelve months, twelve to fifteen months and fifteen to twenty months (Jelan *et al.*, 1996). The ADG for the first month of growth for Thoroughbred foals was found to be in excess of 1.6 kg/day.

From one to four months of age the ADG ranged between 0.9 to 1.0 kg/day, and decreased to roughly 0.5 kg/day at eleven to twelve months of age (Figure 1).

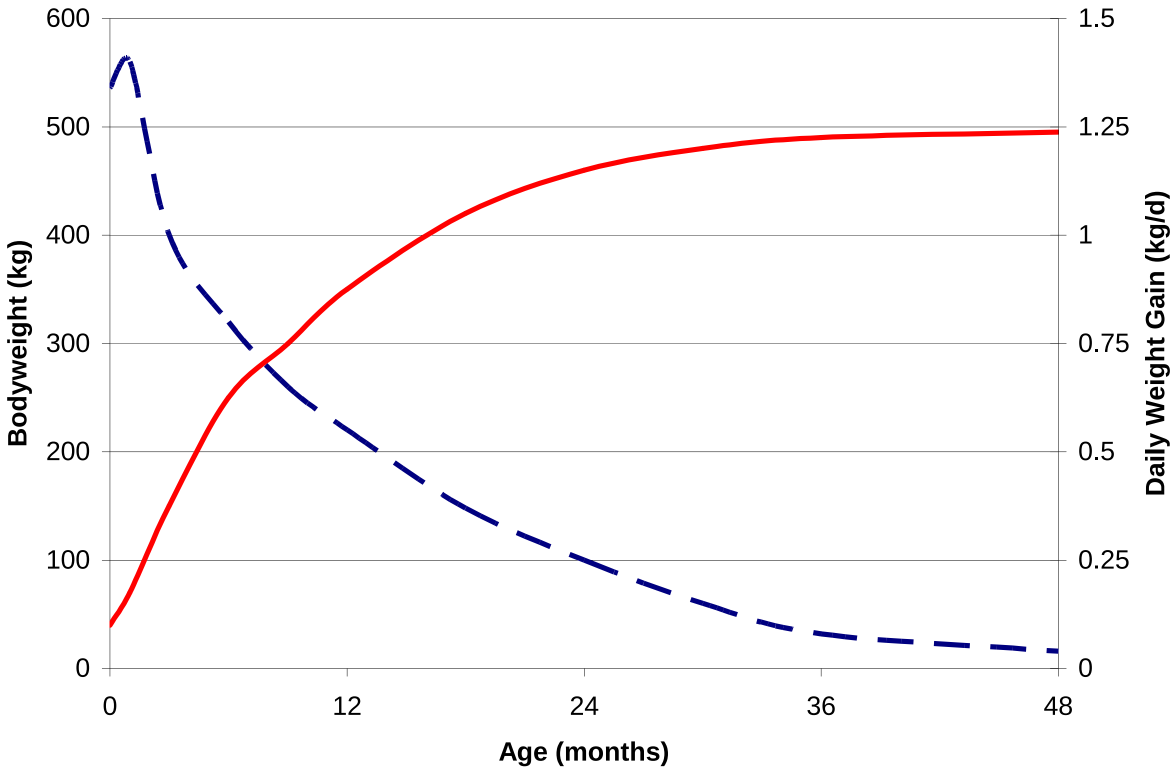

Figure 1: Proportional decrease in the daily weight gain as body weight increases (after Frape, 1986). (—— Body Weight, - - - Daily Weight Gain)

The growth curve of the crossbred ponies described by Campbell (1981) and those of the Thoroughbreds used by Green (1969) were found to be similar. However the ponies grew at a slower rate. Table 2 (Campbell, 1981) shows growth comparisons of the long bones of ponies and Thoroughbreds from birth to one year of age.

Table 2: A comparison of growth (in cm) to twelve months of age of the long bones, in ponies and Thoroughbreds (after Campbell, 1981)

Months	0-3	3-6	6-9	9-12	Total
Mean of 6 pony foals *	13.2	6.6	5.0	3.8	28.6
Mean Of approximately 40 thoroughbred foals^{+}	19.0	9.9	6.1	5.8	40.8

* Campbell (1977) $^{+}$ Green (1969)

There are different phases in the growth of a young horse, with the most intense growth occurring very early in the foal's life during the spring and early summer months before slowing down in late summer (Green, 1976). The growth rates of the yearlings in Kentucky were found to follow pasture growth, season and temperature Pagan *et al.,* (1996). It was found that in the Northern Hemisphere (Kentucky), foals born early in the year during early spring were able to maintain an advantage in size up to maturity over those that were born later in the summer, (Thompson & Smith, 1994). This signals that early nutrition is critical. The growth rate of the foal is related to the amount of milk produced by the mare, her milk yield being largely dependant on her nutritional status (Jelan *et al.,* 1996), which can be related to the seasons. Table 3 shows the effect of month of birth on the wither growth and weight gain.

Table 3: The effects of month of birth on Thoroughbred foals in the Northern Hemisphere (after Hintz *et al*., 1979)

	Age			
	30 days		540 days	
Month of birth	Weight (kg)	Height (cm)	Weight (kg)	Height (cm)
Feb - March	95.3	109.2	396.9	153.7
April	97.5	110.5	402.8	153.7
May	100.7	111.1	403.7	153.7

It has been determined that the height of the withers reflects the long bone growth of the front legs (Frape, 1986). A study by Jelan *et al.,* (1996) found the average height at birth (104.4 cm), six (132 cm) and twelve (146 cm) months were 67.4%, 85% and 94.5 %, respectively, of the height attained by twenty months of age. There is a rapid increase in height at the withers in the first three months of life, as much as 8 cm/month in the first month and then down to less than 3cm/month between months three and four, after which their increase is gradual until at approximately fourteen months of age when the beginning of a plateau is reached (Jelan *et al.,* 1996). By sixteen months the rate of increase in height has dropped to less that 1cm/month and by eighteen months of age there is no noticeable change in wither height (Jelan *et al.,* 1996). The hip height growth rate and that of the wither growth rate were found to progress at a similar rate, with the hip height being slightly longer throughout the trial by 2-3 cm (Thompson, 1995).

Hintz *et al.,* (1979) found that Thoroughbred foals obtained 46%, 67% and 80% of their mature weight (roughly 500 kg) by six, 12 and 18 months, respectively. However, a study by Kavazis & Ott (2003) found that the body weights of the trial animals were lighter at six, twelve and fifteen months of age than horses in the Thompson (1995) trial. Measurements for wither height; body length and hip height were similar to those that were found by Thompson (1995). The differences were likely to be due to (i) the differences in the genetic pool available, as both groups of trial animals were Thoroughbreds however from different areas namely Florida and Kentucky, and (ii) management routines as horses were from different yards, and the trials done by Kavazis & Ott (2003) and Thompson (1995) were conducted 8 years apart.

Body weight gains of both fillies and colts were similar from eight to ten months of age, then the colts grew significantly larger and higher (Thompson, 1995). Table 4 shows the increasing body weight and wither heights of colts and fillies found by Hintz *et al.*, (1980). Green (1969) reported in a trial that there was no significant difference in the average height and girth measurements between colts and fillies. These measurements were taken at 14 days and then at aged one month and then on a monthly basis until one year of age.

Table 4: The increases in body weight and wither height of Thoroughbreds between 2 and 540 days of age (Hintz *et al.*, 1980).

Age (days)	body weight (kg)		Wither Height (cm)	
	Colts	Fillies	Colts	Fillies
2	52.2	51.3	100.3	99.7
60	136.5	134.7	118.3	118.1
180	244.9	235.9	134.6	133.0
540	435.5	401.4	154.3	152.4

At birth the average height measurement of the foal exceeds that of the girth measurement by nearly 17.78 cm (Green, 1969). With the rapid growth of the foal in the first few months of life this changes so that by four months of age the measurements of both height and girth are similar. After four months of age the increase in the girth measurement proceeds at a faster rate than that of the height and at twelve months of age the girth measurements can exceed that of the height by nearly 12.7 cm (Green, 1969).

2.3.1.2 Bone Growth

The equine skeleton consists of various bones (Figure 2) which form the bony scaffold to which muscles attach. These bones form joints at one or both ends producing the supple nature of the skeleton and allow for movement (Hayes, 2002)

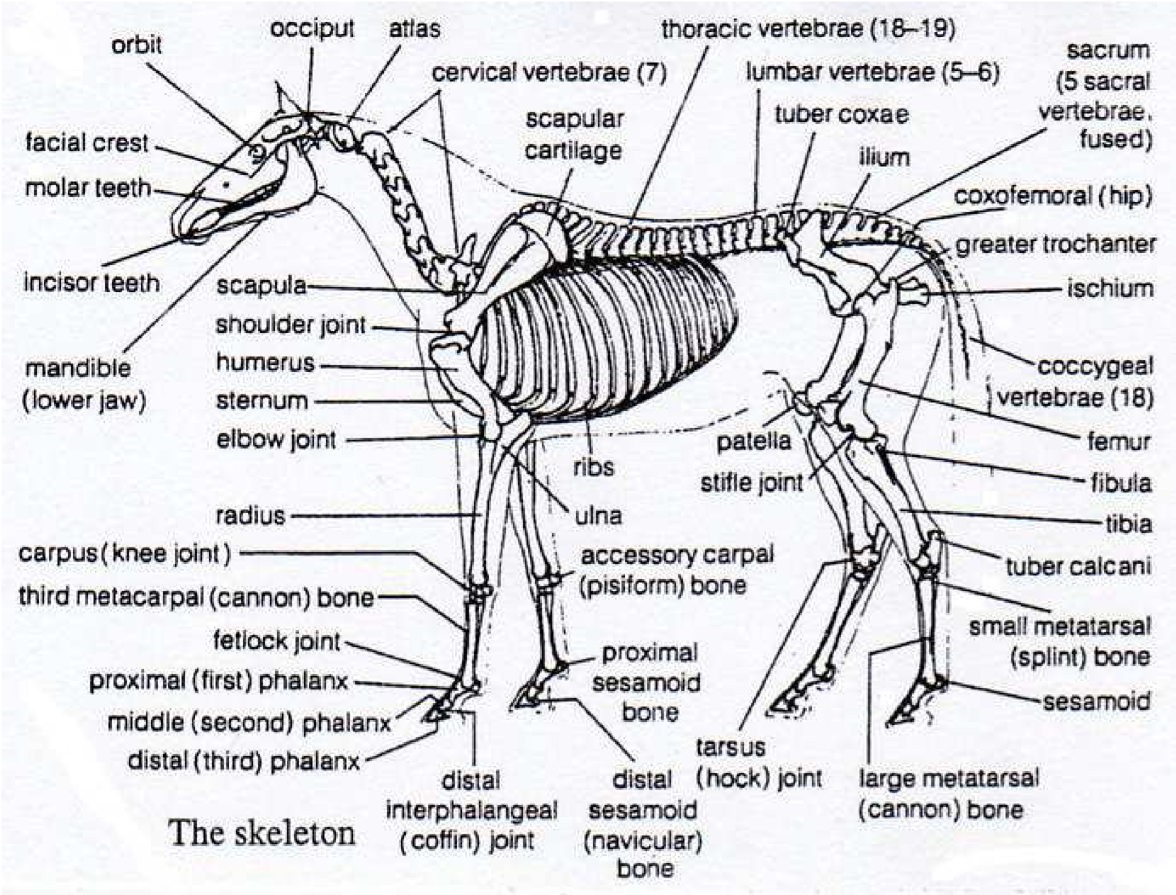

Figure 2: The equine skeleton (after Hayes, 2002)

In order to attain these increases in height and therefore body weight the bones are required to grow. Bone grows (increases in length and width) from the growth plates found at the proximal and distal ends of the long bone, the epiphyseal plates (Jackson *et. al.,* 2003).

The growth rate of foals is intense in the first few months of life and with increasing age this growth rate slows (Green, 1961; 1969). However, after 80 days from birth the rate of growth slows down and there is very little new bone added to the metacarpal, metatarsal bones and the phalanges and no obvious lags or spurts are observed (Campbell, 1981).

Most of the increase in length from the knee to pastern and hock to pastern occurs in the first five months of life. Thompson (1995) found increases in the knee to pastern of only 2.6 and 2.8 cm for colts and fillies, in the first five months and another increase of 1.4 and 1.6 cm, respectively, in the next sixteen months. The increases in the hock to pastern length in the first five months were 3.3 and 3.1 cm for colts and fillies and in the next sixteen months there was an initial increase of 0.7 and 0.5 cm, respectively (Thompson, 1995). The trial that Hintz et *al.*, (1979) conducted found that the greatest amount of bone elongation occurs during the first few months of life.

The average measurements of the circumference of the metacarpal bones was 0.91cm greater in colts at birth than the fillies and at twelve months this difference was recorded to be 0.89 cm greater for the colts than the fillies (Green, 1969). This difference was maintained for the first twelve months of life. The increase in the circumference of the metacarpal bone was not affected by environment, season or work and there was very little gain from twelve to thirty six months of age (Green, 1976).

Low correlations between wither height and cannon bone circumference were found (Hintz *et al*., 1979; Thompson & Smith, 1994). However Hintz *et al.*, (1979) found high correlations between body weight at birth and later in life, which was not found by Thompson & Smith (1994), but found also by Allen *et al.*, (2004). There are low correlations between the growth measurements at the different times and this indicates that there will be difficulty determining body size from single growth measurements (Thompson & Smith, 1994). The highest correlation was found to be between body weight and heart girth (Kavazis & Ott, 2003). There are equations to determine the body weight of a horse based on body length and girth circumference (Carroll & Huntington, 1988)

Growth plates are closed at nine to twelve months of age (Campbell, 1981). After twelve months of age, there are four growth areas in the forelimb that still contribute to growth (Campbell, 1977). Between six and nine months of age, the phalangeal growth plates ossify and therefore no longer contribute to the growth in length of the limbs (Campbell, 1977). The metacarpal, metatarsal bones and the phalanges show little growth, (5 to 10% of their original length), compared to the other bones which show growth of up to 50% of their original length (Campbell, 1981). The closure time and percentage increase in bone length of the fore and hind legs of growing foals is represented in Table 5. The growth of the metacarpal and metatarsal bones is about 4% of the original length and the growth of the phalanges is about 10% of the original length (Campbell, 1981).

Table 5: Time of closure of the physis and percentage increase in length in bones of growing Thoroughbred and Quarter Horse foals (after Campbell, 1981)

Bone	Length of bone (cm)		Increase at each end (%)		Age at closure of growth plates (weeks)	
	0-7 days	2 years	Proximal	Distal	Proximal	Distal
Femur	22	31	24	20	55	55
Tibia	21	29	22	17	60	60
Radius	21	28	12	24	54	69
Humerus	16	23	31	11	80	70
Metatarsal	23	24	5		40-44	
Metacarpal	18	19	5		40-44	

The growth of the third metacarpal bone ceases by ten weeks of age and should therefore not be affected by training conditions after this age. (Fretz *et al*., 1984), therefore any asymmetry found in the third metacarpal bone are a result of the growing process or nutrition of the young racehorse (Watson *et al.,* 2003). The metaphyseal growth plate contributes about 89 %(4.1mm) of the length change (Fretz *et al.*, 1984).

The proximal end of the femur and tibia contribute 55% of the growth and the distal end makes up the remaining 45% of growth (Campbell, 1981). The growth of the femur in foals is different to that of the pig, goat and human. The tibia and humerus growth is similar to other animals (dogs, goats, humans and pigs), contributing 75% of the growth at the proximal end of the humerus. The radius shows greater growth at the distal end than the proximal end as seen in other animals, with the total growth of the radius being less than that of the tibia (Campbell, 1981).

2.3.2 Weaning

Weaning is the process of customising a young mammal to take nourishment from sources other than by suckling from its mother. In order to achieve this, the mare and foal are separated from each other. Foals are generally weaned between four and six months of age, depending on the development and size of the foal, available pasture, seasonal conditions and physical state of the mare, with most naturally weaning themselves by five months of age (Kohnke, 1998). Weaning is one of the most stressful periods in a foal's life and can predispose a foal to injury, disease or reduction in growth rates (Apter & Householder, 1996). McCall *et al.,* (1987) found that a more relaxed emotional state of the weaned foals was beneficial as they were less likely to injure themselves and there was a reduction in disease.

A well managed weaning program is one that minimises the psychological, nutritional and health stress of the foal (Kohnke, 1998). It has been found that weaning a foal with another, as a stall companion, appears less stressful, as there are lower rates of neighing immediately after weaning (Houpt *et al*., 1984), but there can be more incidents of aggression (flattening their ears, biting or threatening to kick) when the weaned foals are placed in stalls in pairs (Hoffman *et al.,* 1995). In an earlier study (Houpt *et al*., 1984), it was found that foals weaned in pairs appeared less stressed, due to lower vocalisation levels. However observation by Hoffman *et al*., (1995) found that foals weaned in pairs were less vocal due to stall companions being involved in aggressive behaviour suggesting that weaning in pairs has little or no apparent advantage.

Short periods of separation from the mare prior to weaning would not appear to lessen the stress of weaning, as foals with experience of separation were more vocal than those that did not have experience of separation (Houpt *et al*., 1984). The release of adrenocorticotropic hormone (ACTH) is a feature of the stress response (Hoffman *et al,*. 1995). There is a high correlation between ACTH response and behaviour score in weaned foals indicating that either can be used as indicators of weaning stress (Hoffman *et al,*. 1995). ACTH levels showed that neither of the sexes coped better with weaning stress (Hoffman *et al.*, 1995). Foals that are separated abruptly from the mares have significantly higher adrenal responses ($P< 0.05$) and pre-ACTH basal ($P<0.05$) and post-ACTH peak plasma cortisol concentrations ($P<0.05$) than foals that are gradually weaned indicating that they are more stressed at abrupt weaning (McCall *et al.*, 1987).

Excessive weaning stress may have negative effects on the foal's appetite, metabolism and immune competency (Hoffman *et al.,* 1995). Loss of weight and failure to grow optimally are the more common problems associated with weaning (Houpt *et al*., 1984). Physical signs of stress include weaving, pawing, rearing, or wood chewing (Hoffman *et al.*, 1995). An increase in frequency in neighing, steps, urination and defecation after weaning were found, indicating an increase in emotionality (Houpt *et al*., 1984).

Rogers *et al*., (2004) found that regardless of the weaning method a decrease in the ADG was seen the first week after weaning with no effect on the post weaning ADG both short term (10 days after weaning) and long term (up to 480 days of age). There was no significant difference between foals weaned abruptly and those weaned gradually with respect to the ADG (McCall *et al*., 1987; Rogers *et al*., 2004). Weaning stress can be significantly reduced if a foal is given a creep feed prior to weaning, be it abrupt, gradual or stall weaning (Apter & Householder, 1996). The availability of a pre-weaning creep feed seems to moderate the stress that is involved in total separation weaning as foals on a pre-weaning creep feed that were abruptly weaned and those of the control (foals fed a creep feed and not separated from the mare) in the trial conducted by McCall *et al*., (1987) were not significantly different in respect to adrenal response. Weanlings should be fed 1 – 1.5 kg/100g body weight daily of a good quality concentrates (Kohnke, 1998). Foals fed pre-weaning rations gained more weight ultimately after weaning. Foals not offered a pre-weaning ration had initially higher weight gain for the first two weeks after weaning. Foals fed the pre-weaning rations were found to be taller from days 10 to 100 (Thompson *et al.*, 1988a) and colts gained more height than fillies ($P < 0.05$) (Ott & Asquith 1989). From days 100 to 130, the non-supplemented foals gained more than the creep fed foals. This early rapid height growth by the creep fed group led to earlier attainment of height and to a slower change in the wither height later in the study (Thompson *et al.*, 1988a).

Feeding a concentrate in regards to weaning stress may have its advantages due to the mineral content that will be supplied to the foals (Hoffman *et al.*, 1995). Foals on pasture supplemented with hay only had lower ACTH levels than those of foals on pasture supplemented with a pelleted concentrate ($P<0.001$) (Hoffman *et al.*, 1995). The physiological response to stress showed that foals on pasture and supplemented with a pelleted concentrate faired better than foals on pasture supplemented with hay only (Hoffman *et al.*, 1995).

2.3.3 Post Weaning Nutrition and Feeding

The rate at which a young animal grows will be a function of the nutrients available, how well its energy and protein needs are met by the diet, the age of the animal, genetic growth potential and its previous growth history (Ott, 2001). During the first week of life, normal healthy foals will suckle between 100 – 105 times (for only about a minute at a time) in a twenty-four hour period (Kohnke, 1998). Table 6 shows the nutritional composition of the mare's milk.

Table 6: The composition of Thoroughbred mares milk (Asai, 2001)

Time after foaling	Total solids (%)	Energy (MJ/ 100g)	Protein (%)	Lactose (%)	Fat (%)	Ca (%)	P (%)	Mg (%)	Cu (%)	Zn (mg/ kg)	Fe (mg/ kg)
O day *	19.1	0.431	12.3	4.0	1.5	0.08	0.07	340	1.1	7.1	1.7
1 week	10.5	0.219	2.7	6.2	1.3	0.12	0.08	90	0.6	2.5	1.3
7 weeks	10.1	0.206	1.9	6.6	1.3	0.08	0.05	40	0.4	2.3	1.1
17weeks	10.2	0.207	1.8	6.8	1.3	0.06	0.04	20	0.3	2.1	0.9

* colostrum

The foal will start imitating its mother by nibbling grass as early as five to seven days of age. Kohnke (1998) found that the forage intake contributes little to its nutrition at this age (Figure 3). The mare's peak in lactation occurs about two months after weaning, coinciding with the foal's most active growing period. Up until this point the mare's milk has been sufficient in supplying the foal with all the nutrients that are required (Kohnke, 1998). The pasture and feed begin to contribute significantly to the requirements of growth after this stage.

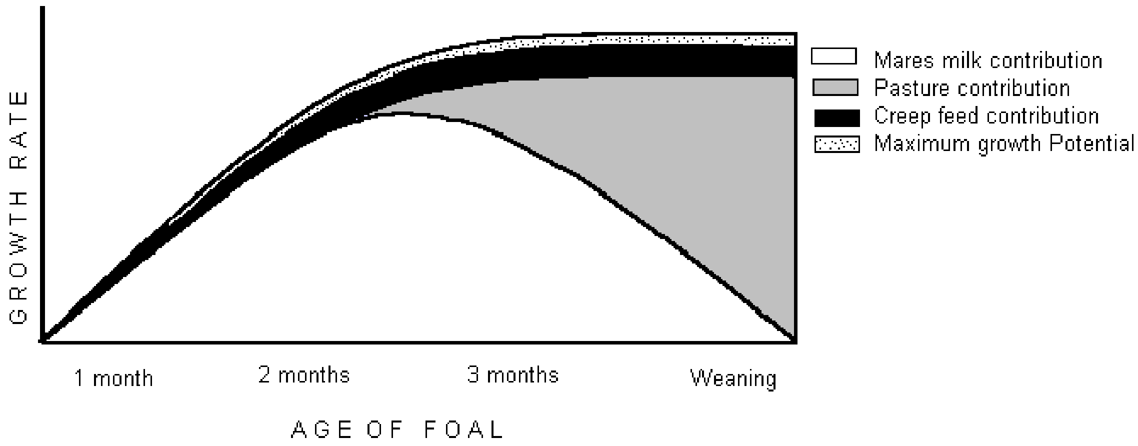

Figure 3: A representation of the contributions of different feeds and the mare's milk to the foal's diet from birth to weaning age. (after Kohnke, 1998)

Creep feeding can increase rate of growth with little decrease in the bone quality as the additional nutrients and minerals are adequate to meet nutritional needs and maintain skeletal quality in fast growing foals (Thompson *et al.*, 1988a). It is better to slightly underfeed a foal, encouraging slower growth rates and prolong their growing period, than maximise growth by over-feeding them and restricting exercise (Kohnke, 1998). Creep feeding was shown to have significantly ($P < 0.05$) greater cumulative effect on the body weight gains, wither height and third metatarsal bone (Mt III) length when compared to non-supplemented foals - which had gains similar to those reported by Hintz *et al*., (1976) and Thompson *et al*., (1988a). The Mt III cumulative gains were significantly higher ($P < 0.05$) for the creep fed group in a trial by Thompson *et al.* (1988a). This suggests that during peak lactation supplemental sources of nutrients may be beneficial to meet requirements for rates of growth that milk supply alone may not be able to meet (Thompson *et al.,* 1988a).

The energy requirements for growth and maintenance are calculated by the following equation (NRC, 1989):

$$\textbf{DE (MJ/day) = maintenance DE (MJ/day) + (4.81 + 1.71 } \boldsymbol{X^2}\textbf{)(ADG)}$$

Where: ADG = Average Daily Gain (kg/d)

X = age (months)

DE = Digestible energy required per kg of gain (MJ/day)

The NRC (1989) provides digestible energy requirements (Table 7) for a growing foal and expected nutritional requirements of a growing foal with mature body weights of 500kg (Table 8). A decrease in growth and development in young animals is seen when there is inadequate protein or lysine intakes (NRC, 1989).

Table 7: Digestible energy requirements for growth of foals (NRC, 1989).

Age	Requirement (Kcal DE/kg of gain)
Weanling, 4 months	38.07
Weanling, 6 months	46.02
Yearling	64.85
Long yearling, 18 months	76.99
2 years old	82.01

Table 8: Daily Nutrient requirements of horses (500-kg mature weight) (NRC, 1989).

Growing Horse	Weight (kg)	Daily Gain (kg)	DE (Kcal/day)	Crude Protein (g)	Lysine (g)	Calcium (g)	Phosphorus (g)	Magnesium (g)	Potassium (g)	Vitamin A (10^3 IU)
Weanling										
4 months	175	0.85	60.25	720	30	34	19	3.7	11.3	8
6 months										
Moderate growth	215	0.65	62.76	750	32	29	16	4.0	12.7	10
Rapid Growth	215	0.85	71.96	860	36	36	20	4.3	13.3	10
Yearling										
Moderate growth	325	0.50	79.08	851	36	29	16	5.5	17.8	15
Rapid Growth	325	0.65	89.12	956	40	34	19	5.7	18.2	15
Long yearling*										
Moderate growth	400	0.35	82.84	893	38	27	15	6.4	21.1	18
Rapid Growth	400	0.35	110.88	1195	50	36	20	8.6	28.2	18
Two year old										
Moderate growth	450	0.20	78.66	800	32	24	13	7.0	23.1	20
Rapid Growth	450	0.20	110.04	1117	45	34	19	9.8	32.2	20

* 18 months of age

The NRC (1989) recommends a ratio of 70:30 for a concentrate: roughage ration for weanlings and 60:40 for yearlings. The data produced by Ott (2001) showed that weanlings consumed concentrate and roughage at a ratio of 62:38 for weanlings and a ratio of 64:36 for yearlings. Ott (2001) found that the daily energy intake (MJ/d) for weanlings was less than that stated by the NRC (1989) by 1.3 MJ/d. For yearlings the intake was found to be 2.59 MJ/d more than stated by the NRC (1989).

A study conducted by Stanier *et al*., (2001) showed that improving the quality of protein fed to growing horses would result in enhanced growth rates. Fortification of lysine and threonine in the growing horse's diet will enable a decrease in the quantity of protein fed while promoting optimum growth in Thoroughbred foals. It is important to maintain a minimum of 1% of Body Weight as roughage intake to maintain good gastrointestinal tract motility (Kohnke, 1989; NRC, 1989).

Foals maintained on pasture fed a diet rich in starch and sugar were found to grow at similar growth rates as foals fed on a diet rich in fat and fibre until ten to twelve months of age where there was a decline in the condition and weight in the foals fed the diet rich in starch and sugar (Hoffman *et al*., 1996). This impaired performance continued until the foals were placed on the fibre/fat rich diet where compensatory growth occurred, with the result that within seven months the two groups were at the same condition and weight (Hoffman *et al*., 1996). It was found that the fat and fibre in a concentrate gave some protection against the high sugar and low fibre content of the spring pasture (Hoffman *et al*., 1996). The wither and hip heights, length of body, forearm and cannon bones, girth and circumference of physis and fetlocks were similar in both groups. The girth circumference did reflect the change in weight but there was no overall change in the frame size (Hoffman *et al*., 1996).

High dietary levels of protein, energy and Ca or varying nutrient: Ca ratio can alter skeletal development (Thompson *et al.*, 1988b). Trace mineral supplementation was found to have a positive effect on the bone mineral deposition of yearlings when the natural diet content of trace minerals contents were lower than the recommendations of the NRC (1989) (Ott & Asquith, 1989). Inadequate trace mineral intake will reduce bone mineral deposition in yearling horses, and the trace minerals most likely to be limiting in typical diets are zinc and copper (Ott & Asquith, 1989).

The bone mineral content of the Third Metacarpus (Mc III) is influenced by the diet and the time (incorporating age, season, weight and diet). In a trial by Hoffman *et al*., (1999) a change in diet (from mainly milk to pasture and supplements) and the onset of winter (resulting in a decrease in activity) resulted in plateaus in the bone mineral content. Mc III bone mineral deposition was significantly increased by the highest level of trace mineral supplementation (1.0%TM premix) in a trial conducted by Ott & Asquith (1989). Growth of the long bone is inhibited when there are deficient levels of Ca in the diet (Thompson *et al.*, 1988b).

The bone formation of the foal may be limited on a diet rich in energy without a proportional increase in protein because the high caloric intake results in an increase in weight gain with very little effect on the skeletal development. However, when the diet is rich in energy and protein, there is an increase in body weight (BW) and skeletal growth (Thompson *et al.*, 1988b). High planes of nutrition increase BW gains and growth rates of several long bones with the skeletal development (cortical area) being compromised (Thompson *et al.*, 1988b).

When horses grazing rapidly growing pastures are supplemented with grain-based concentrates the hydrolysable carbohydrates may become excessive (Hoffman *et al*., 1999). Further complications can be seen as colic, laminitis and developmental orthopaedic diseases. Rapidly fermenting carbohydrates become excessive when rapidly growing pastures are supplemented with concentrates rich in starch and sugar (Hoffman *et al*., 1996).

2.3.3.1 Developmental Orthopaedic Disease (DOD)

Prevention is better than cure when it comes to feeding or overfeeding as by the time the signs of DOD's are present the skeletal damage has been done (Kohnke, 1998). Ott & Asquith, 1989 found that long bone length growth, diaphyseal growth, the presence or absence of microscopic abnormalities and bone mineralisation are all measures of skeletal development of animals. Most DOD's occur from 3-9 months, corresponding to the provision of inadequate exercise, or imbalanced diets (Kohnke, 1998). Foals that are born with or acquire angular and flexural limb deformities require rapid adjustments in order to grow and develop so that future performance is not compromised Trumble (2005). The developmental stage between weaning and yearling age is the most crucial (Kohnke, 1998). It has been found that foals between the ages of six and twelve months of age affected with Developmental Orthopedic Disease (DOD) were heavier than unaffected foals (Jelan *et al*., 1996). Unaffected foals appeared to be taller at the withers, however neither of these differences where found to be significant. By fourteen months of age there was very little difference in weight found between affected and unaffected foals. Early weaning could control the extra weight as well as dietary control and monthly weight monitoring (Pagan *et al*., 1996) in order to minimize any potential DOD's.

Seasonal changes had the largest effect on the leg evaluations (for physitis, joint effusion and flexural and angular limb deformities) rather than the concentrate diet (Hoffman *et al*., 1999). Physitis was related to the nutrient intake prior to weaning and to the spring pasture growth (Hoffman *et al*., 1999). Winter brings cooler temperatures increasing the energy demand for thermoregulation and winter coat growth. Weaning occurs during this time which stresses foals. As well as a change in there feeding habits, pasture quality decreases resulting in less nutrients available for growth all of which results in a decrease in the growth rates (Stanier *et al.,* 2001).

High rates of growth and growth spurts are not advisable as they lead to DOD's (enlarged growth plates or epiphysitis, contracted tendons, internal abnormalities in the knee, hock, and fetlock joints and bone malformations of the spinal canal in the mid and lower vertebra). Over growth is often stimulated by diets excessively high in energy combined with low Ca or imbalanced trace minerals with restricted or inadequate exercise (Kohnke, 1998).

DOD's requiring treatment occur during all phases of growth from birth to sales (as yearlings) with a higher occurrence between weaning and the end of December (the trial was conducted in Ireland, the Northern Hemisphere and therefore in the winter months) (O'Donohue *et al.,* 1992). There was no significant difference in the frequency of the initial diagnosis of DOD's found between the sexes through the seasons except during the suckling period where fillies had a significantly lower incidence of DOD's (O'Donohue *et al.,* 1992). Angular limb deformity is 1.4 times more likely to occur in animals with physeal dysplasia than animals without (O'Donohue *et al*,, 1992). No significant difference was found between the fillies and geldings in the diagnosis of rotational limb deformities between the seasons (O'Donohue *et al.*, 1992).

Some DOD's that commonly affect growing Thoroughbreds are epiphysitis, angular limb deformities, osteochondrosis dissecans (OCD) and Wobbler syndrome.

2.3.4 Exercise

In the first year postpartum the musculoskeletal system passes through a period of dynamic growth, development and intense alterations. Environmental and genetic factors shape the mental and physical abilities of the foal which will determine its athletic ability and can potentially result in clinical developmental orthopaedic diseases (Barneveld & van Weeren, 1999). Thoroughbred racehorses are brought into training at eighteen months of age and are racing in maiden races by the age of two. At this age there is a high turnover of horses in training and competing. If the horse is not performing and the expenses incurred by upkeep and training are found to be unfeasible the horse is sold and removed from the racing circuit. Raub *et al.*, (1989) tested whether exercise would affect the metacarpal size in growing horses and it was found that there was significantly ($P < 0.01$) greater gain in the circumference at the mid-point of the metacarpal in exercised horses. Different measuring techniques have in the past resulted in differences in data reported. For example the measurements reported by Hintz *et al.*, (1979) were found to be less over a similar time period. The increase in size of the third metacarpal bone was due to an increase in bone diameter as well as an increase in the size of the tendons. This would enable the lower leg to withstand the rigors of the work the leg is expected to perform. Growing bone adapts more readily to stress than mature bone and it is therefore in the best interest of the growing foal to be exercised in order to gradually develop more structurally sound bone and reduce the risk of injury or breakdown (Raub *et al.*, 1989).

Raub *et al.*, (1989) found there to be no significant difference between two groups of weanlings, exercised and non-exercised (EX and NEX), in terms of mean wither height ($P > 0.10$) and wither height gain ($P > 0.05$). However the EX group had significantly heavier ($P < 0.05$) body weight. The body weight gains and wither height gains were found to be similar to other studies (Hintz *et al*., 1979; Thompson *et al*., 1988). It was found that young animals are able to respond and recover better than more mature animals as the young tendon can respond to load by synthesising and maintaining the integrity of the matrix while the mature tendon has limited ability to do so. Therefore controlled exercise may have beneficial effects on the development of tendon extracellular matrix which would condition it for the inevitable damage that occurs in the exercised mature animal (Smith *et al.*, 1999).

Barneveld & van Weeren (1999) found that a certain amount of well-distributed exercise is essential for optimal balanced musculoskeletal tissue development and that pasture exercise was the most superior form of exercise. Withholding exercise, in the form of box-rest led to retardation in skeletal development, while sprint training resulted in enhanced bone mineral density compared to pasture exercise. The same results were found with the Na^+/K^+ pump in the muscular tissue (Barneveld & van Weeren, 1999).

Presentation of a balanced diet and an exercise regime that is best suited for the individual horse will minimise the negative effects of bad feeding and training on the development of a growing foal. A simple equation where by nutrition and exercise are controlled and modified to achieve a sound young horse proposed by Kohnke (1998) is:

Balanced Nutrition	+	**Adequate Exercise**	+	**Regular Assessment**	=	**Optimal Steady Growth**
Adequate energy Ca:P ratio 1.2-2.0:1.0, Cu 30-50mg/kg feed, Condition Score 2-3		At least 2-3 hours daily paddock exercise		Every 2-3 weeks to check for limb and hoof abnormalities		Avoid catch up or restricted growth

2.4 ASSESSING GROWTH

Over time the growth of domestic animals has been quantified by body weight, average daily gain and changes in length and circumference. The techniques in obtaining various growth indicators include the calculation Carroll & Huntington (1988) devised (($girth^2$ x length)/11800), taking carcass samples (Barneveld & van Weeren, 1999), the use of digital assessment (Anderson & McIlwraith, 2004; Thompson, 1995), weight and measuring tapes (Carroll & Huntington, 1988), radiographs (Barneveld & van Weeren, 1999; Campbell, 1977 & 1981) and weighing scales (Pagan *et. al.*, 1996).

Constant assessment of growth is expensive and time consuming. Digital photographic measurements provide a simple means of growth assessment. Kavazis & Ott (2003) used this method when determining growth rates of Thoroughbreds in Florida. Data collected using this procedure was found to be similar to measurements taken by Thompson (1995) even though the foals were lighter at 6, 12 and 15 months of age. When comparing measurements taken from photographic material one should factor in the potential for discrepancies that may result from differences in angle of the photograph, movement of the horse, focal length and dimensional planes (Anderson & McIlwraith, 2004) Anderson & McIlwraith (2004) used annual photographs to plot the conformational measurements of Thoroughbred horses over a four year period. The horses were made to stand on a flat horizontal surface with the assistant holding a measuring stick. When taking the photograph a calibration device/measure should be placed in the same plain as the horse being measured in order to ensure accuracy in calibrating the computer program. The measurements were made from specific reference points on the horses in the lateral, caudal and cranial view photographs of each horse. This data was then analysed and revealed strong correlations ($P<0.001$) between the height of the withers and the long bone lengths at all ages. This study found that there is a 5 -7 % increase from weaning to 3 years of age in the third metacarpus, third metatarsus and front and back pastern and that most of the growth was completed prior to reaching yearling status. This coincides with findings by Hintz *et al*., (1979) and by Campbell (1981). In another study by Anderson *et al*., (2004) determining the role of conformation on the musculoskeletal problems in racing Thoroughbreds, the same technique was used to determine body length measurements, as with the work of Mawdsley *et al.* (1996). This tool can provide a useful means for retrieving growth and symmetry measurements for Thoroughbred foals.

2.5 CONCLUSIONS

There has been little to no change in the growth rates of the Thoroughbred horse over the last thirty years providing us with a base for comparison. Animals grow in stages with different segments of the body growing at different rates depending on the nutrition, breed, sex and duration of development of the animal (Anderson *et. al,*. 1984; Berg *et al.* 1978 ; Fortin *et al.,*1981). Besides breed and nutrition, there are numerous factors that can potentially affect the skeletal growth of the Thoroughbred foals. Factors such as stress resulting from weaning time and method, as well as training and exercise may potentially affect the growth and development of individual foals. In ideal conditions with optimal resources, a foal will have every opportunity to attain its potential and perform at its highest level. However, if the conditions are not optimal there is a possibility that the foal will not reach its potential and performance may be affected.

Some stress is manifest as developmental orthopaedic disorders (for example physitis and osteochondrosis) and loss of symmetry. The environment of effects can also manifest in asymmetries of bilateral traits. These effects on the skeletal development of the growing foal can potentially be reduced if the causes can be identified and corrected resulting in more symmetrical and potentially higher performing horses. Symmetry may be inherent but training and racing of the horses may also cause a loss of symmetry, which may influence racing performance. It has been shown that the more symmetrical racehorses compete for longer with higher earnings. Horses also appear to display motor laterality, which can be exploited in racing. If asymmetries can be induced, they can also be managed, with concomitant benefits in the management and performance of the young racehorses.

CHAPTER THREE

A COMPARISON OF PHOTOGRAPHIC AND TAPE MEASUREMENTS IN HOLSTEIN-FRIESIAN CALVES USING IMAGE ANALYSIS, AND THE EFFECTS WEANING TIME WILL HAVE ON GROWTH AND RELATIVE ASYMMETRY.

3.1 INTRODUCTION

Image analysis has been used to monitor and evaluate, *in situ*, the growth of Thoroughbred foals (Anderson & McIlwraith, 2004; Kavazis & Ott, 2003; Thompson, 1995) and has many merits. One should not stress the animal to obtain the required information as this stress can manifest itself in the skeletal development of the animal (Badyaev *et al.*, 2000; Yalçin & Siegel, 2002; Yang *et al.*, 1997). Young animals grow at rapid rates and the monitoring of this growth has significant economical benefits. Weekly body weight measurements in broilers in comparison to the breed management manual (Ross/Cob Manual, 2006) allows adjustments in the feed/environment to be determined. When using continuous assessment any changes in management or growth strategies can be implemented sooner.

Kavazis & Ott (2003) concurred with measurements taken by Thompson (1995) from photographic material even though the foals were lighter in body weight at 6, 12 and 15 months of age. The question of whether a linear image analysis measurement reflects growth of a three dimensional animal has been answered by Thompson (1995), who suggests that all comparisons of growth can be related whether one uses linear measurements obtained through image analysis or *in situ* measurements of the body, as long as a calibration device is used in determining the body/bone lengths.

The developmental process proceeds most efficiently under optimal conditions, from which deviations contribute to the instability of bilateral traits (Yalcin & Siegel, 2003). Consequently, changes in the environment can result to changes in symmetry of the body (Leary & Allendorf, 1989; Yalçin & Siegel, 2002; Yang *et al.*, 1997). Minimal levels of asymmetry are found (Møller *et al*., 1999) when developmental processes occur under optimal conditions (Yalçin & Siegel, 2003). Symmetry is the balance of arrangement of bilateral traits (in this case, bone growth of bilateral traits); asymmetry is lack thereof. That is why weekly/monthly evaluation of growth in animals is important.

In canines the occurrence and severity of orthopaedic diseases is the result of not only inheritance and environment but also of nutrition (Hedhammer, 1996). Too little as well as too much of a nutrient would affect the growth rate of canines, particularly the larger breeds. Horses reflect a similar response to nutritional deficiencies and surpluses (Jelan *et al.*, 1996; Kohnke, 1998; Pagan *et al.*, 1996).

Møller & Swaddle (1997) found that the differences between the two sides of a bilateral trait can be used for sensitive measures of developmental stability. Both sides of a bilateral trait are developed as a consequence of the same genome therefore random deviations from symmetry of these bilateral traits may reflect developmental instabilities under given environmental conditions (Palmer, 1996). Symmetry keeps the body in a state of stable equilibrium; asymmetry disrupts this equilibrium and requires energy to maintain a similar state of equilibrium which occurs at the cost of production resulting in a decreased efficiency. The relation between asymmetry and locomotion performance has been negative in Thoroughbred flat-racing horses (morphological asymmetry and handicap rating), racing dogs (running speed and asymmetry) and chickens (asymmetry and gate quality) (Møller & Swaddle, 1997). Dalin (1985) found that the performance (total earnings, races/ horse and race recordings - min/km) of Standardbred Trotters that were more asymmetrical (with respect to the hindquarters) was lower than the symmetrical horses measured. The more asymmetrical horses had difficulty performing at speed.

The aims of this study were to:

i. determine the relationship between the actual measurements and estimates based on the image analysis (HLMT©) of photographic material, thus ascertaining the suitability of this method for growth monitoring in large ungulates;
ii. determine which bones are most suitable for monitoring using image analysis;
iii. develop relationships which can be used to determine the bone length at a given age; and
iv. use image analysis to determine the RA and to evaluate if the bilateral skeletal growth is affected by the practice of early weaning which induces stress.

3.2 MATERIALS AND METHODS

3.2.1 MANAGEMENT

The trial was conducted at the calf-rearing facility of the Ukulinga Research Farm in Pietermaritzburg, KwaZulu-Natal for a period of twelve weeks. Ten Holstein/Friesian bull calves were weighed and randomly allocated to two weaning programs (Table 9). Milk-replacer (Surromel®) was allocated to each calf according to guidelines specified in the Dairying in KwaZulu-Natal Handbook (Dugmore, 1995; Table 9). Calves that were weaned early (at 6 weeks of age) were fed milk replacer at 6% of initial (birth) body weight; the calves that were weaned late (the more conventional 8 weeks) were fed milk replacer at 8% of initial (birth) body weight. All calves had *ad libitum* access to water, hay (*Themeda Triandra*), and concentrate (commercial calf rearing ration) from the second week of the trial. These feeds were analysed to determine the gross energy, NDF, ADF, crude protein, fat, calcium and phosphorous at the University of KwaZulu Natal feed analysis laboratory (Table 17). Crude Protein, Calcium, Phosphorous Fat, Crude Fibre and ADF analysis were determined by the AOAC Official Method (990.03; 968.08; 965.17; 920.39; 978.10; 973.18 respectively).The NDF value was determined according to the method described by Van Soest *et al.*, (1991).

Table 9: Amounts of milk replacer allocated to each Holstein/Friesian calf group according to initial body weight (Dugmore, 1995)

Group	Calf	Initial Body Weight (kg)	Milk/day (Litres)	Weaning age (weeks)
Early Weaned	1	39.5	2.4	6
	2	44.8	2.7	
	3	47.0	2.8	
	4	34.6	2.1	
	5	44.6	2.7	
	Mean	**42.1**	**2.5**	
Late Weaned	6	37.2	3.0	8
	7	44.6	3.6	
	8	54.8	4.4	
	9	35.6	2.8	
	10	38.1	3.0	
	Mean	**42.1**	**3.4**	

At twelve weeks, calves were moved from individual calf pens and were fed 1kg of calf starter meal twice a day and kept out with other beef steers (in order to cultivate rumen microbes required for digestion). The calves were castrated at 14 days of age with elastic rings, de-wormed every 3 months with alternating de-wormers (Valbazen and Panacur) and dipped for ticks every two weeks using Deadline or Triat-X.

3.2.2 MEASUREMENTS

Calves were measured weekly (7 to 42 days of age) and biweekly (56 to 84 days of age) with a standard measuring tape and digitally photographed at the same time. Each measuring session comprised of taking three photographs for each calf (front view, left and right side views) with a calibration stick (with 5-cm gradations) placed in the same plane as the side of the calf closest to the digital camera.

Bone lengths (Figures 4 & 5 & Table 10) were considered as the distance between the centre points of two joints on either side of each bone (e.g. centre of the tarsocrural joint to the centre of the metatarsal-phalangeal (fetlock) joint). In the case of the whole leg, the measurement was from the olecranon (point of elbow) to the distal end of the first phalanx of the foreleg and from the point of hock to the distal end of the first phalanx of the hind leg. The length of the animal was measured from the point of shoulder (cranial division of the greater tuberosity of the humerus) to point of buttocks (tuber ischium) and the girth was measured as the circumference of the animal at the point of wither. In the photograph measurements, the girth was measured as a linear measurement.

Table 10: Measurements taken on the calf and off the photographs by image analysis, corresponding to letters on Figures 4 and 5.

Side	Letter	Actual measurement	Photographic measurement
General	**A**	Height at Wither	Height at Wither
	B	Height at Croup	Height at Croup
Cranial	**C**	Scapular	Scapular
	D	Radius	Radius
	E	Metacarpus	Metacarpus
	F	First Phalanx	First Phalanx
	G	Foreleg	Foreleg
Caudal	**H**	Tibia	Tibia
	I	Metatarsus	Metatarsus
	J	First Phalanx	First Phalanx
	K	Hind leg	Hind leg

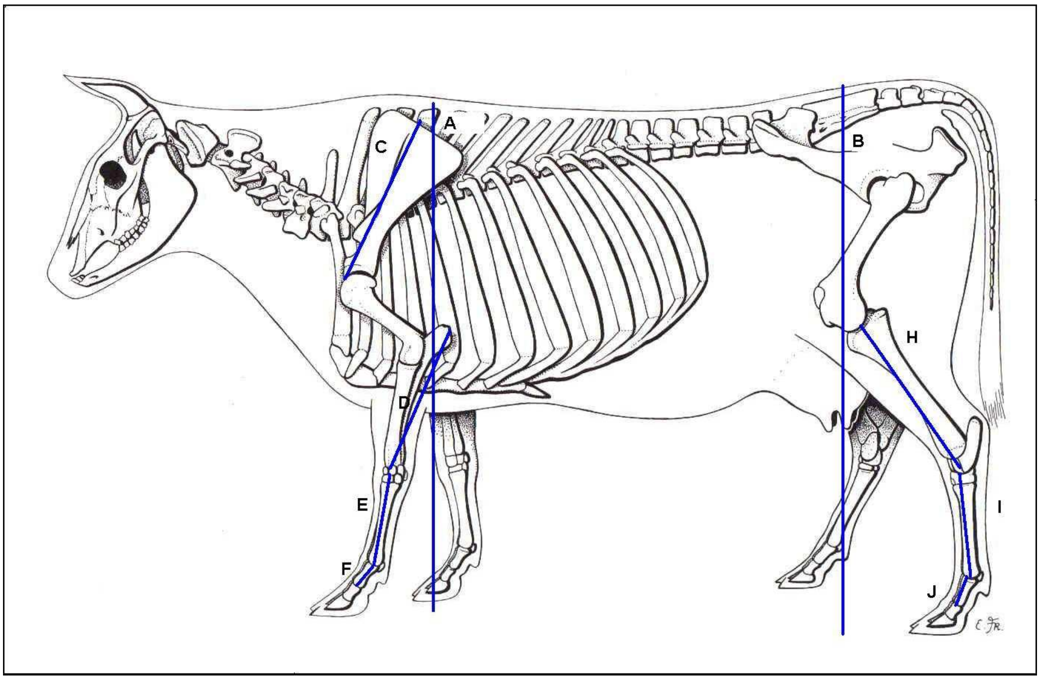

Figure 4: Letters corresponding to the bony landmarks on the bovine skeleton that were measured on the actual calf and from photographs of the calf.

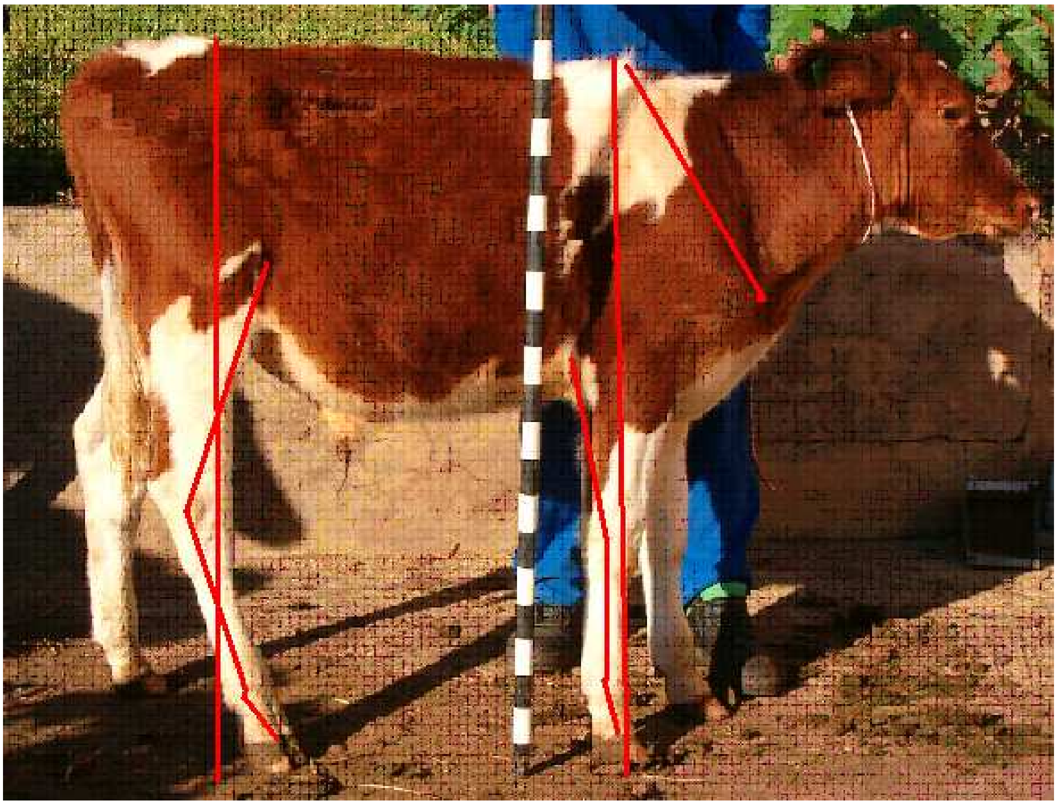

Figure 5: Measurements taken between bony landmarks on the live calf (Author's own).

3.2.3 DATA ANALYSIS

Linear measurements were derived from photographs using the HLMT © program. Regression equations (y=x) and deviations from a slope of 1 and intercept of 0 were determined using SAS 9.1 (2005) to compare actual measurements and the photographic estimates obtained using image analysis. Analysis of variance was used to determine interactions between age, side of body measurement and weaning programme on the linear measurements of the bones. To determine the effects the time of weaning had on the bone length growth, log transformation of the bone length values were done for the regression using weaning programmes as groups. Predictors for bone length over time were determined using regression (GENSTAT 9th edition, 2006) relationships of the log transformed actual bone lengths.

Analysis of variance was used to determine the relationship between weaning group and the symmetry of the animal, to determine the effects of the time of weaning on the symmetrical growth of the calves. Further analysis to determine the effects of weaning time on bone length growth was done by log transformation of the bone length values and regression using weaning programmes as groups. The relative asymmetry (RA) was calculated as the ratio of absolute value of asymmetry over average bilateral trait measurements (Equation 1):

Equation 1 : $RA = (|L - R)| / [(L + R)/2]) \times 100$ (Yang *et al*., 1997).

The closer the number is to zero, the closer the left and right measurements are to each other and therefore the closer the bilateral measurements are to perfect symmetry. The RA equation (using photographic measurements) was used to determine the degree of symmetry expressed by each bone measured for both weaning groups. This was used to deduce the effect of stress (due to weaning) on the skeletal symmetry of the calves.

3.3 RESULTS

3.3.1 FEED

The calves consumed similar amounts of feed during the first four weeks. Thereafter the late weaning calves ate significantly more feed than the early weaned group over the remainder of the trial (Figure 6). From 12 weeks of age all calves were fed the same amount of starter meal so as to eliminate the effect of feed quantity on the growth rate of the calves. The feed was analysed to determine the nutritional content of the feed (Table 11)

Table 11: The nutrient analysis of the hay and calf starter meal supplied *ad libitum* to Holstein/Friesian dairy calves to three months of age

	Protein %	Fat %	NDF %	ADF %	Crude Fibre %	GE MJ/kg
Themeda Triandra	3.73	1.6	64.89	45	34.16	16.24
Commercial calf starter meal	18.7	4.6	21.4	13.5	11.58	16.36

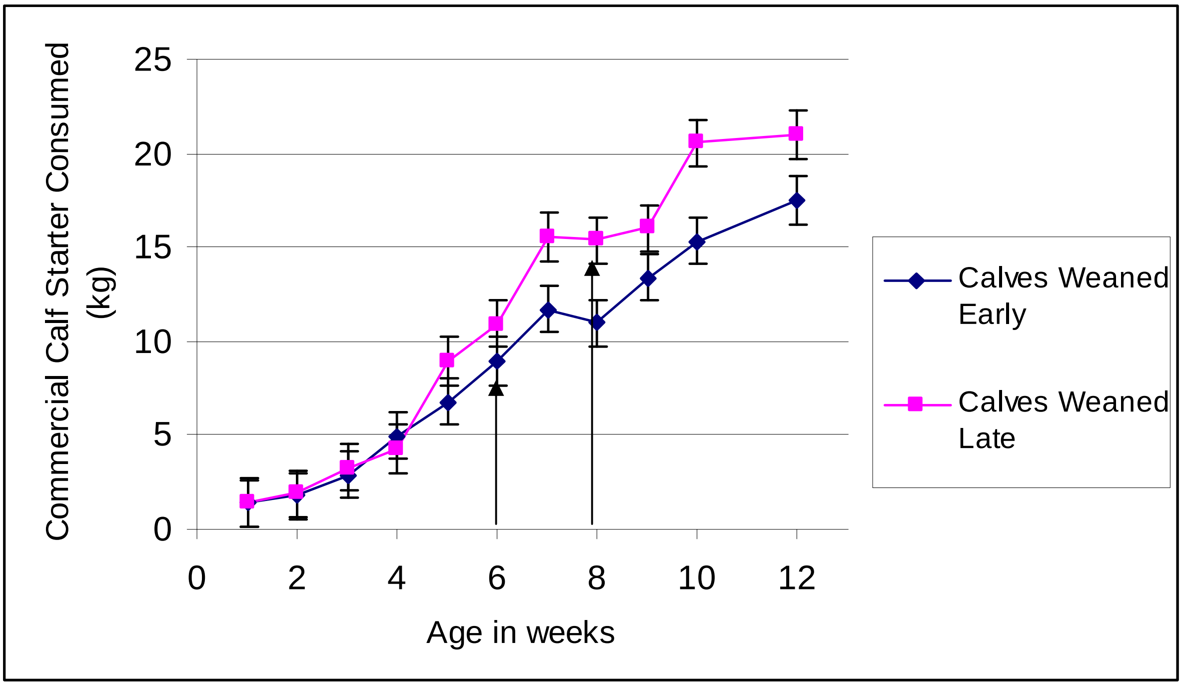

Figure 6: Average weekly feed intake of commercial calf starter meal by late (eight weeks) and early weaned (6 weeks) Holstein/Friesian calves for the first 12 weeks.

Late weaned calves attained higher ($P<0.01$) body weights at the age of weaning (Table 12) however these differences dissipated by 224 days of age and there was no significant difference in the final body weights of the two groups. The late weaned calves had an extra two weeks of milk replacement and were therefore older at weaning. The cumulative feed consumed by age of weaning was 133.63 kg by the early weaned calves and 310.45kg by the late weaned calves. The early weaned calves consumed a total of 613.13 kg of feed from weaning to the closure of the trial while the later weaned calves consumed 812.77 kg.

Table 12: The average body weight of the Holstein/Friesian calves on early and late weaning programmes from birth to weaning and from weaning to 224 days of age

	Body weight at weaning (kg) (± s.e.)	Body weight at 224 days (kg) (± s.e.)
Early weaning	43.94	140.33
	(4.09)	(5.281)
Late weaning	58.67	142.00
	(3.734)	(3.734)
Mean	**52.00**	**141.17**

3.3.2 RELATIONSHIP BETWEEN ACTUAL AND PHOTOGRAPHIC MEASUREMENTS OF BONE LENGTHS

The actual measurements and the photographic estimates of the ten Holstein/Friesian calves over the three-month period are shown in Appendix 1 and 2. Table 13 shows the regression relationship between the actual and photographic estimates (y=x) using image analysis. Deviations from the slope of 1 and the intercept of 0 were evaluated. For four of the bones (scapula, first phalanx of the foreleg, the tibia and the hind leg) measurements, the intercepts and the slopes did not (P>0.05) differ from zero and one, respectively, indicating a close correlation between the actual measurements and the photographic estimates. Three bone measurements (metacarpus, metatarsus and foreleg) had intercepts that differed (P <0.001) from zero but the slopes did not differ (P>0.05) from one. For the first phalanx of the hind leg, the intercept was not different (P>0.05) from zero but the slope was different (P<0.001) from one. For the radius, the intercept and slope differed (P<0.001) from zero and one, respectively.

Table 13 Parameter estimates from regression analysis comparing the measurements taken of ten Holstein/Friesian calves and measurements derived through image analysis of photographs (y=x)

Bone Measurement	Intercept § (± s.e.)	Slope ♦ (± s.e.)	N	Adjusted R^2	Root MSE	P<
Scapula	0.10 (0.749)^{NS}	1.00(0.026)^{NS}	176	0.895	1.327	0.0001
Radius	4.52(0.777)**	0.86(0.030)**	176	0.822	1.388	0.0001
Metacarpus	1.82(0.483)**	0.93(0.027)^{NS}	176	0.875	0.941	0.0001
First Phalanx Foreleg	0.09(0.323)^{NS}	1.07(0.046)^{NS}	176	0.762	0.630	0.0001
Tibia	1.26(0.659)^{NS}	0.97(0.020)^{NS}	176	0.933	1.171	0.0001
Metatarsus	3.94(0.888)**	0.86(0.040)^{NS}	176	0.726	1.726	0.0001
First Phalanx Hind leg	-0.79(0.307)^{NS}	1.20(0.043)**	176	0.817	0.568	0.0001
Foreleg	5.03(1.134)**	0.94(0.022)^{NS}	176	0.911	2.065	0.0001
Hind leg	1.98(1.423)^{NS}	1.00(0.222)^{NS}	176	0.92	2.503	0.0001

^{NS} – (P> 0.05); ** – P<0.001

§ - H_o: intercept = 0; ♦ - H_o: slope = 1;

The lengths of the first phalanx (foreleg), metacarpus, metatarsus, tibia, total foreleg measurements, and total hind leg measurements were all affected (P<0.001) by the weaning programme. The variation in other linear measurements could not be related to the weaning programme. The left and right measurements of the bilateral traits were similar (Table 14). Only the metacarpus (P < 0.001) and radius (P < 0.05) were affected by the weaning programme. The effects of side of bone length measurement were not significant (Table 14). The different weaning groups had no significant effect on the lengths of the first phalanx of the hind leg, the radius and the scapular measurements of the foreleg (Table 14). The calves that were weaned early had longer bone lengths than late weaned calves.

Table 14: Analysis of variance for the linear measurements of the bone lengths of Holstein/Friesian calves weaned at different ages and grown to 224 days of age.

	s.e.d.	LSD	Weaning Group	Side	Age. Weaning Group
First Phalanx Foreleg	0.33	0.65	*	NS	NS
First Phalanx Hind Leg	0.267	0.53	NS	NS	NS
Foreleg	2.00	3.94	*	NS	NS
Hind Leg	1.76	3.47	**	NS	NS
Metacarpus	0.58	1.14	**	NS	**
Metatarsus	0.97	1.91	**	NS	NS
Radius	0.87	1.71	NS	NS	*
Scapular	0.90	1.77	NS	NS	NS
Tibia	0.94	1.86	*	NS	NS

Foreleg comprises of the Scapula, Radius, Metacarpus and First Phalanx of the foreleg

Hind leg comprising of the Tibia, Metatarsus and First Phalanx in the Hind Leg

Weaning Group - Early Weaned and Late Weaned

** - $P < 0.001$; * - $P < 0.05$; NS – Non Significant

Regression equations for predicting bone length as a function of age and weaning programme based on log transformed bone lengths are given in Table 15. These equations demonstrate the effects of weaning age on bone length growth, and gives parameters for bone length growth. Generally, the coefficient of determination (R^2) ranged from 70.1 to 89.6 %, with the exception of the first phalanx of both the fore and hind legs which had R^2 of 58.8 and 61.4 %, respectively. By including the age by weaning group interaction the model for predicting the bone length at various ages was improved (for the metacarpal and metatarsal bones and foreleg measurements). Age and weaning group were sufficient to predict the bone length for the remainder of the measurements, with the exception of the scapula for which age alone explained the growth of the scapula over time.

Table 15: Multiple linear regression relationship of the log transformed bone length measurements of ten Holstein/Friesian calves using weaning programmes as groups.

	R^2	Intercept	Age	Weaning group	Age. Weaning group	N	MSE
Body Weight	89.6	1.5450	0.003	0.035		269	0.0297
		(0.0075)	(0.0001)	(0.0081)			
Scapula	78.9	1.438	0.0006			269	0.0214
		(0.002)	(0.00001)				
Radius	83.3	1.392	0.0006	0.0001		269	0.0206
		(0.0029)	(0.00003)	(0.00004)			
Metacarpus	73.5	1.249	0.0005	-0.0326	0.000226	269	0.0285
		(0.004)	(0.00004)	(0.0054)	(0.00005)		
First Phalanx Foreleg	58.9	0.823	0.0006	0.00515		269	0.0323
		(0.0037)	(0.00003)	(0.0040)			
Tibia	70.1	1.527	0.00047	-0.00612		269	0.0201
		(0.0024)	(0.00002)	(0.00260)			
Metatarsus	72.5	1.333	0.00057	-0.02897	0.000116	269	0.028
		(0.0040)	(0.00004)	(0.0053)	(0.00005)		
First Phalanx Hind leg	61.4	0.829	0.00049	0.00398		269	0.027
		(0.00313)	(0.00002)	(0.0034)			
Foreleg	82.0	1.883	0.00059	-0.0096	0.00006	269	0.0205
		(0.0029)	0.00003)	(0.00388)	(0.00004)		
Hind leg	74.5	1.790	0.00053	-0.00974		269	0.022
		(0.00247)	(0.00002)	(0.00266)			

3.3.3 RELATIVE ASYMMETRY

Figures 7 to 15 graphically represent the relative asymmetry over the 224 days of growth. The smallest RA values were found in the measurements of the tibia. All the relative asymmetries were below 1.197 (RA for the metacarpal bone in the late weaned calves). By the end of the trial all the RA's were below 0.133. The late weaned calves attained lower RA values by the completion of the trial. Throughout the study, the symmetry of the bones fluctuated but the R^2 was never higher than 1.197.

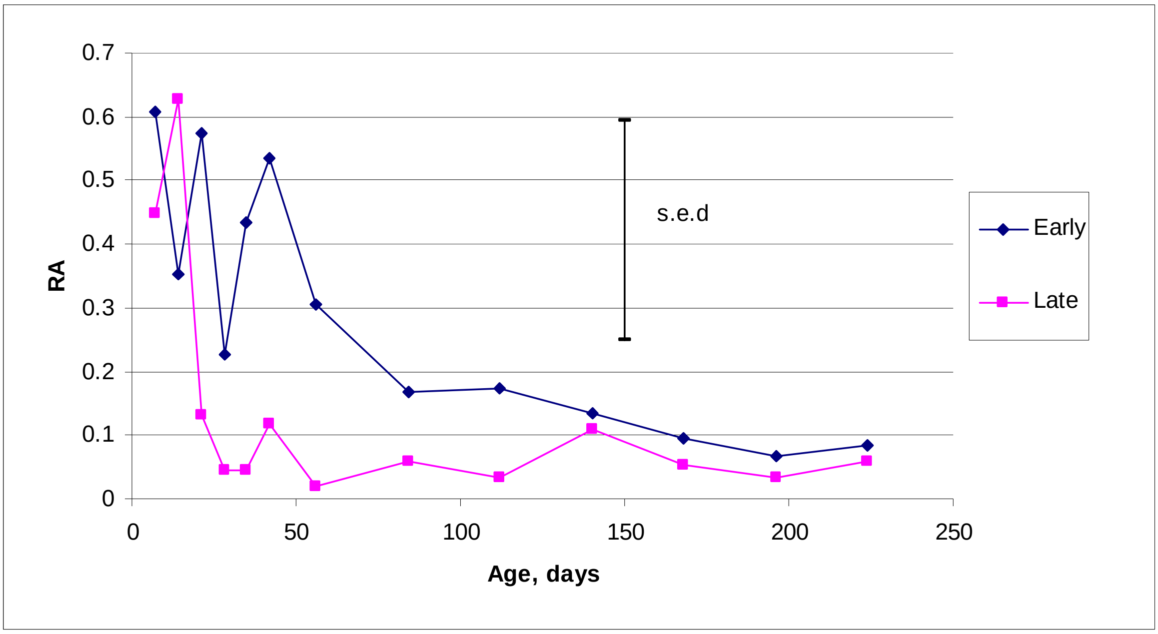

Figure 7: RA in scapular measurements in Holstein calves grouped by weaning time (early and late) from 7 to 225 days of age.

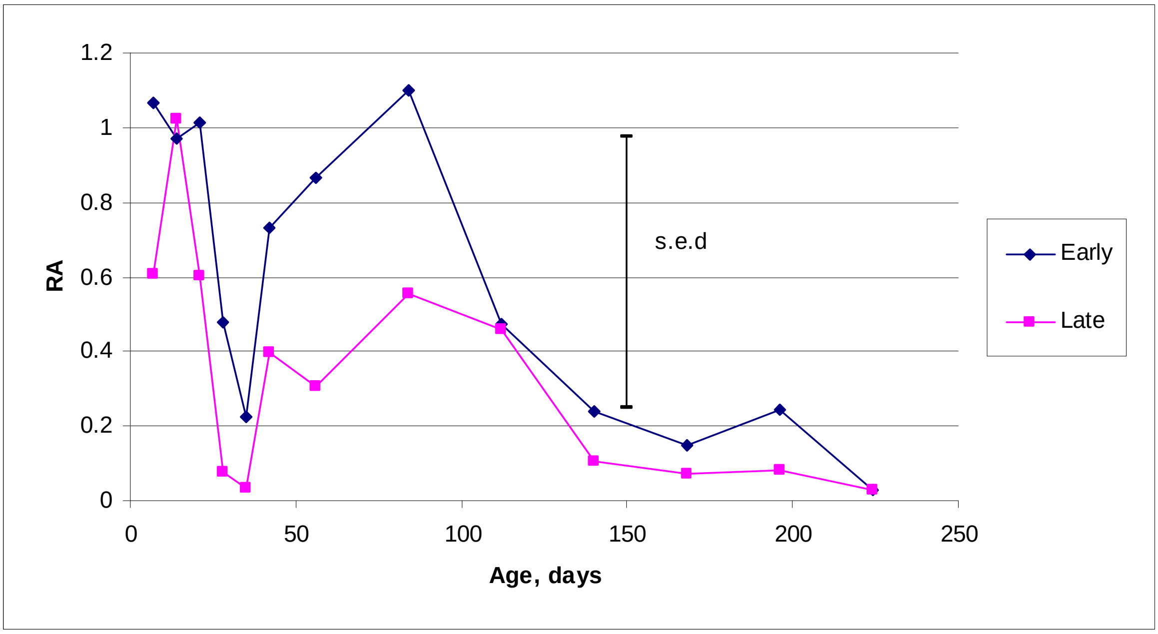

Figure 8: RA in radius measurements in Holstein calves grouped by weaning time (early and late) from 7 to 225 days of age.

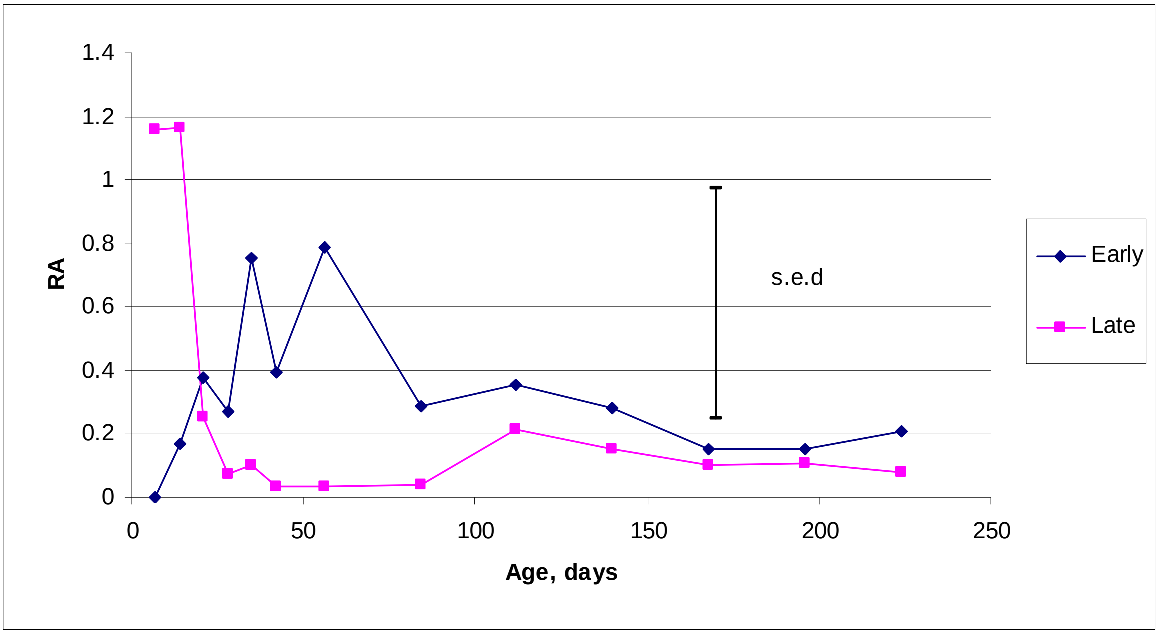

Figure 9: RA in metacarpal measurements in Holstein calves grouped by weaning time (early and late) from 7 to 225 days of age.

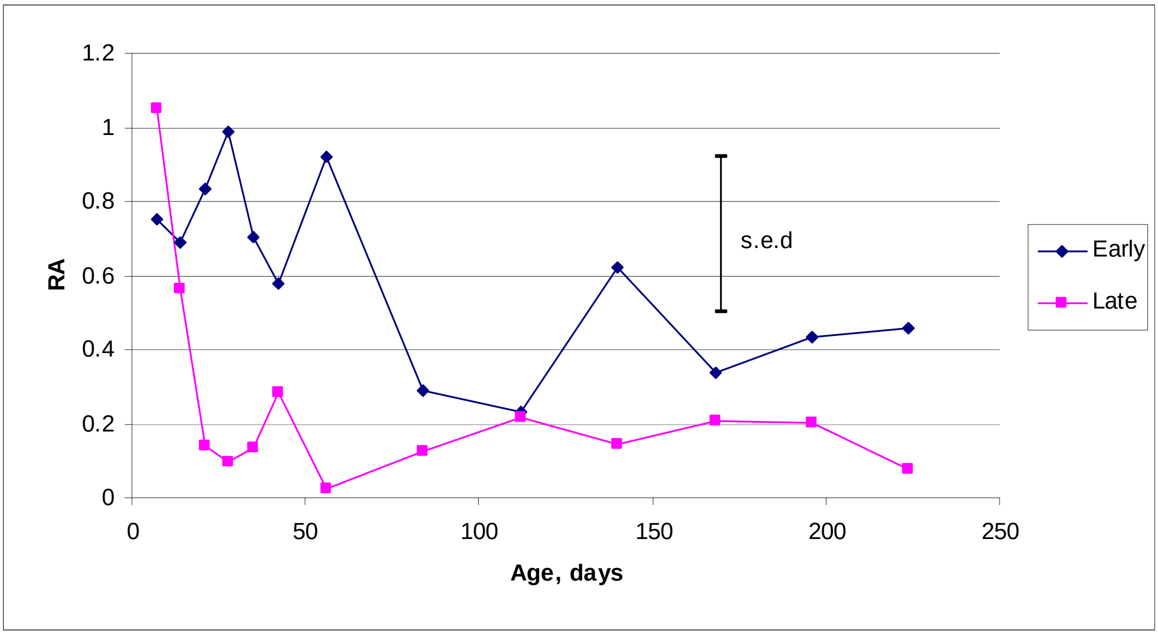

Figure 10: RA in first phalanx of the foreleg measurements in Holstein calves grouped by weaning time (early and late) from 7 to 225 days of age.

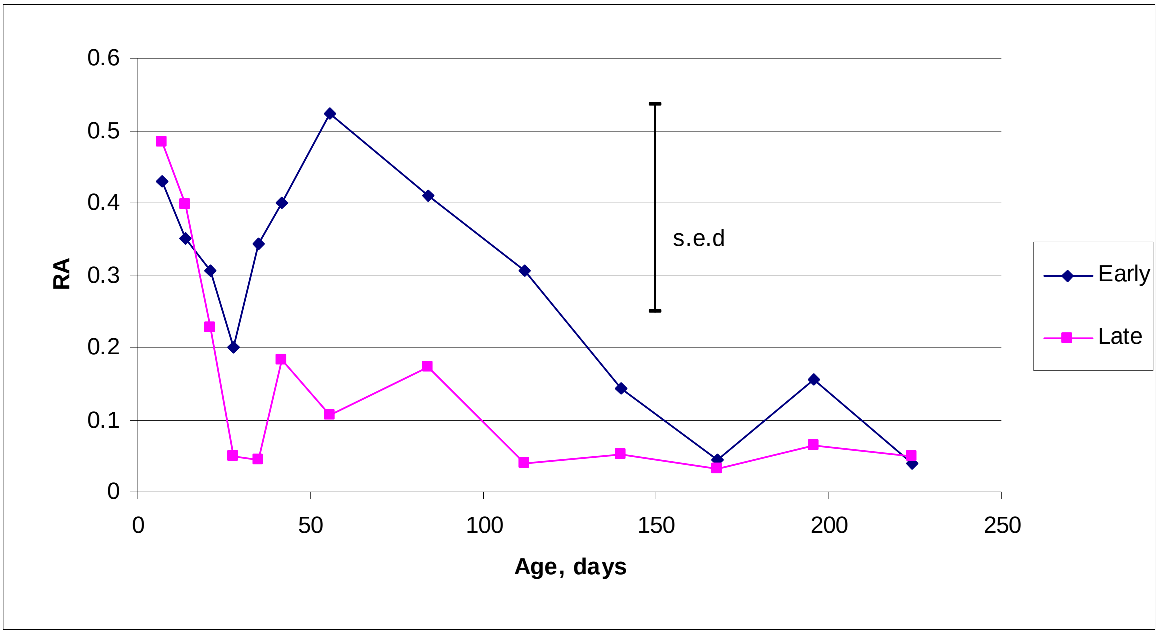

Figure 11: RA in foreleg measurements in Holstein calves grouped by weaning time (early and late) from 7 to 225 days of age.

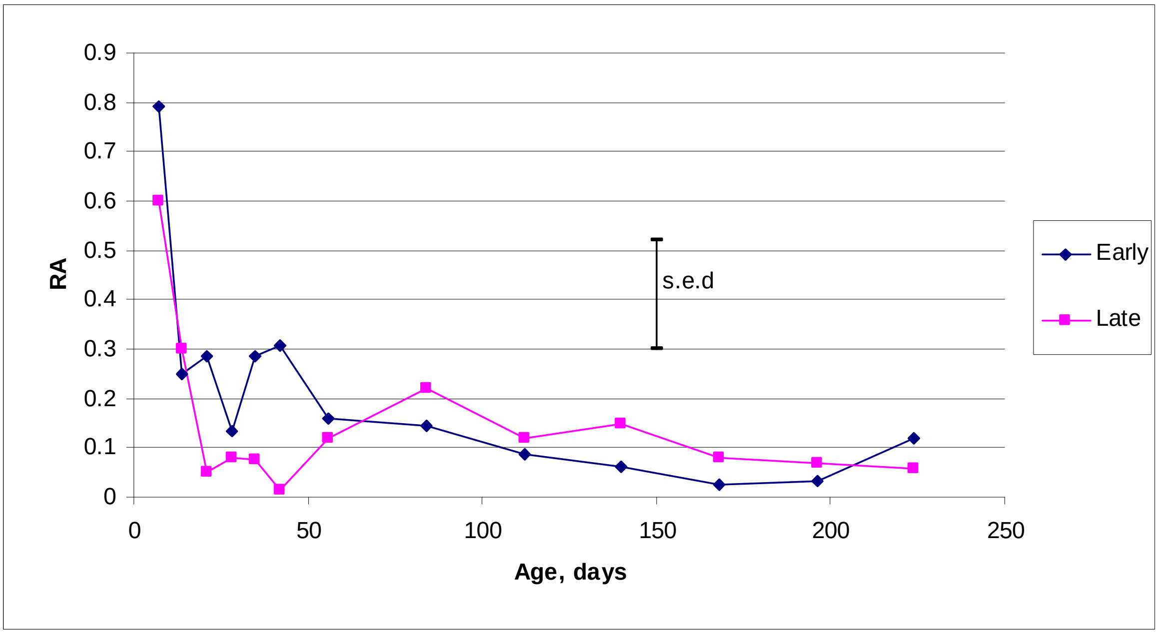

Figure 12: RA in tibia measurements in Holstein calves grouped by weaning time (early and late) from 7 to 225 days of age.

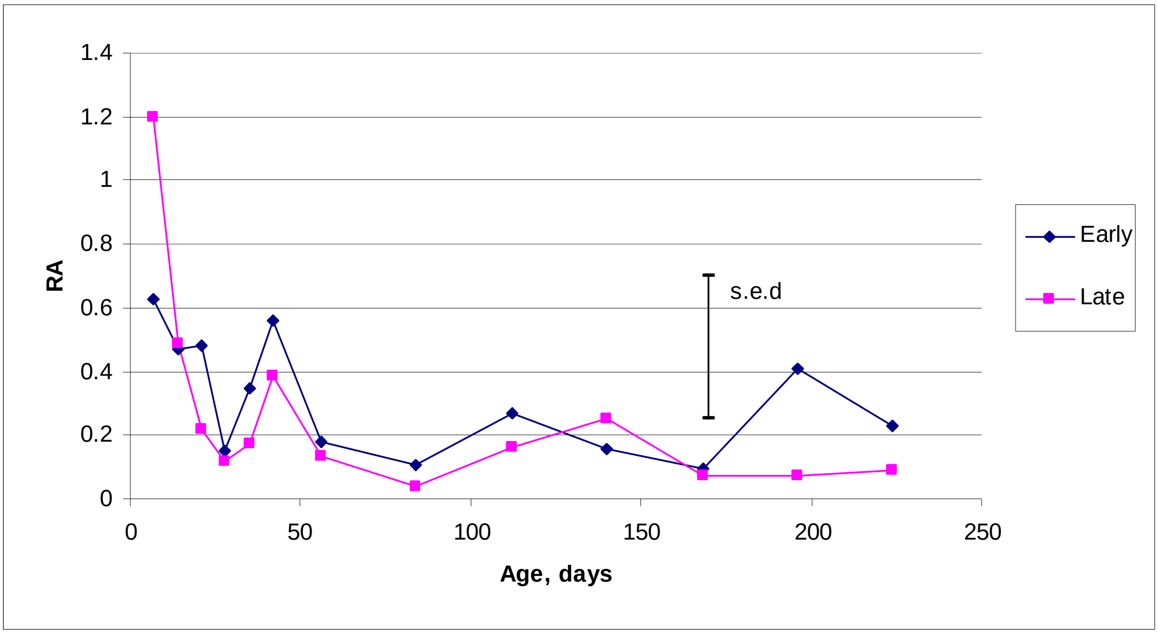

Figure 13: RA in metatarsal measurements in Holstein calves grouped by weaning time (early and late) from 7 to 225 days of age.

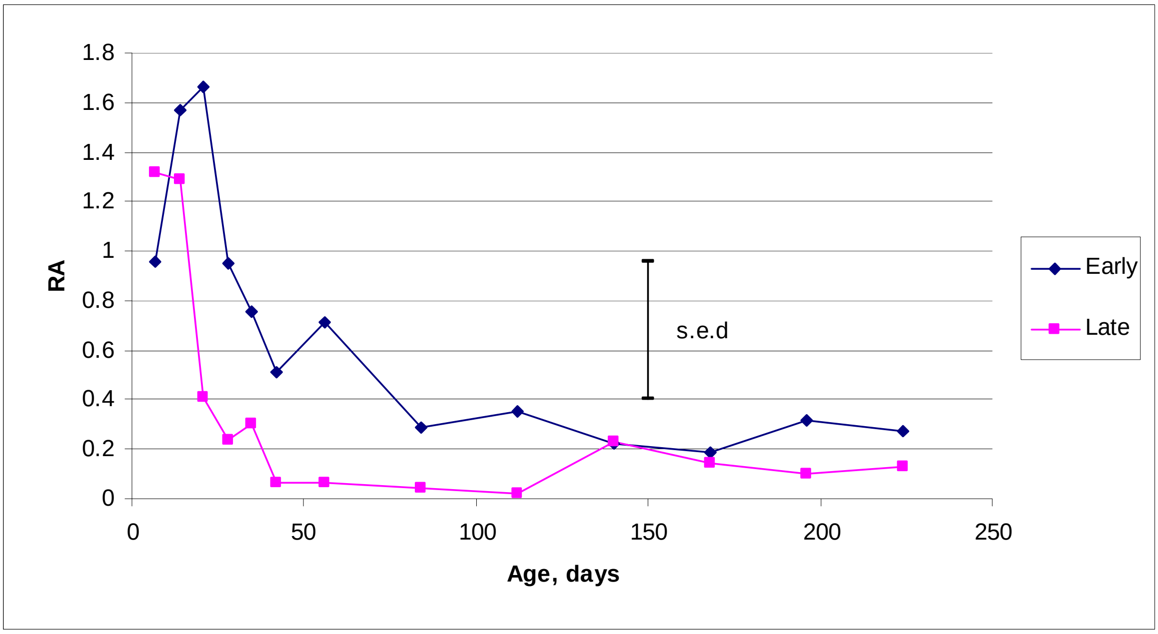

Figure 14: RA in first phalanx for the hind leg measurements in Holstein calves grouped by weaning time (early and late) from 7 to 225 days of age.

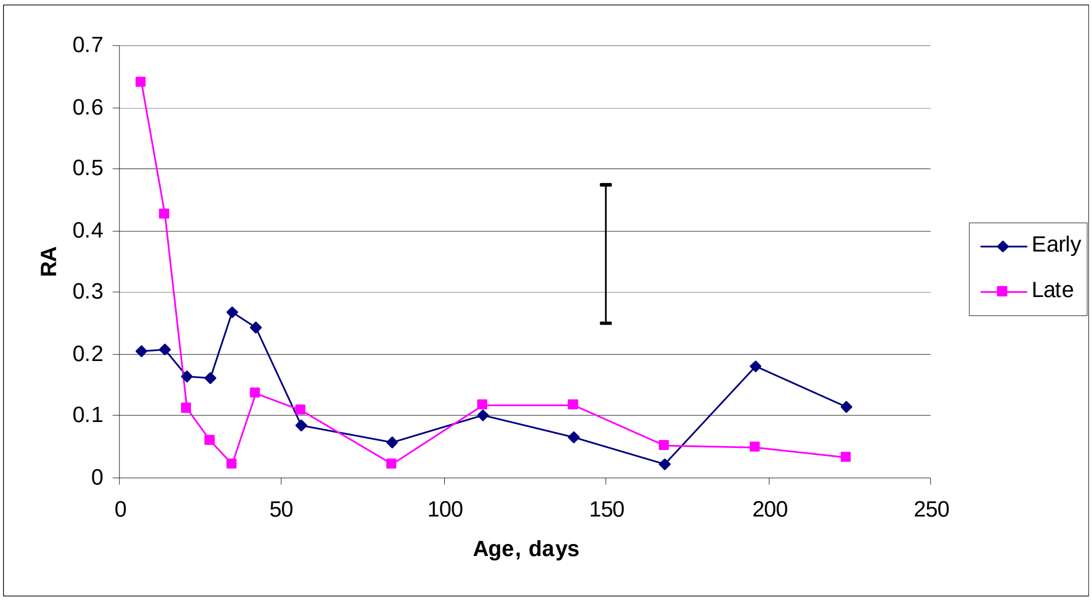

Figure 15: RA in hind leg measurements in Holstein calves grouped by weaning time (early and late) from 7 to 225 days of age.

The RA values were generally lower for the late than for the early weaned group of calves for all bones (Figure 7 to 15). The RA was similar between the weaning groups for the tibia, metacarpal, metatarsal and hind leg bone measurements. The weaning groups differed significantly ($P < 0.001$) for the measurements of the scapular, radius, first phalanx of the fore and hind legs and the hind leg bone measurements.

3.4 DISCUSSION

The first objective of this chapter was to determine the relationship between the actual measurements and those estimated from photographic material using image analysis (HLMT©), to determine the suitability of this method for growth monitoring in large ungulates. The analysis of the actual and photographic measurements determined that the use of the Image Analysis tool (HLMT©) gave statistically accurate measurements for bone lengths of the scapular, tibia, first phalanx of the foreleg and the hind leg measurements (Table 13). Since the intercepts and the slopes of the relationship between the actual and the photographic estimates did not ($P>0.05$) differ from zero and one, respectively, the photographic measurements can be used as true representations of the actual measurements. The fact that the intercepts differed from zero but the slope did not, for the metacarpal, metatarsal and foreleg measurements, indicated that the measurement, though not statistically the same, could be used as a good indicator of bone growth and length. However where the slope differed from one (first phalanx of the hind leg) suggests inadequacy of photographic measurements as estimates of the actual bone length. This study suggests that the photographic method is suitable for estimating the length of long bones only. This correlates with the work done by Thompson (1995), Kavazis & Ott (2003) and Anderson & McIlwraith (2004) as they were able to utilise photographic measurements successfully in order to determine bone lengths of various bones.

Another objective was to determine equations for predicting bone length over time. Regression analysis of the log transformed bone lengths grouped by age and weaning groups was performed and equations were established (Table 15). The variance accounted for by regressions of bone lengths and body weights against age was relatively high (between 89.6 to 70.1%) except for the first phalanx of both the fore and hind legs (58.8 and 61.4 %, respectively). The inclusion of age and weaning group interaction into the regression model for predicting the bone length at various ages for the metacarpal and metatarsal bones and foreleg measurements improved the model, thus concurring with others (McCall *et* al., 1987; Houpt *et* al., 1984; Hoffman *et al.,* 1995; Apter & Householder, 1996) that time of weaning does have an effect on the skeletal bone growth. Age and weaning group were sufficient for the prediction of the bone length for all measurements, with the exception of the scapular, where age was sufficient to determine the length of the scapular at various ages. The scapular length is therefore not affected by time of weaning.

RA was used to evaluate if the stress of early weaning in calves affects skeletal growth as happens in other animals. The closer the RA value is to 0 the closer the two bones are to symmetry. The significance of the parameters influencing the linear measurement of the bone lengths of the actual and photographic measurements (Table 14) showed no differences in the measurements of the sides (left and right sides) of the animals between the actual and photographic material. Log transformations of the photographic measurements for the two weaning groups discerned no difference in RA between the weaning groups for the tibia, metacarpal, metatarsal and hind leg bone measurements (Table 15). The weaning groups differed ($P < 0.001$) in the measurements of the scapular, radius, first phalanx of the fore and hind legs and the hind leg bone measurements. Due to the relative smallness of these bones the accuracy of the initial measurements may have been poor and with practice and length during growth, the accuracy of these measurements would have improved. Throughout the trial it was found that the tape measurements were generally higher than the measurements taken from the photographical material, but the disparity between them decreased over time (pg 30, Appendix 1 & 2). By the end of the trial, all the RA's were below 0.133, indicating that the animals were growing towards symmetry regardless of the initial weaning stress that was placed on them. This was the general trend across all bones. Møller & Swaddle (1997) and Palmer (1996) established that under stressful conditions bilateral skeletal traits are affected differently, resulting in deviations from prefect symmetry. Apter & Householder (1996) and McCall *et al.* (1987) found the weaning time was indeed a time of stress. The calves that were weaned later attained lower RA values by the conclusion of the trial. Early weaned calves were affected to a greater extent by weaning time stress than the late weaned calves. Calves weaned later benefited from the consumption of milk replacement for a longer period and had a higher body weights than those on the earlier weaning program.

Weaning time has a significant effect ($P<0.001$) on the total hind leg, metacarpal and metatarsal measurements (Table 14) and to a lesser degree on the foreleg and tibia length measurements ($P<0.05$). Calves on the earlier weaning program were found to be smaller, although body weight was restored by 224 days of age. Therefore weaning time does have an effect on the height, body weight and bone lengths of Holstein/Friesian calves, as the calves were able to reduce the difference between the two weaning groups by 224 days of age (Figures 6 to 13 and Appendix 1 & 2). It can be deduced that the effect of weaning time can be ameliorated during the remainder of the growing period.

As stress has been shown to affect the skeletal symmetry of an animal and the animal's ability to rectify this asymmetry during growth (Apter &Householder, 1996; McCall *et al.*, 1987), and it has been established in literature that weaning time is a stressful time in the animal's life (Houpt *et al.*, 1984; McCall *et al.*, 1987; Hoffman *et al.*, 1995; Apter &Householder, 1996; Kohnke, 1998), any lack of asymmetry may reflect that the animals are not under a great deal of stress. As the calves were able to reduce the deviation from symmetry, one could consider that the animal would need to experience the stress for longer or a stress induced closer to the end of growth would have a more lasting effect on the skeletal symmetry of the adult animal. Any lack of asymmetry may reflect that the animals are not under a great deal of stress as evidenced also by the rapid restoration of body weight by the conclusion of the trial in this instance.

The most suitable bones for monitoring the growth of large ungulates were found to be the scapular, first phalanx of the foreleg, the tibia and the hind leg. The photographic and actual measurements of the metacarpal, metatarsal and the foreleg were found to be increasing at the same rate, but did not start at the same lengths. These bones can thus be used as good indicators of the growth of the bones. Obtaining measurements photographically for the bones of the radius and the first phalanx of the hind leg would not be suggested as these bones do not give accurate correlations to live measurements.

3.5 CONCLUSIONS

The calves have provided a useful biological model to determine the implications of stressors (weaning time) on growth in large ungulates. The photographic method of acquiring measurements can be successfully used on animals to obtain bone lengths for the long bones. The weaning programme served to produce different rates of growth in the calves, with associated differences in bone length. The smaller bones posed a problem with their small length and rate of change and it is therefore advised not to consider this tool for smaller bone measurements which have only small increases in length.

Equations to predict the length of various bones were developed using regression models of log transformed bones lengths which can be utilised to predict the bone length at a given age.

CHAPTER FOUR
RELATIVE ASYMMETRY AND GROWTH OF THOROUGHBRED FOALS FROM BIRTH TO 300 DAYS OF AGE AND RELATIVE ASYMMETRY IN TWO-YEAR-OLD PRE-TRAINERS FROM TWO RACING YARDS IN KWAZULU-NATAL

4.1 INTRODUCTION

Plants and animals have copies of morphological structures, which are controlled genetically. Two sides of a bilateral trait can be expected to be identical and any deviations from symmetry can be used as an indicator of disturbed development due to stresses (Leary & Allendorf, 1989). Any reduction in the availability of energy for growth, maintenance, survival and reproduction results in a higher frequency of asymmetric phenotypes (Møller & Swaddle, 1997). Deviations from symmetry may reflect the inability of the individual to overcome stresses of genetic or environmental origin (Yalçin *et al*., 1997). Developmental instability measures can provide easy, potentially useful, non-invasive tools to identify stresses for a range of animal breeding and animal welfare problems (Møller *et al*., 1999).

Stress (both genetic and environmental) is a disturbing influence with physiological consequences (Rasmuson, 2002). Relative asymmetry provides information about the levels of stress (Møller *et al*., 1999). Fluctuating asymmetry (FA) is a sensitive measure of the ability of individuals with a particular genetic background to cope with developmental precision when confronted with adverse environmental conditions, like adverse temperatures, nutritional stress, chemical stress, population densities, and audiogenic (noise) stress. These have been implicated in causing FA in birds, lizards, laboratory rats and mice (Rasmuson, 2002), poultry (Yalçin, 2001; Yalçin & Siegel, 2003), snakes and trout (Møller & Swaddle, 1997) and may be used as an indicator of rearing conditions in domestic livestock (Møller *et al.*, 1999) and are a reliable measure of genetic stress in poultry and livestock (Yang *et al.*, 1997). Nutritional stress has been directly related to developmental stability as birds subjected to harsh food deprivation regimes develop increasingly asymmetrical wing feathers during moulting (Møller & Swaddle, 1997).

Symmetry keeps the body in a state of stable equilibrium; asymmetry disrupts this equilibrium and requires energy to maintain a similar state of equilibrium. Energy can be used at the cost of production resulting in a decrease in efficiency. Locomotion performance and asymmetry are negatively correlated and have been recorded in Thoroughbred flat-racing horses (morphological asymmetry and handicap rating), racing dogs (running speed and asymmetry) and chickens (asymmetry and gait quality) (Møller & Swaddle, 1997). The ability to race and the soundness of racing around turns may be affected by large differences between the left and right bones of the limbs of the racehorse (Watson *et al.*, 2003). Watson *et al*., (2003) suggested that there is selection against horses with large differences between the left and right third metacarpal bones. Horses with a longer right third metacarpal bone when racing clockwise were found to have an advantage over horses that had less of a difference in the lengths of their third metacarpal bones.

For a horse to compete at a respectable level it needs to be fit and the training to reach this fitness may have an effect on the horse's laterality if the training is not balanced (Dalin *et al.,* 1985; Drevemo *et al.,* 1987). Raub *et al.* (1989) found greater gain in the circumference at the mid-point of the metacarpus attributed to exercise regimes in horses (medium trot for 20 min 5days a week vs. no exercise). This increase in circumference is due to an adaptation in order to provide optimal support.

The ability to race and the soundness of a horse racing around the turns may be affected by differences between the left and right bones of the limbs of the racehorse (Watson *et al.,* 2003). Watson *et al*. (2003) suggests that there is selection in favour of horses with large differences between the third metacarpal bones (longer right third metacarpal bone) when racing clockwise because these horses had some advantage over horses with less difference.

An analysis of symmetry in Thoroughbred foals to one year of age would be insightful in determining the consequence of stress at weaning, and the degree of asymmetry at which the horses enter pre-training as a racehorse so that we can determine when the skeletal asymmetries are arising. The aims of this study are to:

i. contrast the foal growth to that which has been previously published and establish tools by which age can be used to predict the body weight and height;
ii. quantify the degree of symmetry in Thoroughbred foals and stage of deviation from symmetry;

iii. investigate bilateral skeletal limb measurements in young (birth to two years of age) racing Thoroughbreds, and
iv. determine the effect of sex on skeletal symmetry in young (birth to two years of age) racing Thoroughbreds.

Obviously the observation of race horses in training precludes the imposition of genetic, feeding or exercise treatments, and the measurements taken were intended to corroborate experimental observations from literature, as well as indicate whether any deviations from symmetry can be expected in the pre-training period, using horses that were made available for observation.

PART A: Relative asymmetry and growth of Thoroughbred foals from 7 to 300 days of age

4.2 MATERIALS AND METHODS

4.2.1 MANAGEMENT

Seventeen Thoroughbred foals (5 colts and 12 fillies) from Camargue Stud in the KwaZulu-Natal Midlands were photographed and weighed for a period of 300 days (between August 2004 and July 2005). The foals remained with their dams in a standard production system until weaning at approximately 8 months of age. Foals were weaned according to age with the older foals in the herd being weaned first. The mare and foal were stabled at night for the first two weeks of age and allowed out on pasture during the day. From two weeks of age the dams and foals were left out on pasture for the remainder of their stay on the farm. Dams and foals were only brought in when visited by the farrier (every four weeks) or the veterinarian. Foals were allowed access to creep feed (a commercial 12% Vuma concentrate) from 4 weeks of age and *ad libitum* access to grazing and hay. The foals were fed the Vuma concentrate until weaning, after which they received a 14% Vuma ration, at about 20% of their daily intake in two meals per day, in addition to the kikuyu grass and *Eragrostis curvula* hay which were available at all times. At weaning, the foals were fed a 14% Vuma diet with an allocation of 4kg of feed daily and were kept on the same feeding regime as the mares. The mares had *ad libitum* access to the kikuyu, as they were kept out. Mares were allocated 5 kg of feed/day (14% Vuma ration), in two meals. Stabled mares were fed 3kg of feed daily with *ad libitum* access to hay.

The feed, hay and grazing was analysed for gross energy, NDF, ADF, crude protein, fat, calcium and phosphorous at the University of KwaZulu Natal feed analysis laboratory. Crude Protein, Calcium, Phosphorous Fat, Crude Fibre and ADF analysis were determined by the AOAC Official Method (990.03; 968.08; 965.17; 920.39; 978.10; 973.18 respectively).The NDF value was determined according to the method described by van Soest *et al.*, (1991).

Weaning was done gradually where four to five mares were removed from the herd at a time until all mares were removed. Mares were thus removed during the following dates: 6 April, 10 June and 17 June. Of the foals that remained to weaning age, foals 1, 5, 6 and 8 were weaned first between 235 and 250 days of age on the 6 April 2005. The next foals to be weaned were foals 2, 4, 7, 9, and 10 on the 10 June 2005 (weaned between the ages of 284 and 300 days of age). Foals 12, 13, 14 and 16 were weaned on the 17 June 2005 (weaned between the ages of 219 and 281 days of age). Foals 3, 11, 15 and 17 left the property before time of weaning and measurement capture for these foals continued to time of departure. The average weaning age was 266 days (8.9 months old) according to the practice of the farm.

4.2.2 MEASUREMENTS AND ANALYSIS

This study lasted for 300 days, during which, starting at the birth of the foals, digital photographs were taken weekly for ten weeks, then bimonthly for a month and then monthly for approximately 202 days. Three photographs were taken at each session (left hand side, right hand side and cranial views) of each foal, with a calibration stick (with 5-cm gradations) placed in the same plane as the side of the foal closest to the digital camera. Linear measurements (Table 16 and Figure 16 &17) were derived from the photographs using the HLMT © program. As in the previous chapter the bone lengths were considered as the distance between the centres of two joints on either side of each bone (e.g. centre of the tarsocrural joint to the centre of the metatarsal-phalangeal (fetlock) joint)

Table 16: Linear measurements determined from digital photographs of Thoroughbred foals to one year of age.

General	Cranial	Caudal
Height at wither	Scapula	
Height at croup	Radius	Tibia
Girth	Metacarpus	Metatarsus
Length		

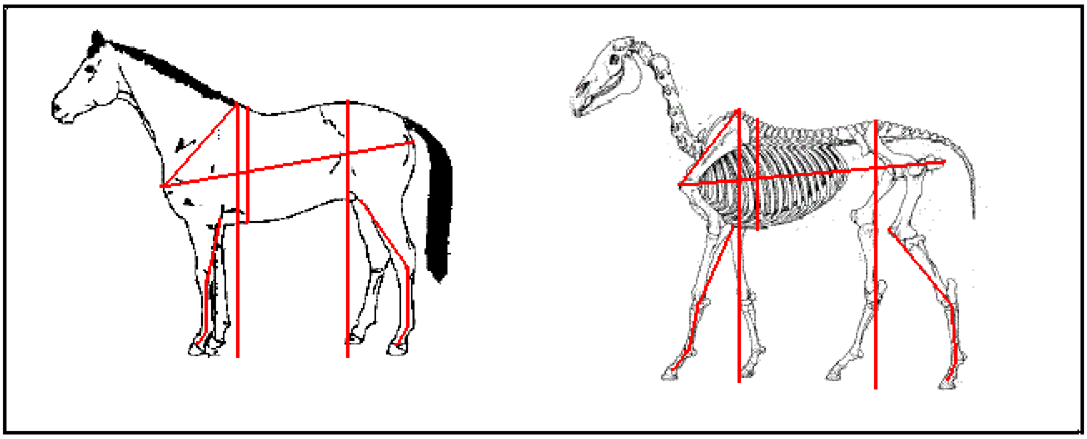

Figure 16: Diagrammatic representation of the measurements taken from each foal

Figure 17: Example of digital image with calibration stick used to obtain measurements *in situ* on Thoroughbred horses from birth to 300 days of age (Author's own)

There is scant regard of height at point of tuber sacrale in the literature (Thompson, 1995). The hind quarters are critical in determining the speed a racehorse can achieve (Manning & Ockenden, 1994) and therefore the study of the height of the tuber calcanei and the hindquarters will be included in the evaluation of symmetry in young racing animals, and the height at point of hip is included in this study

Bodyweight and linear measurements were analysed using GENSTAT 9th edition (2006). A covariate of initial body weight was included in the analysis with age, side and sex as explanatory variables and groups. Relative asymmetries were calculated (Equation 1) and square root transformed for analysis of variance to determine the site and age of onset of asymmetry in the growth of the foals, in respect of bilateral traits and of cranial/caudal symmetry as well. Height at withers, height at point of hip and live weight (as y-variants) were regressed against the age of the foals to establish quadratic relationships.

4.3 RESULTS

The composition of feeds, hay and grazing available to the horses and foals at Camargue Stud is reported in Table 17.

Table 17: DM analysis of hay, grass and concentrate feed offered to mares and foals, as creep feed, at Camargue Stud.

	Protein %	Ca %	P %	Fat %	NDF %	ADF %	C Fibre %	GE MJ/kg
Vuma 12 %	12.90	0.67	0.51	5.06	21.63	11.12	9.78	17.84
Vuma 14%	15.65	1.50	0.51	4.91	20.81	9.70	8.81	18.17
Eragrostis	7.75	0.27	0.14	1.45	82.27	47.15	39.00	20.29
Kikuyu	24.67	0.41	0.31	2.60	44.74	23.71	18.32	18.46

Ca – calcium, P – Phosphorous,

A correlation matrix was obtained with all the measurements and body weights to establish that body weight and length measurements were highly correlated. Height at wither, height at tuber sacrale, scapular length and foreleg measurements were found to have the highest correlation (94% to 96%).

The following quadratic regression equations describe the pattern of body weight change, height at point of wither and height at tuber sacrale for foals between 7 and 300 days of age.

Body weight (R^2 = 0.948):

$$y= (64.99\pm2.31) + (1.1177\pm0.0213)age + (-0.0008052\pm0.0000389)age^2$$

Height at point of wither (R^2 = 0.8762):

$$y = (101.360 \pm 1.773) + (0.362 \pm 0.0297)age – (0.000387 \pm 0.00010)age^2$$

Height at point of hip (R^2 = 0.8950):

$$y = (101.880 \pm 1.65) + (0.377 \pm 0.0277) age – (0.000422 \pm 0.00094)age^2$$

Fillies tended to have longer scapulae than the colts at any given age ($P<0.05$). Coefficients of variation of between 10.5% (body weight) and 3.1% (hind leg measurement) indicate low variation of the measurements about the mean (Table 18).

Table 18: Data from an analysis of variance, showing the effect of age and sex on linear body measurements of 17 foals from birth to 300 days of age at Camargue Stud, KZN.

	cv%	s.e.	l.s.d.	s.e.d	mean	Age	Sex	Age.Sex
Actual Body Weight	10.5	20.70	14.06	7.10	191.00	**	NS	NS
Height at Wither	6.3	8.74	5.69	3.09	139.04	**	NS	NS
Height tuber sacrale	5.8	8.12	5.69	2.87	140.65	**	NS	NS
Scapula	4.6	2.17	0.63	0.32	**Colt 46.31** **Filly 47.44**	**	******	*****
Foreleg	3.5	3.13	0.89	0.46	89.43	**	NS	NS
Hind Leg	3.1	3.13	0.89	0.46	99.64	**	NS	NS
Metacarpus	4.4	1.47	0.42	0.21	33.16	**	NS	NS
Metatarsus	3.9	1.46	0.42	0.21	37.79	**	NS	NS
Tibia	5.0	2.40	0.70	0.35	47.47	**	NS	NS

Regression equations for predicting bone lengths are given in Table 19. This was done to obtain the bone length at various ages. The variance coefficient of determination (R^2) ranged from 77.4% to 88%. By including the age by sex group interaction, the model for predicting the bone length at various ages was improved (for the scapular and metatarsal measurements). Age and sex was sufficient to predict the bone length for the remainder of the measurements.

Table 19: Regression relationship of the log transformed bone length measurements of 17 Thoroughbred foals from birth to 300 days of age in the KwaZulu-Natal Midlands

	R^2	Intercept	Age	Sex	Age. Sex	N	MSE
Body Weight	87.8	1.9244	0.00233			136	0.0781
		(0.0118)	(0.00007)				
Scapula	88.0	1.5406	0.00089	-0.0031	0.00010	136	0.0318
		(0.0084)	(0.00005)	(0.0010)	(0.00006)		
Metacarpus	77.4	1.4406	0.00058			136	0.0282
		(0.00423)	(0.00003)				
Tibia	81.9	1.5685	0.00077			136	0.0327
		(0.00489)	(0.00003)				
Metatarsus	80.9	1.4900	0.00059	0.01759	-0.00006	136	0.0242
		(0.00639)	(0.00004)	(0.0078)	(0.00005)		
Foreleg	86.9	2.02782	0.00074	0.00619		136	0.0261
		(0.00510)	(0.00002)	(0.0048)			
Hind leg	85.6	1.90364	0.000658	0.00536		136	0.0244
		(0.00477)	(0.00002)	(0.00445)			

The relative asymmetry for the actual bone measurements was calculated (Equation 1) and transformed (square root), the resulting RA's were all small with the average values below 1% (Table 20). From 180 days of age the RA values started to increase, this increase in RA coincided with and increase in handling (farrier and vet). The foals were weaned at approximately 266 days of age; the RA values exhibit a further increase at this time.

Table 20: Relative asymmetry and measures of dispersion of bilateral linear measurements of 17 Thoroughbred foals from birth to 300 days of age

Age	Foreleg	Hind Leg	Metacarpus	Metatarsus	Scapula	Tibia
7	0.654	0.701	0.708	0.753	0.594	0.852
30	0.497	0.371	0.63	0.454	0.384	0.417
60	0.451	0.225	0.448	0.289	0.241	0.276
90	0.265	0.247	0.216	0.336	0.228	0.241
120	0.302	0.252	0.304	0.267	0.293	0.317
150	0.289	0.265	0.364	0.299	0.276	0.376
180	0.318	0.291	0.492	0.43	0.381	0.35
210	0.252	0.259	0.353	0.435	0.274	0.381
240	0.399	0.374	0.469	0.466	0.331	0.484
270	0.449	0.327	0.612	0.54	0.339	0.428
300	0.417	0.361	0.486	0.43	0.406	0.294
Grand Mean	0.393	0.34	0.463	0.425	0.343	0.412
cv%	54.8	64	58.4	68.4	61.3	70.7
s.e.	0.2154	0.2178	0.2704	0.2928	0.2105	0.2914
LSD	0.1509	0.1525	0.1894	0.2051	0.1474	0.2041
s.e.d	0.0762	0.077	0.0956	0.1035	0.0744	0.103

PART B: Linear measurements and relative asymmetry in two year old Thoroughbred racehorses from two racing yards in KwaZulu-Natal

4.4 MATERIALS AND METHODS

4.4. 1 MANAGEMENT

Thirty-eight male and female pre-trainers Thoroughbred racehorses (average age 30 months) from two racing yards (9 male horses and 10 female horse in the Ashburton yard and 11 male horses and 8 female horses in the Summerveld yard), in the province of KwaZulu-Natal were photographed and measured. The horses trained on the straight and on a right bend. All horses were warmed up on the left rein in the warm up arenas.

Horses stabled in Summerveld (yard 1) were fed a 50:50 mix of Epol 16% Racehorse Cubes and Epol Rider Cubes while the horses stabled in Ashburton (yard 2) were fed milled Race Meal and Epol 14% Racehorse Cubes and 500g of crushed oats/ day. Concentrate feeds were offered at an average of 6.5kgs/day in the Ashburton yard and 6kgs/day in the Summerveld yard to the horses of the two yards.

4.4.2 MEASUREMENTS

All feeds offered were subjected to analysis at the University of KwaZulu-Natal. Samples of the feeds were analysed for Crude Protein, Calcium, Phosphorous, Fat, Crude Fibre and ADF (AOAC Official Methods 990.03; 968.08; 965.17; 920.39; 978.10; 973.18 respectively, 2007). NDF was determined according to the method described by Van Soest, Robertson & Lewis (1991). The National Research Council (NRC, 1989) researched the nutritional requirements for horses at various ages; Table 8, represents the nutritional requirements for two-year-old horse in training averaging 500kgs at mature weight. This information is necessary to establish that daily nutritional requirements in all the horses in this study were met.

Four photographs were taken of each horse (left hand side, right hand side, caudal and cranial views), with a calibration stick (with 5-cm gradations) placed in the same plane as the side of the horse closest to the digital camera. From these photographs various measurements (Table 16 in previous chapter) were taken using image analysis with the HLMT © program. As with chapters 3 and 4, the bone lengths were considered as the distance between the centres of two joints on either side of each bone (e.g. centre of the tarsocrural joint to the centre of the metatarsal-phalangeal (fetlock) joint).

Body weights for all the horses were determined using the equation developed by Carroll & Huntingdon (1989):

$$\text{Body Weight} = (\text{length x girth}^2)/11800$$

The linear measurements were analysed by means of Analysis of Variance (GENSTAT 9th edition, 2006) with yard and sex as treatment structures. The relative asymmetries were calculated (Equation 1) and transformed (square root) to determine the bones in which deviation from symmetry occurred.

4.5 RESULTS

The analysis of the feeds offered to the horse in the two yards is presented in Table 21. The calculation of the nutrient intake explains why the Ashburton horses were heavier ($p<0.001$), although body condition scores (Henneke *et al.*, 1985) of the horses were not significantly different.

Table 21: Nutrient analysis of four complete feeds and one feed supplement fed to Thoroughbred racehorses in training at each of two training yards in KwaZulu-Natal

Ingredient	Yard	Protein %	Ca %	P %	Fat %	NDF %	ADF %	CF %	Ash %	GE (MJ/kg)	DE(KCal/kg DM)
Milled Racehorse Cubes (16%) (EPOL)	1	19.21	1.14	0.07	3.84	26.37	10.30	9.26	8.87	16.11	2990.49
Rider Cubes (EPOL)	1	12.80	1.34	0.73	3.64	30.15	8.23	7.66	9.89	15.41	2910.40
Milled Race Meal (VUMA)	2	17.51	1.04	0.51	4.98	22.48	11.26	9.97	8.53	15.88	3139.73
Oats	2	9.93	0.06	0.29	6.88	31.67	13.57	11.19	2.31	17.61	3307.56
Milled Racehorse Cubes (14%) (EPOL)	2	15.80	0.96	0.59	3.63	24.63	9.91	7.42	7.92	15.91	3101.70

Yard 1 – Summerveld, Yard 2 –Ashburton

NDF – Neutral Detergent Fibre

ADF – Acid Detergent Fibre

CF – Crude Fibre

GE – Gross Energy

Ca – calcium

P – Phosphorous

DE = 2118 + 12.18 x Protein% + 9.37 x ADF - 3.83 x (NDF - ADF) + 47.18 x Fat% +20.35 (100 -Protein% - Fat% - NDF - ADF) - 26.3 x Ash%

There was no difference between the body weight of fillies and males (colts/geldings); however fillies were heavier than the males in the Summerveld yard, but lighter than the males in the Ashburton yard. Horses had similar wither heights (P>0.05), but fillies had shorter height of the hip than the males (P<0.05) (Table 22)

Table 22: The body weight, height and both hip and wither for the two year old fillies and male horses in training at the two yards in KwaZulu-Natal

	Males	Fillies	s.e.d	l.s.d	Cv%	Yard	Sex	Yard. Sex
Calculated Body Weight†			13.60	27.64	6.56	**	NS	*
Summerveld	389.50	407.00						
Ashburton	461.90	445.30						
Mean	**425.70**	**426.20**						
Height at Wither			4.79	9.74	6.30	NS	NS	NS
Summerveld	160.08	158.30						
Ashburton	158.62	147.62						
Mean	**159.35**	**152.96**						
Height at Tuber Sacrale			5.41	10.99	7.09	NS	*	NS
Summerveld	160.30	157.30						
Ashburton	162.00	145.80						
Mean	**161.15**	**151.55**						

Where: CV% = coefficient of variation, s.e.d = standard error of difference, l.s.d. = least significant difference, NS – Not Significant ** P < 0.01, * P < 0.05

† - Carroll & Huntingdon (1989)

Horses in both yards had similar RA's for all the bones of the foreleg. There was no effect of sex on the RA of the lengths of the foreleg (Table 23) bones.

Table 23: The relative asymmetry of the bone lengths of the foreleg of Thoroughbred two-year-old racehorses at Summerveld and Ashburton race training establishments

	Males	Fillies	**MEAN**	s.e.d	l.s.d	Cv%	Yard	Sex	Yard. Sex
Scapula				0.288	0.5843	76.46	NS	NS	NS
Summerveld	0.79	0.92	**0.86**						
Ashburton	0.67	0.71	**0.69**						
MEAN	**0.73**	**0.82**							
Metacarpus				0.868	1.765	72.40	NS	NS	NS
Summerveld	2.51	2.33	**2.42**						
Ashburton	2.52	2.51	**2.52**						
MEAN	**2.52**	**2.42**							
Foreleg				0.569	1.157	85.57	NS	NS	NS
Summerveld	1.48	1.58	**1.53**						
Ashburton	1.41	0.94	**1.18**						
MEAN	**1.45**	**1.26**							

Foreleg consists of the Radius, Metacarpus and First Phalanx of the foreleg

Where: CV% = coefficient of variation, s.e.d = standard error of difference, l.s.d. = least significant difference, NS – Not Significant ** $P < 0.01$, * $P < 0.05$

Irrespective of training direction, asymmetries were present in the two year old pre trainers. These asymmetries were larger ($P < 0.05$) in the tibia, tuber calcanei heights, metatarsus and the total hind leg measurements in the Summerveld than in the Ashburton yard (Table 24). Fillies were more asymmetrical with respect to the first phalanx and hind leg than the males. Whilst males differed very little between the two yards, the tibia length was more asymmetrical at Summerveld than at Ashburton.

Table 24: The relative asymmetry (square rooted) of the bone lengths of the Hind leg of 38 Thoroughbred two-year-old racehorses in the Summerveld and Ashburton.

	Males	Fillies	**MEAN**	s.e.d	l.s.d	Cv%	Yard	Sex	Yard. Sex
Tibia				0.615	1.249	87.24	*	NS	*
Summerveld	0.99	2.66	**1.83**						
Ashburton	1.16	0.86	**1.01**						
MEAN	**1.08**	**1.76**							
Tuber Calcanei Height				0.248	0.503	87.68	*	NS	NS
Summerveld	0.889	0.88	**0.88**						
Ashburton	0.246	0.32	**0.28**						
MEAN	**0.57**	**0.60**							
Metatarsus				0.649	0.132	66.28	*	NS	NS
Summerveld	2.53	2.70	**2.62**						
Ashburton	1.17	1.75	**1.46**						
MEAN	**1.85**	**2.23**							
Hind leg				0.413	0.840	66.71	*	*	NS
Summerveld	1.14	2.17	**1.66**						
Ashburton	0.82	0.93	**0.88**						
MEAN	**0.98**	**1.55**							

Hind leg consists of the Tibia, Metatarsus and First Phalanx in the Hind Leg

Where: CV% = coefficient of variation, s.e.d = standard error of difference, l.s.d. = least significant difference, NS – Not Significant ** P < 0.01, * P < 0.05

4.6 DISCUSSION

4.6.1 Part A

When a correlation matrix was constructed using all the bone measurements it was determined that the age and height of wither are both highly correlated with body weight (96.9% and 95.3% respectively). The age of the foal at a particular height and weight can be a useful tool to determine its growth and development compared to the growth of other foals of the same age and breed. The equations on page 56 can be utilised for this propose. Predictions of growth curves of the Thoroughbreds in this study in comparison to the growth of foals in the literature (equations pg. 56), suggested that foals in KwaZulu-Natal grow significantly taller at the point of wither (Figure 17) than the foals reported in literature (Hintz *et al.*, l979; Raub, 1989; Thompson, 1995; Stanier *et al*., 2001; Kavazis & Ott, 2003). The foals were however not significantly different in body weight over 300 days (Figure 18) from those reported over the last twenty-eight years (Kavazis &. Ott 2003; Hintz *et al.*, l979; Raub, 1989; Stanier *et al*., 2001; Thompson, 1995) and it can thus be inferred that there is a difference in the body condition scores of the foals, *inter alia*. Body condition score can be used as an indication of the adequacy of the nutritional programme (Henneke *et al.,* 1985). The body condition scores of the horses from the literature were not reported and thus could not be compared. Differences in height but not body weight of growing Thoroughbreds may also be as a result of nutrition (foals growing faster due to higher planes of nutrition) or genetic make-up.

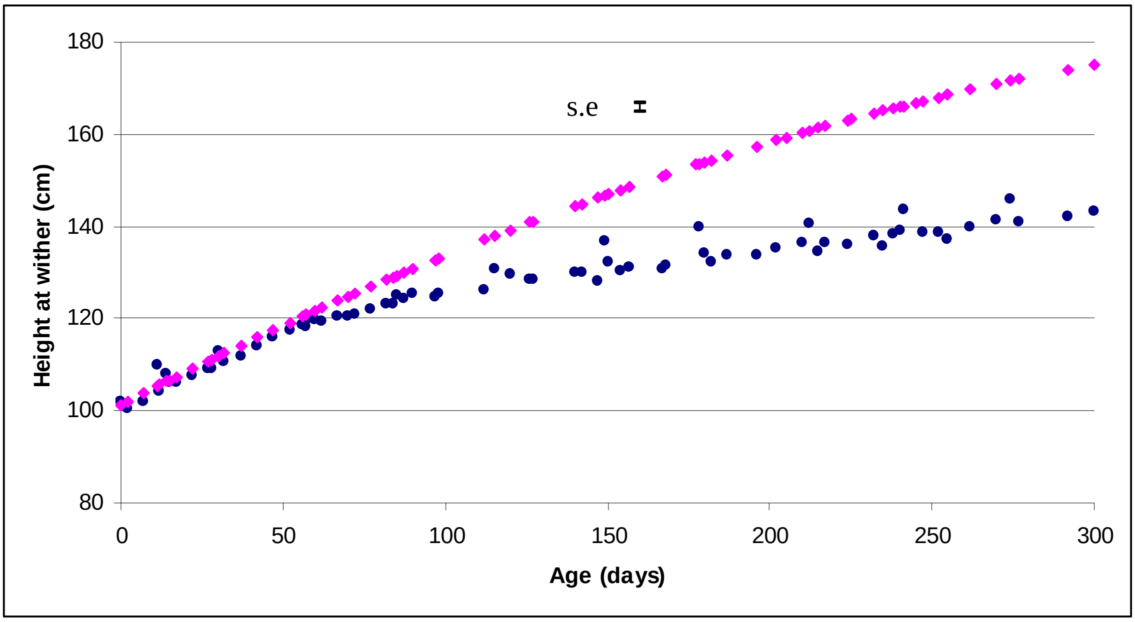

Figure 17: Increase in wither height over time predicted actual data [♦] and that from Literature [•] (after Hintz *et al*., l979; Raub, 1989; Thompson, 1995; Stanier *et al*., 2001; Kavazis & Ott, 2003).

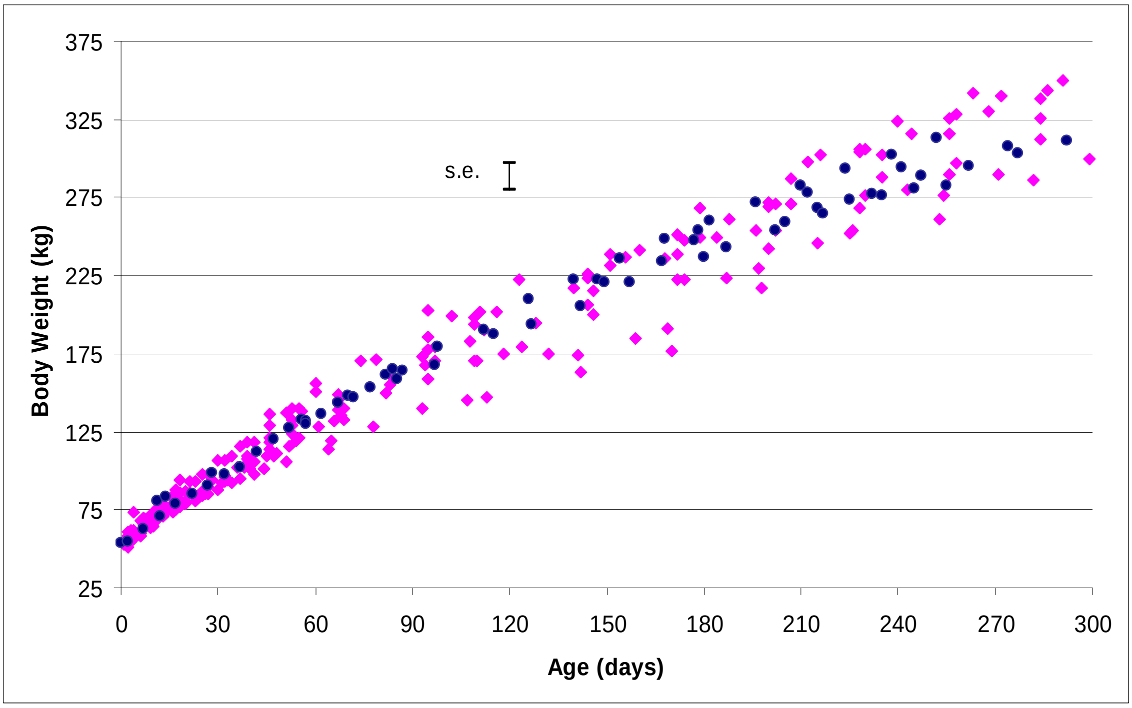

Figure 18: Increase in body weight over time predicted actual data [♦] and that from Literature [•] (after Hintz *et al*., l979; Raub, 1989; Thompson, 1995; Stanier *et al*., 2001; Kavazis & Ott, 2003).

There was no difference between the near and off sides of the bilateral traits measured in the growing Thoroughbreds from 0 to 300 days of age. Consequently the RA for all the bones were below 1% (Table 20), which is relatively low compared to the RA reported by Møller & Swaddle (1997) and Watson *et al.* (2003). Stress can have an effect on the bone growth of animals (Møller e*t al.,* 1999) and weaning time has been established as a stressful time (Houpt *et al.,* 1984; Hoffman *et al*., 1995). However the stress incurred at weaning time in a standard production breeding system may not induce sufficient stress to effect the symmetry of bone growth. It was noted that the amount of RA expressed by the growing Thoroughbreds from birth to 300 days (though not significantly different) was initially relatively high and decreased until 150 days when the RA slowly started to increase again. This increase in asymmetry corresponded to an increase in management of the foals, when farrier and veterinarian visits commenced. The foals were weaned at approximately 266 days of age and this did not express itself as a dramatic increase in the RA expressed by the animals, possible because weaning was late.

4.6.2 Part B

The RA measurements for the two yards revealed that the length of bone on the forelegs was similar. However, in the hind leg, the RA of all bones measured differed for the two yards; the hind leg bones of the Summerveld horses being more asymmetrical than the Ashburton horses. Asymmetries present in the hind leg were found to be yard related (Table 25). It is clear that the hind leg, which determines racing performance (Clayton, 2004), is responding to some stress. The literature would suggest that departures from symmetry do impact racing performance (times over short/long distances and the relationship between "breaking down" (loss of performance) and asymmetry, (Manning & Ockenden, 1994). This study could pilot further studies in the two year old pre-training category of racehorse to elucidate training methods, nutrition, genetics and training intensity and performance measures in Thoroughbred racehorses in KwaZulu-Natal

Sex of the horse in young racing Thoroughbreds did not in fact have an effect on the body weight of the sexes from birth to two years of age (Tables 19 & 23). There was however a difference ($P < 0.001$) in the body weights attained by each sex within each yard. The males in the Ashburton ward weighed on average 16.6 kg more and the fillies in the

Summerveld yard were found to be 17.5 kg more than their male counterparts (Table 23). As there were no significant differences in the heights of wither and tuber sacrale of either yard, it is possible that these weight differences are nutrition and/or training related. The height at point of hip was affected by the sex of the horse as the males were found to be taller. Sex was also found to have a significant ($P < 0.001$) effect on the lengths of the scapular, metatarsal, foreleg and hind leg measurements of the foals from birth to 300 days of age and the height of hip and hind leg measurements of the two year old racing Thoroughbreds.

Of the measurements taken in Part A the scapular was the only measurement that was indeed affected by sex as the fillies developed longer scapular lengths (1.13 cm). In Part B, sex had no effect on the RA of the bones measured in the foreleg or the hind leg (Table 24 & 25) of the horse. The RA of the hind leg in horses at the Summerveld yards was larger, and across yards, the fillies were found be more asymmetrical.

The equations that were developed using the regression model (Table 19) can be used as a management tool to predict the growth of the young growing Thoroughbreds. Derived in the South African context, they provide a valuable resource for the conscientious Thoroughbred breeder seeking to optimise foal growth and subsequent racing performance and value. Because of management systems in South Africa, this method is shown to be sufficiently accurate to obviate the need for markers on the foals. Markers on the bony landmarks could be used to improve accuracy, but obviously the digital method is being assessed for exactly the purpose of monitoring growth in unhandled, flighty young stock. Tools of this nature, derived across breeding establishments could be used to tailor management practices according to early warning signs that can be determined. Early adjustments are far more effective than correcting chronic deviations which can potentially impact the racing career of young Thoroughbreds. With the photographs (Image Analysis) and the extrapolation of growth results, as well as the increased intimacy with the growth process in the Thoroughbred, developmental orthopaedic disease and other pathologies associated with the growth process can be monitored and identified timeously.

4.7 CONCLUSION

The foals in this trial were found to reach a higher height at the point of wither sooner than that data from the literature. This increased growth in height did not result in a difference in body weight. Equations were established (page 56) which can be utilised in determining the bone growth of various bones at a given age from birth to 300 days of age.

Management to 300 days in Thoroughbred foals in a standard production system did not seem to elicit any deviation from symmetry and stability in growth. The investigation into the RA in the two year old Thoroughbred racehorses revealed that there were asymmetries developing in the hind legs and not in the forelimbs. As these horses derive most of their speed from the hind legs, this is a potentially worrying factor in terms of racing performance of young Thoroughbreds. Sex did have an effect on the body weights of the young racing animals however this difference was not consistent over both of the investigated yards and it can therefore be concluded that the differences in body weight may be a result of nutrition, training or management. The height of the hip was also found to be sex related as the male horses were found to be significantly taller than their female counterparts.

CHAPTER FIVE
GENERAL SUMMARY AND CONCLUSIONS

This thesis considers skeletal growth in the Thoroughbred foal, and making use of Holstein calves, explores the concepts of skeletal symmetry and the way in which we can measure it, incorporating the use of digital image analysis as a means of measuring growth in large ungulates. Calves were measured to determine if deviations from symmetry exist, and whether these might be induced by imposing a stress, and then Thoroughbred foals were assessed to determine both the growth and symmetry during the stress of weaning and training.

The work of Yalçin & Siegel, (2002) investigated stress as the cause of skeletal asymmetry in chickens. Further research in chickens, quails, shrews and racing dogs (Badyaev *et al.*, 2000, Møller & Swaddle, 1997) has shown that animals do indeed respond skeletally to a change in their environment, however not much work has been done on ungulates. Yalçin & Siegel's (2002) work raises two issues – one that skeletal symmetries exist, and two, that they can be induced by stress. This thesis aimed to explore these two facets with respect to ungulates.

The literature provided some evidence of the means employed to analyse growth. These include calculations (Carroll & Huntington, 1988), carcass samples (Barneveld & van Weeren, 1999), digital assessment (Anderson & McIlwraith, 2004; Thompson, 1995), measuring tapes (Carroll & Huntington, 1988), radiographs (Barneveld & van Weeren, 1999; Campbell, 1977 & 1981) and weighing scales (Pagan *et al.*, 1996). The use of these methods may be preclusive due to time, expense or relevance. It was decided to use image analysis (Thompson, 1995) to obtain a measurement of skeletal growth in large animals.

Image analysis as a management tool in large animals was used to develop relationships which can be utilised to determine the bone length at a given age and to evaluate the response in bilateral skeletal growth to weaning practice. The disparity between the actual measurements on the animal and those taken from an image decrease as the length of the bone increases. Photographs give a reasonable approximation of skeletal growth in long bones of large animals. The bones that were found to be suitable for measuring were the scapula, tibia, first phalanx of the foreleg and the total hind leg measurement (Table 13).

The metacarpal, metatarsal and total foreleg measurements give adequate indications of the bone lengths, although consistently smaller, and can be used to represent increases in bone length over time. Suggestions for improvement in the method would be to attach a marker to the bony landmarks prior to taking the photograph in order to improve accuracy when reviewing the images.

In order to predict length in a variety of bones at any given time, equations were developed using regression analysis of log transformed bone lengths (Table 15). These equations can be utilised as a tool to determine if calves are in fact growing at a normal growth rate on one of two weaning programmes (the conventional eight weeks of age or an early six weeks weaning).

Weaning time did have an effect on the symmetrical bone growth of the Holstein calves between birth and 224 days of age The calves that were weaned early grew at a slower rate and achieved less height at wither and croup than the later weaned calves. At 224 days of age, the body weights were all similar, but the weaning programme had affected the skeletal growth of the calves from birth to 224 days of age. Calves that were weaned earlier were proportionally more asymmetrical than the calves that were weaned later (Table 14). The asymmetry diminished as the animals continued to grow, suggesting that the age of the stress, and the duration of it were important in influencing lasting skeletal asymmetry as the animals were able to correct the asymmetries that were developed during the initial growth period.

Racing Thoroughbred foals raised to maturity can cost a small fortune depending on breeding and racing performance. Their productive goal is racing and then breeding performance, and billions of dollars and rands feature in the breeding, training and performance of these horses in their lifetime (Dalin, 1985; Manning & Ockenden, 1994; Møller & Swaddle, 1997). The growth rate and maximum body weight of Thoroughbred foals has not changed significantly over the last twenty eight years (Figure 17 & 18), but the expectation of their performance certainly has. If it is true that horses that train predominantly on a left rein are better suited to racing on a left bend (Manning & Ockenden, 1994; Watson *et. al.,* 2003), then performance can surely be enhanced by applying results from investigations of the degree to which motor laterality can be influenced by training and conditioning. Are there skeletal manifestations of training, is the stage of development of the horse important in training, or can developmental orthopaedic issues affect a horse's racing performance? How can the stud manager assess growth and at what stage might asymmetry be observed?

Equations were developed (pg 56), using the data from this trial, which could be used to determine the predicted height at point of wither and hip and the body weight of a growing foal from birth to 300 days of age. These predictions could be utilised to determine if the Thoroughbred foal is in fact growing at the correct rate so early adjustments could be implemented to correct any deviations for this growth rate.

Literature has proven that stress does in fact affect the symmetry of an animal and literature has also proven that weaning time is perceived as a stress in a young growing animal. The degree of asymmetry that was revealed by the growing foals over the time of weaning was all below 1 %, this is very low compared to the relative asymmetries reported by Møller & Swaddle (1997) and Watson *et al.* (2003). As a result it can be reasoned that the stress perceived by the foals was not sufficient to produce dramatic skeletal asymmetries. It was observed that there was an increase in the skeletal asymmetries at the time of an increase in management and handling of the foals. This did not bring the asymmetries beyond the 1% value. Foals do respond to stress with skeletal asymmetries, and these asymmetries can be corrected, when the age of closing of the growth plate and the duration of stress are considered.

Young racehorses starting their careers (18 to 24 months) displayed asymmetries in the hind leg (tibia length, metatarsus length, height tuber calcani and therefore hind leg length), but there were no significant differences found in the forelimb between the two race training yards in KwaZulu-Natal (Ashburton and Summerveld). It is the hind leg that produces the power when racing and asymmetry will decrease the performance level of the hindquarters and therefore racing ability (Dalin, 1985). Small differences in bone length between left and right limbs (in particular that of the metatarsus/metacarpus bones) are likely to have an effect on coordination and balance, whereas larger differences between the left and right bones may affect the ability to race around turns (Watson *et al*., 2003). The asymmetries in bone length and the angles between these bones will have determined the limb conformation and will affect the leverage during motion (Clayton, 2004).

Drevemo *et al,* (1987) found that there were pronounced deviations between left and right diagonals and steps at ages eight, 12 and 18 months of age, indicating asymmetries in locomotion pattern from an early age. The stride length may be influenced by early muscle development and skeletal structure of the horse (Drevemo *et al.,* 1987). Winning by a nose makes the optimisation of stride length imperative. Skeletal asymmetries can lead to a decrease in performance, with respect to total earnings and the number of races started (Dalin, 1985), with the more asymmetrical horses not performing as well as the more symmetrical horses, and ending their careers a lot earlier (Møller & Swaddle, 1997).

Sex did not affect the heights achieved by the foals in the first 300 days and therefore any differences between males and fillies are achieved after 300 days of age. Sex did not affect the symmetrical growth of the foals to 300 days of age, but did have an effect on the several bone lengths in the appendicular skeleton. Body weight was affected by the sex of the animal, but these differences were not constant over the yards and could be a result of nutrition, trainings or management. The height of hip was found to be sex related as the male horses were found to be significantly taller than the fillies in this study. Sex was found to have a significant ($P < 0.001$) effect on the lengths of the scapular, metatarsal, foreleg and hind leg measurements of the foals from birth to 300 days of age and the height of hip and hind leg measurements of the two year old racing Thoroughbreds.

So, breeders could make use of image analysis to monitor the growth profile of young race horses. Regression equations can provide weight for age data in a South African context, and skeletal symmetry can give some indication of the pressure perceived by the animal as it performs the tasks expected of it. Further work could concentrate on the implementation of image analysis as a management tool in the growth of the foals. Investigation is also warranted into the asymmetry of the two year old horses in training and whether the idiosyncratic motor laterality induced by the symmetry can be correlated with performance in their racing careers.

The South African racing industry contributes greatly to the Gross Domestic Product of SA, as well as creating activity in the employment, veterinary, export and recreational sectors. Equine enthusiasts, scientists, veterinarians, nutritionists and complementary health care science professionals all have a vested interest in the continued health and welfare of the Thoroughbred racehorse, both in the direct sense and in the resale market. A study that produces a novel technique using the Thoroughbred horse, and highlights concerns of stress in weaning and training with an appropriate quantitative assessment of this, adds value indeed to a very lucrative and performance-driven industry.

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Appendix 1: Foreleg measurements (cm) of Holstein/Friesian bull calves & measurements obtained from their photographs.

	Age								**s.e.d**	**Lsd**	**cv%**	**Side**	**Age**	**EW/ LW**	**P/T**	**EW/LW. P/T**	**EW/ LW. Age**	**P/ T. Age**
	7	**14**	**21**	**28**	**35**	**42**	**56**	**84**										
Scapula																		
P	25.9	27.4	27.9	28.6	29.2	30.3	31.5	32.3										
T	26.1	26.8	27.5	28.7	29.1	29.6	31.6	33.1										
Mean	26.0	27.1	27.7	28.7	29.2	29.9	31.5	32.7	0.55	1.08	3.3	NS	**	**	NS	**	**	*
Radius																		
P	23.8	24.4	24.8	25.4	26.2	27.2	28.2	29.0										
T	24.3	25.0	25.6	26.3	26.6	26.7	27.5	28.5										
Mean	24.1	24.7	25.2	25.9	26.4	26.9	27.8	28.8	0.50	0.98	3.3	NS	**	NS	NS	NS	NS	**
Metacarpus																		
P	15.2	16.6	17.3	17.9	18.5	19.2	20.0	20.7										
T	15.1	17.8	18.6	19.0	19.2	19.5	20.2	21.0										
Mean	15.1	17.2	17.9	18.5	18.9	19.4	20.1	20.8	0.38	0.74	3.5	NS	**	**	**	**	**	**
First Phalanx																		
P	5.9	6.4	6.7	7.1	7.3	7.5	7.7	7.8										
T	5.7	7.1	7.7	7.9	8.3	8.3	8.5	8.8										
Mean	5.8	6.8	7.2	7.5	7.8	7.9	8.1	8.3	0.22	0.43	5.1	NS	**	**	**	NS	NS	**
Total Foreleg																		
P	70.9	74.9	76.7	79.0	81.2	84.3	87.4	89.7										
T	71.1	76.7	79.4	82.0	83.2	84.0	87.8	91.4										
Mean	71.0	75.8	78.0	80.5	82.2	84.1	87.6	90.5	1.01	1.98	2.1	NS	**	**	*	**	**	**

Total Foreleg measures the radius, metacarpus and first phalanx together

EW/LW – Early Weaned / Late Weaned **P/T** – Photographic Material / Tape Measure Material

** $P < 0.01$

* $P < 0.05$

NS – Non Significant

Appendix 2: Hind leg measurements (cm) of Holstein/Friesian bull calves & measurements obtained from their photographs.

	Age								s.e.d	Lsd	cv%	Side	Age	EW/LW	P/T	EW/LW. P/T	EW/ LW. Age	P/ T. Age
	7	**14**	**21**	**28**	**35**	**42**	**56**	**84**										
Tibia																		
P	31.6	33.2	33.7	34.8	35.6	36.7	37.8	38.7										
T	31.9	32.4	33.3	34.6	35.7	36.0	37.2	38.9										
Mean	31.8	32.8	33.5	34.7	35.6	36.3	37.5	38.8	0.53	1.04	2.6	NS	**	*	NS	**	**	NS
Metatarsus																		
P	19.4	20.3	21.2	21.8	22.5	23.3	24.0	25.0										
T	19.1	22.0	22.8	23.4	23.9	24.2	24.7	25.7										
Mean	19.2	21.1	22.0	22.6	23.2	23.8	24.4	25.3	0.62	1.23	4.7	NS	**	NS	**	**	NS	**
First Phalanx																		
P	6.2	6.5	6.9	7.1	7.4	7.6	7.7	7.7										
T	6.1	7.0	7.4	7.8	8.2	8.3	8.7	9.0										
Mean	6.2	6.7	7.1	7.5	7.8	8.0	8.2	8.4	0.24	0.47	5.5	NS	**	**	**	NS	NS	**
Total Hind leg																		
P	57.1	60.0	61.7	63.6	65.4	67.5	69.4	71.3										
T	57.3	61.4	63.6	65.9	67.8	68.6	70.7	73.6										
Mean	57.2	60.7	62.6	64.8	66.6	68.1	70.1	72.4	1.04	2.05	2.8	NS	**	NS	**	**	**	NS

Total Hind leg measures the tibia, metatarsus and first phalanx together
EW/LW – Early Weaned / Late Weaned **P/T** – Photographic Material / Tape Measure Material
** $P < 0.01$
* $P < 0.05$
NS – Non Signifiant