Angular Limb Deformities in the Foal.

An Overview of Treatments and a Review of 10 cases.

A Thesis

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by

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Frontpiece: Case number 1 at initial presentation. Note surgical sites have been clipped.

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Cases 1 through 4, were seen by clinicians other than myself. I am grateful for the access to their case notes. The radiographs for these cases were also done by the radiography staff of the surgery department of Glasgow Veterinary School. The remaining cases were seen by myself often under the auspices of my supervisor Mr. Graham Munroe, to whom I am grateful. The best part of the radiographs of these cases were taken by myself with the aid of the radiography personnel and other members of the staff of the Department of Large Animal surgery, Glasgow Veterinary School. The fabrication and application of the extension shoes was done by Mr. James Ferrie F.W.C.F.

James A. Wood

1 February 1992

To Pasha & Joe,

Not the fleetest of foot,

but always the surest.

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Summary

The literature concerning angular limb deformities (ALD) in the foal has been reviewed. In this review the condition of angular limb deformities has been defined in its clinical presentation and radiological appearance. The various treatments and aetiopathogenesis have been considered. The accepted nomenclature has been adhered to.

Ten clinical cases are described in an effort to illustrate the variability in both the presentation and treatment. A need for further standardization of the clinical approach has been discussed along with the need for objective criticism of management and treatment techniques and their implementation.

Introduction/Review of the Literature

Foal limb deformities come in a variety of forms and hence have a variable presentation. As a group they include: rotational, axial, diaphyseal, articular and physeal deformities. This group can also be expanded to include polydactylitic deformities.

Foal limb deformities can present themselves as single or multiple entities. They can be unilateral, bilateral or multiple. Congenital or acquired deformities are recognized. Those limb deformities which give rise to a change in the angular orientation medially or laterally in the transverse plane, of the appendicular skeleton, are referred to as angular limb deformities (Stashak 1987, Auer 1990). It is these deformities that are the subject matter of this dissertation.

Nomenclature

It will be assumed that the reader is versed in standard anatomical nomenclature and hence no explanation or detailed consideration of either the terms themselves or the underlying and surrounding anatomy will be made. The reader is referred to the standard anatomy texts (Getty 1975, Nickel, Schummer, Seiferle, Frewein, Wilkins et al 1986).

Two terms which are themselves unique to a description of angular limb deformities are valgus and varus. There has been some confusion in the past as to their application but it is now largely accepted that valgus denotes a tilt or deviation away from the body, whereas varus denotes a tilt towards the body (Fretz, Pharr, McIlwraith, Piermattei and Turner 1982).

These adjectives 'valgus' and 'varus', are used in conjunction with the name of the joint which is associated or involved in the angular deformity. A rotational deformity is considered to be a distinct entity. Rotational deformities result from torsion of the limb about the weight bearing axis (Bramlage and Embertson 1990). Rotational deformities are known to appear secondary to certain angular deformities (Bramlage and Embertson 1990, Auer 1990, 1991) and it is only in this capacity that they will be further considered here.

AETIOPATHOGENESIS

i) Introduction

It is widely accepted that the majority of foals are born with some minor degree of angular limb deformity which self-corrects within the first few weeks of life (Ellis 1976, 1981; Auer, Martens and Morris 1982, Wyn-Jones 1988; Adams 1990; Auer 1990, 1991; Bramlage and Embertson 1990). This deformity is usually a valgus stance and is exaggerated as the foal feeds (Pool 1987). Even more attention has recently been drawn to the need for a greater understanding of the "normal" conformation of the foal and the plastic or dynamic nature of this conformation as the foal ages. Such knowledge is of paramount importance when selecting the management or surgical treatment of these cases (Bramlage and Embertson 1990).

ii) Clinical Signs

The clinical signs are that of a valgus and/or varus deviation. This may include a rotational deformity. Most carpal valgus deformities have an apparent external rotation or supination (Bramlage and Embertson 1990; Auer 1991) and many fetlock varus deformities, an internal rotation or pronation (Bramlage and Embertson 1990). More than one type of angular deviation may exist within a particular limb.

Other possible clinical signs are swelling of the joint or physis associated with the deviation, with or without pain, heat or lameness (Stashak 1987). McIlwraith (1982) states that lameness is not generally a factor in limb deformities. It may be present in those cases of traumatic or infectious origin and lameness may develop with ensuing degenerative joint disease. In cases of unilateral involvement, there may be lameness in the contralateral limb (Stashak 1987). An alteration in gait may be seen as an adaptation to lameness or the deformity itself. Foals with tarsal bone collapse often have a characteristic "bunny-hop" gait and appear "sickle" or "cow-hocked" with a curblike appearance (McIlwraith 1982, Turner 1986, Stashak 1987).

iii) <u>Sites</u>

There exist predilection sites from which angular limb deformities typically arise. These sites or regions are presented in **Table 1** in decreasing order of frequency.

<u>TABLE 1: Predilection sites of angular limb deformities</u>[1]

ANATOMICAL POSITION	COMMON FINDING/DEVIATION
Distal Radius/Carpus	Valgus
Distal third metacarpus/ metatarsus	Varus
Distal tibia/tarsus	Valgus
Proximal phalanx	Variable
Diaphysis of third metacarpus/tarsus	Variable (RARE)

Specifically, the site of the origin of these deviations may be seated at the level of the growth complex of the longbones or within the osseous components of complex joints (ie; the cuboidal bones of the carpus/tarsus). Both sites may however, be contributing concurrently to the deviation (Auer, Martens and Morris 1982, 1983, Wyn-Jones 1988). Not all angular deformities are a result of a deviation at the aforementioned sites. Angular limb deformities can be due to a laxity of the periarticular structures (see later).

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1. Source: Auer, Martens and Morris 1982; McIlwraith 1982; White 1983; Turner 1986; McIlwraith and Turner 1987b; Stashak 1987; Auer 1991; DeBowes 1991.

iv) **Aetiopathogenesis: Incidence**

Angular limb deformities are known to occur in foals of all breeds and an increased frequency of occurrence has been noted in the horse population (Heinze 1963; Heinze 1966; Fretz, Turner and Pharr 1978; Fretz 1980). There is however, one report of a higher incidence in Quarter horse foals (Fretz and McIlwraith 1983) but the authors concede that this may simply be a reflection of the local equine population. Similarily, a higher incidence in colts was noted by one author (Heinze 1969) but he acknowledged that this was probably not indicative of the true distribution.

v) **Aetiopathogenesis: Age of Occurrence**

The age at which angular limb deformities may arise is related to the "mechanism" of the disease (Auer 1991). This mechanism in turn, can be broadly classified into congenital factors which lead to the presence of limb deformities at or near birth or acquired factors whereby the deformity arises at a later date (Fretz 1980; Auer, Martens and Morris 1982, 1983). It should be said that to date the aetiopathogenesis is not completely understood but it is well recognised that it is a multifactoral disease complex (Auer 1991, DeBowes 1991). These factors are summarised in figure 1, from which discussion follows.

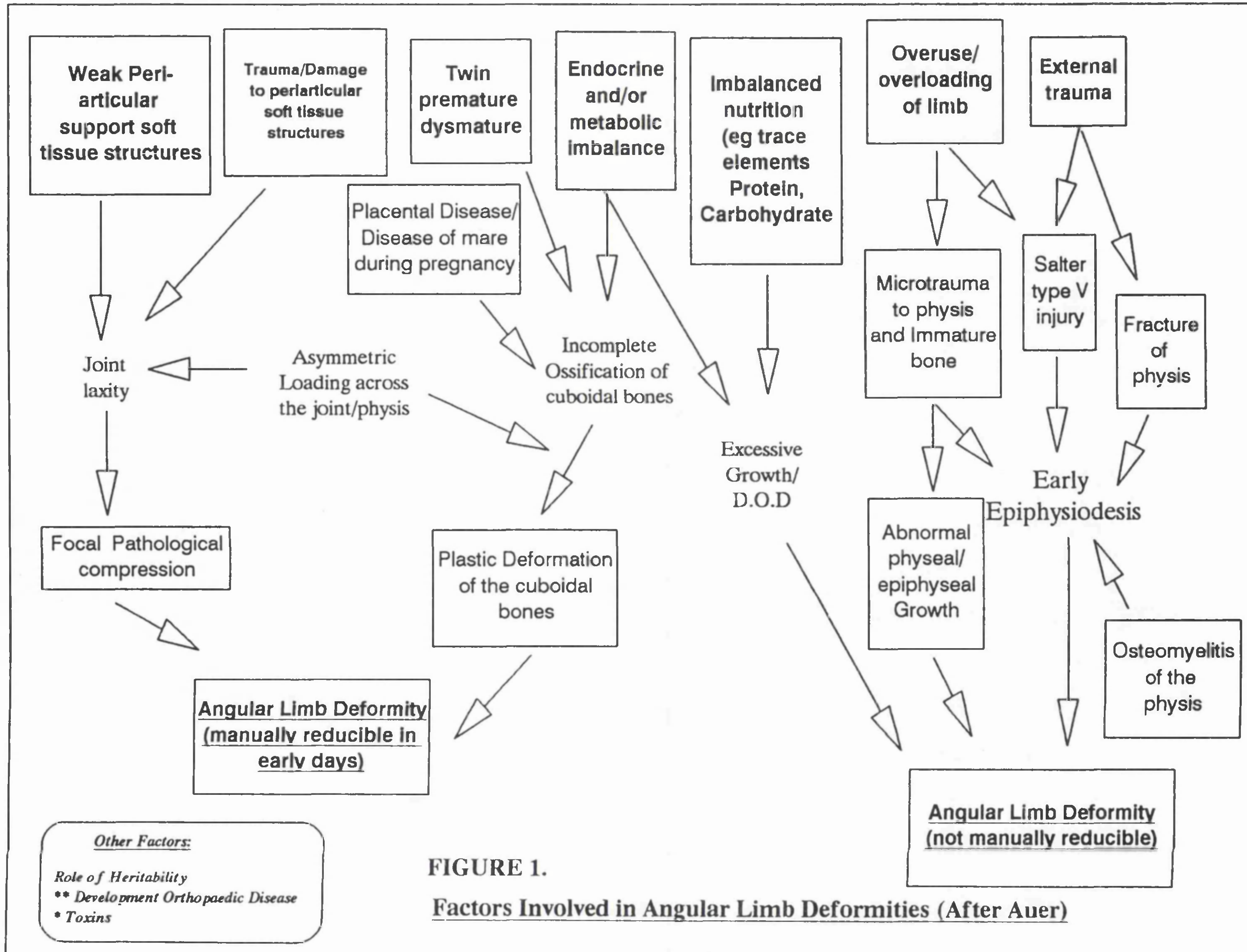

FIGURE 1.

Factors Involved in Angular Limb Deformities (After Auer)

vi) Aetiopathogenesis: Heritability

There is much speculation that a heritable component to angular limb deformities exist (Adams 1966, 1974) but this is not yet conclusive. Some evidence of the role of a heritable factor in the aetiopathogenesis of development orthopaedic disease (D.O.D) has been demonstrated (Wagner, Grant, Watrons et al 1985). Acquired forms of angular limb deformities have been considered to be a developmental orthopaedic disease (Bramlage 1987, Lucas 1991). From this a heritable component can perhaps be inferred, however, the question remains whether this heritable for the disease itself or simply a heritable predisposition for rapid growth (Lucas 1991).

vii) **Aetiopathogenesis: Joint Laxity**

Joint laxity is not an unusual congenital finding in the neonatal foal (Leitch 1979; Fretz 1980; Auer, Martens and Morris 1982; Stashak 1987; Wagner and Watrous 1991). Joint laxity or instability is the result of a weakness and/or flaccidity of the peri-articular supporting soft tissue structures. This has been attributed to malpositioning in utero (Adams 1974) or to perinatal soft tissue trauma (Auer and Martens 1980; Auer, Martens and Morris 1982). Mason (1981) cited in support of the theory of the role of abnormal positioning in utero, the occurrence of 17 cases of congenital angular limb deformities in a group of foals born one season at a stud farm to mares recognised to be grossly obese. In his investigation the only factor he could not eliminate was the unusual feeding regime resulting in the dams being markedly overweight during the last half of pregnancy. Considerations were made of the possible role of heritability, toxins, disease of the mares as well as calcium and phosphorus levels. No investigation of the role of trace elements and nutrients now suspected of playing a part in the development of orthorpaedic conditions such as angular limb deformities, were made. Mason's investigations did not include radiographic or pathological investigations as it was deemed that none of the deformities were severe and all self-corrected within four weeks.

The majority of cases of angular limb deformities due to simple joint laxity are corrected within the first two to four weeks of life with the increasing muscle tone and coordination (Leitch 1979; Auer, Martens and Morris 1982). This spontaneous correction does not occur in severe cases or in those cases complicated with other concurrent problems such as incomplete ossification. Such cases would be candidates for some form of external support (Auer, Martens and Morris 1982; Adams 1990; Wagner and Watrons 1991).

Severe joint laxity or joint laxity which does not correct in the immediate peri-natal period (2-4 weeks) results in an asymmetrical load across the growth plate complex. This load results in compression and tension, which, if excessive, may exceed the physiological limits by which compensatory growth can occur (Frost 1988). The net result may be initially cartilagous lesions followed by osseous pathology. Typically, this involves the lateral portion of the third carpal bone, the fourth and the ulna carpal bones and occasionally the intermediate and second carpal bones (Guffy and Coffmann 1968; Leitch 1979; Fretz 1980; McLaughlin, Doige, Fretz and Pharr 1981, DeBowes 1990).

The pathology generally includes abnormalities of size and shape of these bones, their positioning, subluxation of the metacarpal and carpometacarpal joints and cartilage lesions previously described as osteochondrosis or osteochondritis dissecans (Kirk 1979; McLaughlin, Doige, Fretz and Pharr 1981). Pathology as such is not necessarily confined to angular limb deformities associated with joint laxity but rather are increasingly reported under the guise of developmental orthopaedic disease (Bramlage 1987; Pool 1987).

viii) **Aetiopathogenesis: Incomplete Ossification of Cuboidal Bones**

The cuboidal bones of the carpus and tarsus ossify in the last two to three months of gestation (Auer, Smallwood, Morris, Martens, McCall et al 1982; Smallwood, Auer, Martens, Morris, McCall et al 1984). Because of this late ossification, foals born premature (less than 320 days gestation) are predisposed to a high incidence of angular limb deformities due to this incomplete ossification or cuboidal bone hypoplasia (Leitch 1985; McLlwraith 1982; Stashak 1987; Adams 1990). Occasionally, foals carried to term may be born skeletally dysmature and can be similarly affected. These foals are often small for their gestational age and the cause of this in-utero growth retardation is not always clear (Adams 1990; DeBowes 1990).

Disease conditions of the pregnant mare are thought to possibly cause placental insufficiency and hence in-utero growth retardation (Auer, Martens and Morris 1982; Adams 1990).

Twin foals or a surviving twin are usually born with incompletely ossified cuboidal bones. This is attributed to the two foetuses having to compete for placental space (Auer, Martens and Morris 1982; Stashak 1987; Adams 1990).

Thyroid abnormalities (hyperplastic goitre, hypothyroidism) may cause a delay in ossification (Shaver, Fretz, Doige and Williams 1979; McLaughlin and Doige 1982).

Hypothyroidism in the foal has been associated with a retardation of the ossification of the cuboidal bones, especially those of the tarsus. McLaughlin and Doige (1982) reported on the degree of ossification of the carpal and tarsal bones in normal foals and in hypothyroid and thyroidectomised foals. Their findings were consistent with a previous report of tarsal bone abnormalities in which Shaver, Fretz, Doige and Williams (1979) reported on two clinical cases of suspected hypothyroidism. In these two cases there was a marked collapse of the central and third tarsal bones. It is interesting to note that their findings both radiographic and pathological were very similar to those described by Morgan (1967) as asceptic necrosis of the third tarsal bone. Morgan briefly described 9 cases of third tarsal bone collpase in foals. Although he made some suggestion of the aetiology involved and even suggested the possibility of hypothyroidism, no assessment of the thyroid status appears to have been carried out. The role of the thyroid hormones has been further considered in the development of Developmental Orthopaedic Diseases (D.O.D).

If the foal subjects the incompletely ossified bones to even the normal activities of weightbearing, they will undergo a plastic deformation and fissuring of their articular sufaces (DeBowes 1990). The situation is made worse with increased activity and asymmetrical loading.

Shear forces may act, causing a tearing of the cartilage from their osseous core, and the prognosis becomes diminished with the development of degenerative joint disease (DeBowes 1990, Auer 1991). The similarity between these lesions which may arise in cases of hypoplastic cuboidal bones and those lesions of osteochondrosis / osteochondritis dissecans has been made repeatedly by others and will not be considered further (Kirk 1979; Shaver, Fretz, Doige and Williams 1979; Fretz 1980; McLaughlin and Doige 1982; Stashak 1987 and DeBowes 1990).

ix) **Aetiopathogenesis: Early Epiphysiodesis**

Premature closure of the physis (early epiphysiodesis) can result in the acquisition of an angular limb deformity (Vaughan 1976; Ellis 1976; Turner and Fretz 1977; Auer, Martens and Morris 1983; Denny 1989). Aetiological factors (figure 1) are primarily, external trauma, overuse/ overloading of the limb and possibly a septic osteomyelitis of the physeal region (Vaughan 1976; Turner and Fretz 1977; Martens and Auer 1980; Auer, Martens and Morris 1983; Denny 1989). If the septic osteomyelitis is severe enough to destroy the growth plate, an angular limb deformity may ensue, even if the therapy has been successful (Martens and Auer 1980; Auer, Martens and Morris 1983; Auer 1991).

Angular limb deformities arising from overuse due to excessive weightbearing (overloading), are said to generally manifest as an acquired unilateral varus deformity secondary to a lameness in the contralateral limb (McLlwraith 1982; Turner 1986; Auer 1990,1991). These angular limb deformities will not be manually reducible on clinical examination which implies the possible need for surgical intervention in order to obtain a correction (Auer, Martens and Morris 1983; Auer 1990, 1991).

Injuries to the growth plate complex have been said to cause angular limb deformities. These injuries have been categorised using the Salter-Harris (S-H) system for epiphyseal injuries typically a S-H type V (Vaughan 1976;

Ellis 1976; Turner and Fretz 1977; Auer, Martens and Morris 1983; Denny 1989). Heinze (1977a) questioned this, contesting that the Salter-Harris type classification as it has been described (Salter and Harris 1963) is not applicable in the foal. In children a S-H type V injury is irreversible, whereas in the equine the S-H type V classification has been applied to cases of angular limb deformities which have proved amenable to surgical correction (Vaughan 1976; Turner and Fretz 1977; Heinze 1977a; Auer, Martens and Morris 1983; Denny 1989). Because of this, the role of S-H type V injuries as an aetiological factor probably warrants further consideration in the horse and is possibly not as prevalent or as relevant as thought (Heinze 1977a). Ellis (1976) acknowledges that Salter-Harris types I to IV are rare. Although not originally described by Salter and Harris (1963) a type VI injury in the foal, has been recognised by some authors (Turner 1986, Wyn-Jones 1988, Denny 1989). Turner (1986) however acknowledges that a S-H type VI is rare and occurs usually in response to localised infection or surgical trauma (figure 2).

Figure 2: Salter-Harris type VI injury secondary to surgical trauma/osteomyelitis.

The forces (compression, tension and flexion) generated by excessive use or overloading of the limb are said to cause microtrauma to the physis and the nearby immature bone (Kirk 1979; Fretz 1980; Auer, Martens and Morris 1983; Auer 1990, 1991). This is thought to cause a disruption of endochondral ossification by incurring an alteration in the blood supply to the zone of provisional calcification as well as causing microfractures of the newly formed trabecular bone (Kirk 1979; Fretz 1980). All of this in turn results in defective endochondral ossification which has been considered to be a form or manifestation of osteochondrosis (Kirk 1979; Fretz 1980; McLaughlin, Doige, Fretz and Pharr 1981; Pharr and Fretz 1981).

A defect in endochondral ossification as such, could lead to a developing angular limb deformity either by causing an asymmetrical closure of the physis or an aberration in physeal and/or epiphyseal growth (Auer, Martens and Morris 1983; Auer 1991). Frost (1988) elaborated the roles of the forces of compression, tension and flexion across the growth complex. He noted in his models of growth regulation that an increased physiological force would bring about an increased growth. If this force was distributed eccentrically, an asymmetric growth would result in an effort to correct or even out the forces acting across the growth complex. This itself could lead to the formation of an angular limb deformity (Brown and MacCallum 1976).

x) **Aetiopathogenesis: Toxic Insult**

McLlwraith and James (1983) reported the occurrence of angular limb deformities in foals born to a mare from a group of mares known to have ingested locoweed (Astragalus mellisimus) during pregnancy.

Flexural deformities were widespread in the other foals of this group and the angular deformity appeared to be an isolated case. It is, therefore, it is difficult to incriminate the ingestion of Astragalus mellisimus as an aetiological cause of angular limb deformities especially as no radiographic or post mortem samples were seen. No other reports of the effects of toxins and induction of limb deformities appear elsewhere in the literature. There does exist, however, several well known associations between limb deformities and toxic insult in utero, in other species. The effects of thalidomide in man being a well known example.

xi) **Aetiopathogenesis: Imbalanced Nutrition**

A great deal of current research is focused on the role of nutrition, and the development of orthopaedic diseases which includes acquired angular limb deformities (Bramlage 1987; Lewis 1987; Lucas 1991). Typically in the past the concentration and ratio of calcium and phosphorus has been discussed as a possible aetiological factor along with an association between high level feeding regimes and rapidly growing heavy bodied foals (Adams 1974; Fretz 1980; Mason 1981; McIlwraith 1982).

Adams (1974) considered that in these cases of angular limb deformities which developed after birth, a form of "rickets" played a role in the aetiology and recommended that the nutritional status of these foals and that of others "at risk" be ascertained with attention to deficiencies in calcium, phosphorus, vitamin A, carotene or vitamin D.

Lucas (1991) notes three major areas of nutrition which are of concern with respect to the development of orthopaedic disease. These are:

1) Mineral deficiencies
2) Mineral imbalances or excesses and
3) over-feeding of protein and energy.

Copper, zinc, calcium, phosphorus and magnesium have been the subject of much current research and interest (Lucas 1991). This is not to say however that the other minerals or constituents of feed rations are no longer considered. A copper deficiency has been incriminated in the aetiology of osteochondrosis or development bone disease (Bridges, Womak, Harris and Scrutchfield 1984; Knight, Weisbrode, Schmall and Gabel 1987). The role of copper in stabilising bone collagen and elastin synthesis has been recognised whereby copper functions with the enzyme lysyl oxidase (Bridges, Womak, Harris and Scrutchfield 1984; Lewis 1987). An induced copper deficiency associated with excessive zinc intake has been described as well as the antagonistic role of molybdenum to that of copper (Bridges, Womak, Harris and Scrutchfield 1984; Knight, Weisbrode, Schmall and Gabel 1987).

Knight et al (1987) consider that excessive levels in protein, calcium, and phosphorus may induce deficiencies in several trace minerals, further qualifying this by stating that "adding large amounts of any mineral will have effects on the availability of other minerals". These same authors also suggest that manganese was unlikely to be involved in the disease processes in their study. The same group of workers continued with their study of nutrition or feed-ration adjustment. In a follow-up study (Gabel, Knight, Reed, Puttz, Paver et al 1987) noted a decrease in the incidence of developmental orthopaedic disease in the foal crop of the same farms one year later following ration adjustment. The nutrient which was most significantly changed was copper. The foals in this group also had higher levels of calcium, phosphorus and zinc but these increased levels failed when subject to statistical analysis. The authors acknowledged that a direct diet-disease relationship was not established but they inferred from their data, that the higher levels of these nutrients may be beneficial in the prevention of D.O.D. and chief amongst these nutrients identified in these studies was copper. The authors also emphasised that the ration adjustment did not eliminate D.O.D. but that a statistical correlation between a reduction in it's incidence and ration adjustment existed.

It is interesting to note that in their study, there existed no correlation between protein and energy levels even when these levels were greater than that which has been suggested to be responsible for the increase in osteochondrosis in young horse (Glade and Belling 1986). Protein and energy have been acknowledged to influence the growth rate (Stromberg 1978) and excessive growth has been considered as aetiological factor in the development of angular limb deformity (see Figure 1). Again, variance in the levels of protein and energy will bring about a variance in both the levels and bio-availability of minerals (Kronfield and Donoghue 1987). The role of nutrition becomes increasingly complex as one considers the regulation of carbohydrates (sugars and starches) by hormones (eg;

insulin, insulin-like growth factor-1, thyroid hormones; T4/T3) which in turn influence the synthesis in cartilage of proteoglycans and collagen (Kronfield and Donoghue 1987).

In summation, developmental orthopaedic disease including some forms of angular limb deformities, has a nutritional component in it's aetiological background but it is accepted that this nutritional component functions in conjunction, often overlapping, with other factors such as genetics, hormonal, metabolical and mechanical factors (Hintz 1987; Kronfield and Donoghue 1987; Lewis 1987 and Lucas 1991).

The upshot of this all is that an angular limb deformity may result due to the defective ossification or "bone softening" (Turner 1986) whereby the diseased growth complexes will be unable to withstand the loading of weightbearing (Auer 1991). This may be made worse if the animal either grows to a size excessive for its age or is obese (Stashak 1987).

3. **Radiology**

i) **Reasons/Candidates for Radiography**

Radiology is an essential component in the examination of the foal with limb deformities and in the identification of those foals at risk of developing angular limb deformities.

Auer (1988, 1990) advocates that all foals of any value should have one carpus (dorsopalmar view) and one tarsus (lateromedial view) radiographed at birth to assess the degree of ossification. Adams and Poulos (1987, 1988) initially identified two groups of foals who are prone to incomplete ossification:

1) premature foals (<320 days gestation) and
2) foals small for their gestational age.

Adams (1990) later expanded this to include twins and those foals born to mares who were thought to have had uterine infections. Adams and Poulos (1987, 1988) suggest that foals of these high risk groups be routinely radiographed prior to 2 weeks of age. These same authors have also proposed a skeletal ossification index to aid in the standardisation of the radiographic evaluation of these foals. Other researchers, (Brown and MacCallum 1975) have also developed grading systems of ossification which however, were not specific to foals with or at risk of limb deformities.

The contention that all foals of value be radiographed at birth, is further supported by the findings of radiographological studies of the carpus (Auer, Smallwood, Morris, Martens, McCall et al 1982) and of the tarsus (Smallwood, Auer, Martens, Morris, McCall et al 1984).

These workers sequentially radiographed the carpi and tarsi of 9 foals from birth to six months of age. Both of these studies demonstrated a great variance in the degree of ossification at these sites when compared with the length of gestation, body size and foals age. Thus, the contention that all foals should be radiographed at birth is perhaps justly prudent, however, other authors have different options as to when radiography is called for. Mase (1987) recommends that all foals with an angulation greater than 5 degrees and possessing "positive joint trust" be radiographically evaluated. Leitch (1979) considers that those foals with an angulation greater than 15 degrees or those foals with a limb deformity which does not self-correct by 5-7 days be considered for radiography. All authors seem to be in accord that radiography is indicated in the presence of a lameness.

ii) <u>Radiographic views/Positioning</u>

For carpal and fetlock deformities, craniocandal or dorsopalmar/plantar, respectively, and lateromedial views are standard (Fretz 1980; Pharr and Fretz 1981). These views need to incorporate as much as possible of the 'longbones' proximal and distal to the joint or growth complex involved.

The inclusion of 50-75% of their total length will enhance the accuracy of an analysis of the degree of angulation (O'Brien and Meagher 1971; Leitch 1979; Fretz 1980). This necessitates the use of long or oversize (e.g. 18 cm x 43 cm or 35 cm x 43 cm plates). Care must be taken in the positioning of these animals to ensure that the radiographic appearance will be a proper reflection of the clinical appearance (Fretz 1980).

Iatrogenic exaggeration is easily produced by malpositioning (figures 3 and 4). The presence of an accompanying rotational deformity can also produce an altered radiographic appearance to that of the clinical picture (Pharr and Fretz 1981). Standing the foal square and evenly weight bearing is usually sufficient to circumvent iatrogenic exaggeration.

Figure 3

Figure 4

Figures 3 and 4: Craniocaudal views of the leftfore fetlock. Note that positioning is such that rotation in figure 2 yields a 18 degrees angulation which did not exist (see figure 4).

The use of the "Nancy View" (figure 5) is said to produce a radiographic image more true to form (Mase 1987, Fretz 1991, Pers. Comm.) of carpal deformities.

For forelimb fetlock deformities it has been suggested the limb be held in suspension at the carpus for dorsopalmar views. This in turn allows the phalanges to lie in the same frontal plane true to the third metacarpal bone (Auer 1988). The anatomical relationship of the tibia and third metatarsal bone is such that they do not lie in the same frontal plane (Getty 1975; Nickel, Schummer, Seiferle, Frewin, Wilkens et al 1986).

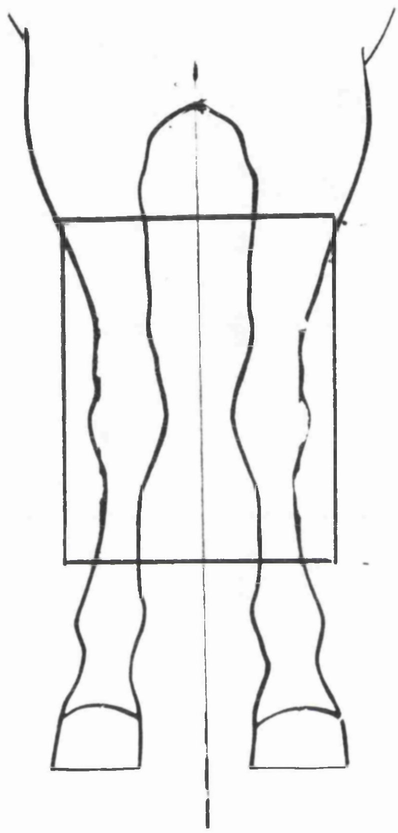

Figure 5: The "Nancy View" (Fretz 1991 pers. comm.)
Note the positioning of the radiographic plate as well as the aim of the X-ray beam. Necessitates use of 35 cm x 45 cm plate (Illustration to scale).

Because of this an assessment of the degrees of angulation is considered to be not as accurate as in the carpus, so the inclusion in the radiographic field of the lengths of the tibia and third metatarsal bones is not as important (Auer, Martens and Morris 1983; Auer 1990; Adams 1990).

Flexed or oblique views may be useful adjunctants especially in those cases of suspected morphological changes (Auer 1985).

iii) <u>Analysis of the Radiographs</u>

The analysis of the radiographs should be carried out in two stages (Fretz 1980; Pharr and Fretz 1981; Stashak 1987). First, a morphological evaluation of the osseous and soft tissue components and secondly, a geometric analysis.

a) <u>Morphological Evaluation</u>

A variety of radiographic abnormalities may be present. Often there will be more than one abnormality or site of involvement (Pharr and Fretz 1981; Auer 1982; Stashak 1987). In general, signs of degenerative joint disease, fracture, infection, congenital abnormalities and abnormal bone morphology must also be considered as well as those abnormalities commonly associated or involved with angular limb deviations (Adams 1990).

More specifically, there exist common radiographic abnormalities which have been associated with angular limb deformities, these are presented here in Table 2.

<u>Table 2: Common Radiographic Abnormalities</u>[1]

ANATOMICAL POSITION	COMMON FINDING
Metaphysis	Metaphyseal flare, Metaphyseal sclerosis
Physis	Ectasia (complete or incomplete)
Epiphysis	Epiphyseal wedging, Epiphyseal flare - (often accompanying metaphyseal flare)
Cuboidal bones of carpus/tarsus	Deformed, hypoplastic or collapsed. Occasionally may seem to be displaced or subluxated
Proximal aspectof second or fourth metacarpus/metatarsus	Displacement of small metacarpal/ metatarsal bones at proximal head
Diaphysis of third metacarpus/metatarsus	Diaphyseal remodelling leading to an asymmetry of the cortical thickness

There are other abnormalities which appear with less frequency. Osteochondrosis - like lesions usually located at the level of the metaphysis (Pharr and Fretz 1981; Stashak 1987; DeBowes 1991 pers. comm.) is one such example (figure 6).

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1. Source: Pharr and Fretz 1981; McLaughlin, Doige, Fretz and Pharr 1981; Bertone, Park and Turner 1985; Stashak 1987).

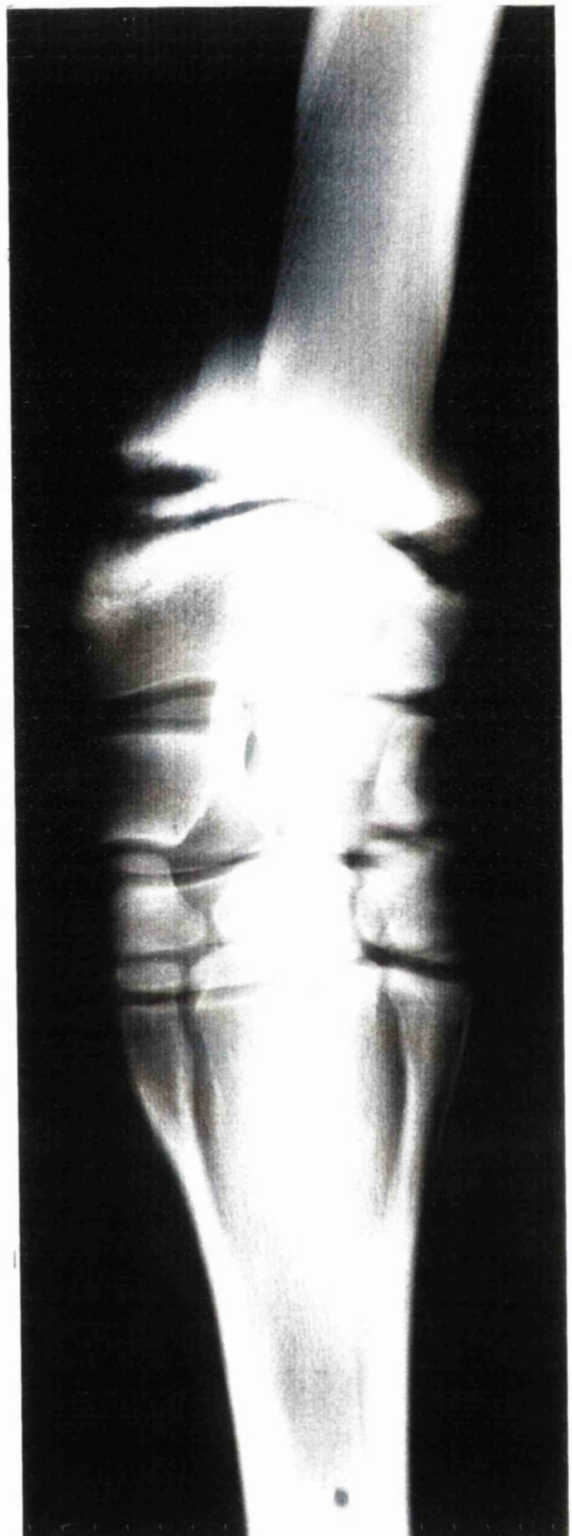


Figure 6: Case number 7 - Note the "O.C.D.-like" lesion at the level of the medial aspect of the distal radial metaphysis.

Aseptic necrosis of the central and third tarsal bones have been reported (Morgan 1967; Pharr and Fretz 1981) but such changes are now generally interpreted as a collapse of these bones (Turner 1986).

b) **Geometric Analysis**

Geometric analysis was initially described by O'Brien and Meagher (1971) to assess the degrees of deviation. Fretz (1980) later drew attention to the point of intersection of the axes of the longbones, referring to this as the pivot point. He remarked that the pivot point would be located at the level of the cause/pathology contributing most to the angular limb deformity. This was later reiterated by Auer, Martens and Morris (1982) who stressed that there often can be more than one underlying cause of the deformity. They noted that in those cases with more than one cause pivot point would be shifted further distally than expected.

It was also found that the position of the pivot point is quite variable in those cases with periarticular laxity. These same workers put forth an alternative means of geometrically analysing complex carpal/tarsal angular limb deformities. This method involves drawing lines through the physis and individual joint spaces which are then compared to the axes of the associated longbones. Such an analysis can demonstrate the individual contributions at the different levels/joints to the deformity.

All authors agree that the great value of the determination of the pivot point lies in drawing greater attention to the radiographic features of these cases (Fretz 1980; Auer, Martens and Morries 1982, 1983; Stashak 1987).

iv) <u>Radiographic appearance as an index of prognosis</u>

Attempts have been made to collate a prognosis with respect to both the morphological changes and the degrees of angulation (Guffy and Coffman 1969; Fretz 1980; Pharr and Fretz 1981). Bertone, Park and Turner (1985) in a retrospective study of 35 angular limb deformities, found that they were unable to make a correlation between mild (<5 degrees) or moderate (5-15 degrees) geometric changes, as well as mild to moderate morphological changes, and the outcome over a 2 year period.

It is however, inferred that the greater the changes the poorer the prognosis, all of which is exacerbated by advancing age, with respect to the possible development of degenerative joint disease and the time of physiological closure of the physis.

4. **Treatment**

i) Introduction

It is commonly acknowledged that all foals are born with some degree of angular limb deformities which generally self-correct in the immediate peri-natal period (Leitch 1979, Auer, Martens and Morris 1982; Wyn-Jones 1988; Adams 1990). It is also known that foals afflicted with limb deformities which are severe or fail to correct within a reasonable period of time require some form of treatment.

ii) The primary goal of treatment is to correct the deformity thereby:

a) preserving or maintaining athletic potential

b) minimise secondary changes

c) salvaging the animal for either breeding purposes or pasture soundness.

iii) Types of treatment

An overview of treatment used both past and present in the management of angular limb deformities, would include:

I) Conservative Management

- observation
- restricted exercise/box rest
- hoof trimming
- corrective shoeing
- dietary management
- orthotics (e.g. casts, splints or braces)

II) Growth Retardation Technique

- X-IRRADIATION
- Temporary Transphyseal Bridging (TTPB) using:
    - i) bone plates or;
    - ii) staples or;
    - iii) screws and wires.

III) Growth Acceleration Techniques

- i) Hemicircumferential Periosteal transection and Periosteal Stripping (HCPT and PS)
- ii) Periosteal Elevation/Stripping

IV) Transfixation of the lateral Styloid Process

V) Transfixation of the lateral malleolus of the tibia

VI) Osteotomies

- i) wedge
- ii) Dome
- iii) Step

VII) Salvage Arthrodesis

iv) __The Selection of Techniques__

The institution of one particular technique is in part, dictated by the underlying aetiological cause, site involved morphological changes and age of animal. One technique is not necessarily selected to the exclusion of another, concurrent treatment. The majority of treatments and therefore, their selection, have their effect only if the potential for, and necessary amount of, growth at the site involved still exists.

There have been attempts to quantify the data of the degrees of deviation, site of origin, age and amount of correction achievable using a specific, usually surgical technique, (Campbell 1977, Adams 1990) but difficulties arise due to the large number of variables, and individual options.

As examples, Leitch (1979) considers that those deviations greater than 15 degrees or those which do not respond to exercise during the first 5-7 days of life warrant investigations of the aetiology. She fails to qualify this further as to the application of treatment.

Adams (1990) suggests that those 15 degrees or greater call for immediate treatment. Turner (1986) suggests these deformities of the carpus/tarsus still present at 60 days of age, or those of the fetlock still present at 30-60 days as well as those deformities which are getting progressively worse, be considered as surgical candidates. Turner qualifies these criteria further by stating that he occasionally considers surgery at 45 days but if the leg is nearly straight, wait a further 30 days (carpal/tarsal deformities). Other authors recognise or attempt to consider the complexity of angular limb deformities and offer complex concepts by which to judge the need for surgery.

Mase (1987) introduces the principle of "joint trust" as borrowed from human paediatrics. Joint trust is said to exist when there is an increase in the angulation of the limb during the weight bearing phase. A positive joint trust is considered pathological. Its presence in those cases with an angulation greater than five degrees which were unresponsive to constructive management would be considered by Mase as a surgical candidate, provided adequate growth potential still existed.

Bramlage and Embertson (1990) defined the indications for surgical intervention as:

(1) those deformities too severe for self-correction within the time of natural growth.

(2) those deformities which are being corrected too slowly by natural ways, within the time frame of the natural growth period.

(3) Deformities that are leading to or are going to cause a secondary deformity or injury.

In summation there exists some difficulty in the determination of the need for surgical interference. Time of physeal closure and the length of growth period often determines the procedure selected. Early diagnosis and treatment are important.

vi) <u>Treatment of angular limb deformity: Conservative Management</u>

There exists a wealth of publications on the possible surgical techniques for the treatment of foals with angular limb deformities. These are reviewed later. In contrast, there are a limited number of publications detailing the conservative management of these cases and the criteria by which the need for surgical intervention is called for (Mase 1987, Adams 1990, Bramlage and Embertson 1990).

Conservative management consists of: hoof trimming, extension shoes, restricted exercise, application of splints, casts or braces and dietary correction where an imbalance or excessive plane of nutrition has been determined.

Hoof trimming without a doubt, is the backbone of the treatment of angular limb deformities. Regardless of what treatment is chosen, surgical or conservative, the need for early and regular balanced hoof trimming is of underlying importance to a successful outcome (Heinze 1966, 1969, 1977a,b; Mase 1987; Adams 1990; Auer 1990,1991).

It is no longer recommended that foals with angular limb deformities, have their hoofs trimmed in such a way as to attempt to counteract abnormal stresses. This in itself may lead to an alteration of the axial alignment of the limb complicating the existing deformity (Adams 1990, DeBowes and

White 1991 pers.comm).

Recently, the whole theory that changes in the hoof balance would alter forces acting across the growth plate, has been challenged. Studies employing strain gauges implanted at the level of the third metacarpus and distal radius in neonatal foals, demonstrated a rapid adaptation to altered hoof balance (12-15 degrees) with a reestablishment of compressive and tensile forces as previously recorded at these sites prior to the change in balance (Firth, Schamhardt and Hartman 1988). Studies such as these also bring into question the effectiveness of the use of corrective shoes whereby extensions which protrude beyond the hoof wall on the side opposite the deformity are used in efforts to shift the weight-bearing axis such as to achieve a more evenly distributed compressive force (Fackelman, Reid, Leitch and Cimprich 1975; Auer, Martens and Morris 1983).

It is generally acknowledged that restricted exercise will be of benefit to the foal with an angular limb deformity. This in itself is common sense, however, the degree of restriction is somewhat arbitrary. It should be recognised that angular limb deformities due to periarticular laxity will usually improve with judicious exercise and deformities due to conditions such as cuboidal bone hypoplasia, collapse or incomplete ossification, can worsen. These latter conditions as well as severe cases of periarticular laxity warrant the use of some form of external support be it a cast, splint or brace (Stashak 1987, Adams 1990, Auer 1991). The application of external supports and the potential benefits and complications are widely discussed in the literature and will not be considered further, however, some mention of dynamic orthotic devices is warranted. Dynamic orthotic devices consist of braces, splints or casts which in their application exert a redistribution of forces to encourage normal growth. Reports of the actual use of dynamic orthotic devices appear only infrequently in the literature. Heinze (1963) illustrated two orthotic techniques for the correction of carpal valgus deformities, presumedly emanating from level of distal radial growth complex (figure 7). These two techniques were apparently only illustrated as a contrast to the then, newly described technique of epiphyseal stapling. Adams (1966, 1974) elaborated only slightly more on these techniques, noting the potential substitution of aspen or bass wood in lieu of the yucca board. Adams (1974) highlighted the potential hazards of pressure necrosis and the development of flexural flaccidity. He also noted the development of special braces with hinged joints and their successful application in cases of carpal valgus deformities, citing the advantage that "muscular atrophy would not be as great". None of these early reports specify the situation in which such forms of external support could be applied.

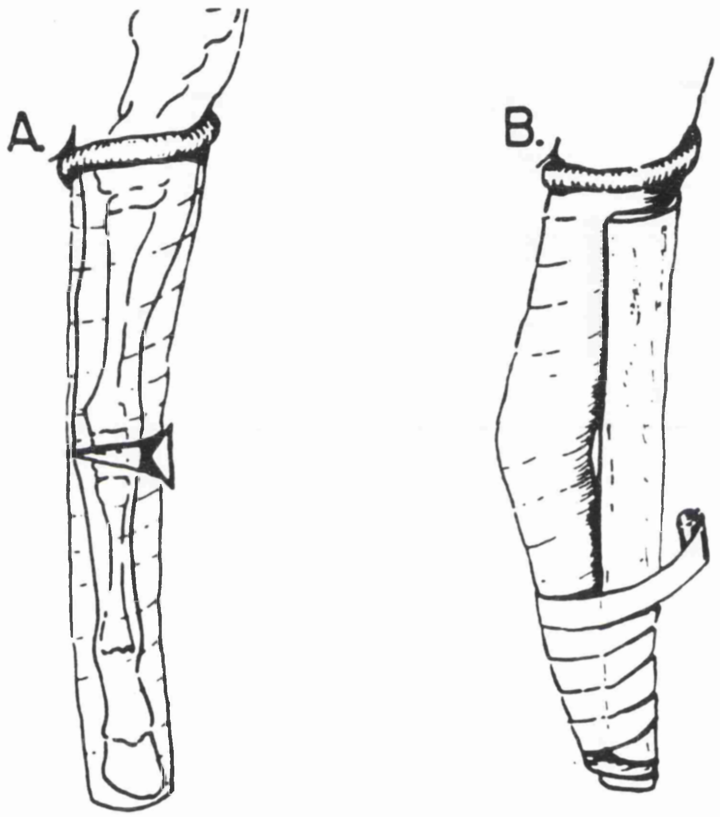


Figure 7: Two examples of dynamic orthotic devices.
A: Wedging the dry cast. B: Yucca board applied over "green" cast.
(Courtesy of Dr. C.D. Heinze and the American Association of Equine Practitioners.)

Auer (1991) states that foals with asynchronous metaphyseal growth should not be treated by means of external support but rather they are surgical candidates. This view is reiterated by McIlwraith (1982) and it appears that the general consensus is currently in favour of the use of external support only in those cases of incomplete ossification and in cases of joint instability secondary to severe periarticular laxity (Adams 1990, Wagner and Watrous 1991). Contrary to this are the views of Redden (1991 pers. comm.) and Farley (1989, 1991 pers. comm.) both of whom manufacture and fit speciality braces to foals. This is done not just as single procedure but rather the whole of the treatment is carried out under their direct supervision. Both Redden and Farley claim "good" results for "all types" of angular limb deformities.

It should be noted that other manufactures of equine orthotic devices exist (eg; Smith and Nephew Roylan Inc. Menomanee Falls, WI., U.S.A.).

vi) <u>Growth Retardation Techniques: X-Irradiation</u>

The use of x-irradiation, generated by a standard x-ray machine, as an alternative method to retard growth was reported by O'Brien and Meagher (1971). They described the technique, and its' application in a case series of 11 foals with angular deformities ranging from 6-18.5 degrees emanating from the distal radius.

The results of the treatment were considered good with respect to a correction of the deviation. The authors did however, note problems with skin reaction (erythema, dry desquamation, epilation and depigmentation) and in one foal osteonecrosis and severe skin reaction.

O'Brien and Meagher conceded that much more work needed to be done in determination of the optimal dose noting a reduced dose (<750 rads over 3.5 cm diameter area) would produce less skin changes and that the possibility of a smaller dose and a second treatment should be explored.

No other subsequent reports of this procedure appear in the literature. O'Brien and Meagher must also be credited as being the first to illustrate the method utilised for the measurement of forelimb angulation which was later expanded on by Fretz (1980) and Auer, Martens and Morris (1982).

vii) **Growth Retardation Techniques:**

Temporary Transphyseal Bridging

Temporary transphyseal bridging techniques were the earliest surgical procedures used in efforts to correct angular limb deformities. They are still employed in instances where little growth potential remains, often in conjugation with a growth acceleration technique on the contralateral side of the bone.

Growth Retardation Technique: Bone Plates

In 1953 Delahanty and Gibbons reported on the successful treatment of a congenital, unilateral carpal valgus in a 4 week old foal. In their procedure they employed a 3.5 cm venable-type vitallium bone plate with 2 screws, one placed into the metaphysis and the other into the epiphysis, effectively creating a transphyseal bridge. This was later removed following the correction of the angular deformity 11 weeks later.

Campbell (1977) in a report on epiphyseal compression in the foal, described the use of compression plates verses screws with compression wires as a means of transphyseal bridging to correct angular deviations. In this report he cited a case of a fetlock varus in a 3 month old foal which was unsuccessfully treated using a compression plate. Campbell speculated that the epiphysodesis which soon followed the surgery was due to the transmission of compression along the lengths of the screws, as opposed to a focal compression at the level of the heads of screws as would be the case with compression wiring. This appears to be the reasoning used by later workers in this field (Turner and Fretz 1977) as to the ineffectiveness of a compression plate for transphyseal bridging.

Auer, Martens and Morris (1983) cites the successful use of bone plates, to achieve a temporary transphyseal bridge, by another worker but they elaborate only by citing the high implant cost as a disadvantage. Auer (1990) now however, considers it as his "preferred technique" noting the lack of blemish formation as it's key attribute along with it's effectiveness.

In retrospect of Campbell's report, the age of the animal (3 months) was at the upper limit of what is now accepted as the age of physiological physeal closure of the fetlock (Fretz 1980). Campbell had addressed the rate of growth and it's patterns of physeal closure in his publication but his time criteria was based on that of earlier workers (Green 1961,1969; Sisson and Grossman 1948) now known not to be correct with respect to physiological physeal closure times. Vaughan (1976) made similar errors citing 6 months as the uppermost time limit at which temporary transphyseal bridging of the distal physis of the third metacarpus/tarsus.

<u>Growth Retardation Technique: Staples</u>

The use of staples as an implant for temporary transphyseal bridging was initially reported by Heinze (1963). He referred to the technique as "epiphyseal stapling" and reported on it's successful use for the correction of carpal and tarsal limb deformities arising at the distal radius and distal tibia respectively.

Heinze continued to be a proponent of this technique reporting upon both improvements in the make and design of the implants themselves and the technique of their application (Heinze 1963, 1966, 1969, 1977b, Heinze, Miller, Reed, Rooney 1965).

The initial staples used were made from lengths of either Kirschner wires or Steinman pins (Heinze 1963). Later forged staples with reinforced tines became available and were used in preference to those staples made from Kirschner wires or Steinmann pins due to their greater strength, resistance to spread and enhanced ease of location for extraction (Heinze 1966).

The use of epiphyseal stapling in the treatment of angular limb deformities was popularised in the standard texts at the time (Adams 1974, McIlwraith 1982). Auer (1990) acknowledges that it is still used successfully by many competent clinicians without fault.

It is interesting to note that the application of epiphyseal stapling for fetlock deformities was not reported until some 14 years later (Heinze 1977b). The reason for this is not clear.

Ellis (1981) considered the treatment of tibial valgus deformities using a single cancellous bone screw set obliquely across the physis to "compress the growth plate". Ellis however, gave little more detail of this procedure and no other reports of the technique appear.

Growth Retardation Technique: Screws with Tension Band Wires

Fackelman and Frölich (1972) in a report on the current status of ASIF technique in large animals presented the procedure of "tension band fixation" for treatment of carpal valgus.

This appears to be the first reported use of screws and wires in the foal for the condition of angular limb deformities. They advocated their technique over that of epiphyseal stapling or external fixation, noting the "drawbacks" associated with the former. (see Table 2)

Table 2: <u>Disadvantages of Epiphyseal Stapling</u> (after Fackelman and Frölich 1972)

1. The placement of one tine of the staple automatically determines that of the other tine.
2. In the fitting of the staple to the contours of the bone, the cross-bar of the staple would have to bend thereby possibly changing the orientation of the staples tines which would in turn further traumatise the bone.
3. The accompanying tissue proliferation around the staple makes their location and extraction difficult.

They stated that the screws and wire technique possessed none of these disadvantages, and that extraction was performed through 3 stab incisions with a gratifying post-op appearance having little blemish formation.

Further reports appear in the literature of variations on the technique from that originally reported by Fackelman and Frölich as well as comparing and contrasting the stapling versus compression wiring techniques (Turner and Fretz 1977; Campbell 1977; Fretz, Turner and Pharr 1978; Fretz and Donecker 1983).These reports generally acknowledge that while neither technique was necessarily better at actually correcting the deformity, there exist fewer complications with screws and wires. They also put forth the contention that there would be an immediate compressive effect with the wiring technique that would not exist in that of stapling.

Heinze (1977a) contested this by noting cases of angular deformities of similar magnitude which had been corrected by stapling in a similar period of time.

The technique of tension band wiring continued to be popularized in equine surgery (McIlwraith 1982; McIlwraith and Turner 1987b; Stashak 1987) and appears to be currently in more widespread use than stapling.

Recently, their use in the correction of rotational deformities at the level of the distal metacarpal physis has been advocated (Krpan 1990; Krpan, White, Grant, Sande, Gallina and Newbury 1985).

viii) **Growth Acceleration Techniques:**

Periosteal Transection and Stripping

The technique of periosteal transection with periosteal stripping was first presented in the literature as a novel surgical treatment "worthy of further consideration" (Auer and Martens 1980).

At that time the primary impetus sited for it's use was a fear that the growth retardation techniques result in a bone which was shorter in length hence a technique which encouraged growth at the shorter side as opposed to retarding growth at the longer side, would be superior.

It is interesting to note that Heinze (1961) remarked that in cases of unilateral angular limb deformities which he treated with staples, the legs were of an equal length to that of the contralateral limbs. Heinze did suggest that this may not be so on a radiographic analysis. To date no one appears to have further addressed this contention.

The initial report by Auer and Martens (1980) was soon followed by other papers by the same group of workers. These papers outline the technique of periosteal transection and elevation/stripping, variations and improvement in technique and increasingly recognised merits and applications of periosteal transection and elevation (Auer 1982; Auer and Martens 1982; Auer, Martens and Williams 1982; Auer, Martens and Morris 1983).

In early experimental studies, Auer and Martens (1982) used the technique at the level of the lateral aspect of the distal radius, to first induce a valgus deformity and then again on the medial side to successfully correct the ALD. During the study the contralateral limb served as a control and the foals were kept on pasture and allowed to exercise. This in itself is somewhat astonishing given that even under these circumstances which would worsen the deformity, they were corrected following the second procedure. None of the foals overcorrected as a result of the second operation.

In a following report of 53 clinical cases treated by periosteal transection and stripping again, no overcorrection occurred (Auer 1982). The technique was originally applied deviations arising at the level of the distal radius and tibia (Auer and Martens 1980) then for the distal third metacarpal/tarsal bone (Auer 1982) for fetlock deviations. This in turn was followed by the report of the successful correction of deviations at the level of proximal phalanx (Auer 1985).

Auer has reported on it's use in the correction foals with a "bench" or "offset knee" conformation (Auer 1988, 1991). A condition he believes is a result of two opposing angular limb deformities, these being a valgus at the distal radius and a varus deformity of the proximal third of the third metacarpal bone. Other authors consider it to be an axial deformity uncorrectable by surgical means (Bramlage and Embertson 1990).

Variations and improvements on the technique included studies of the incisional axis in their orientation, along with the inclusion or exclusion of periosteal stripping (elevation) with a view towards the greatest success rate.

Auer and Martens (1982) found that in all cases where the periosteum was transected horizontally with or without periosteal elevation, clinical improvement was apparent within 5 months. In one foal with a bilateral carpal valgus, a single vertical periosteal incision was made (just proximal at the physis) in one limb and a similar incision was made in the periosteum of the other limb but with a conjoining horizontal hemicircumferential incision at the distal end of the vertical incision (an inverted "T-shaped" incision). The limb with the single vertical incision failed to correct by 2 months time whereas the contralateral limb with the inverted "T-shaped" incision had a correction of 7 degrees by 2 months time. They subsequently adopted this inverted T-incision on their following cases along with the incorporation of periosteal elevation without further consideration of the other 2 variants.

It is this procedure which has been popularised by the standard texts (McIlwraith and Turner 1987a, Stashak 1987, McIlwraith 1982, Auer 1990). Other authors (Bertone, Turner and Park 1985) state that hemicircumferential transection alone will correct angular deformities.

More recent studies have now suggested that it may be periosteal elevation, rather than transection and stripping, which is needed for this surgery to be successful (Mase 1987). This is a contention which is perhaps in conflict with the suggested aetiology whereby the periosteum is acting as a fibroelastic tube that surrounds the diaphysis and unites the two epiphysis into a competitive pair (Houghton and Dekel 1979). It also casts the belief that the rudimentary ulna (figure 8) is acting as an anchoring or tethering device which leads to carpal valgus formation (Auer 1982; Bertone, Turner and Park 1985; McIlwraith and Turner 1987) into some disrepute.

Figure 8:
The distal aspect of the rudimentary equine ulna (arrow).

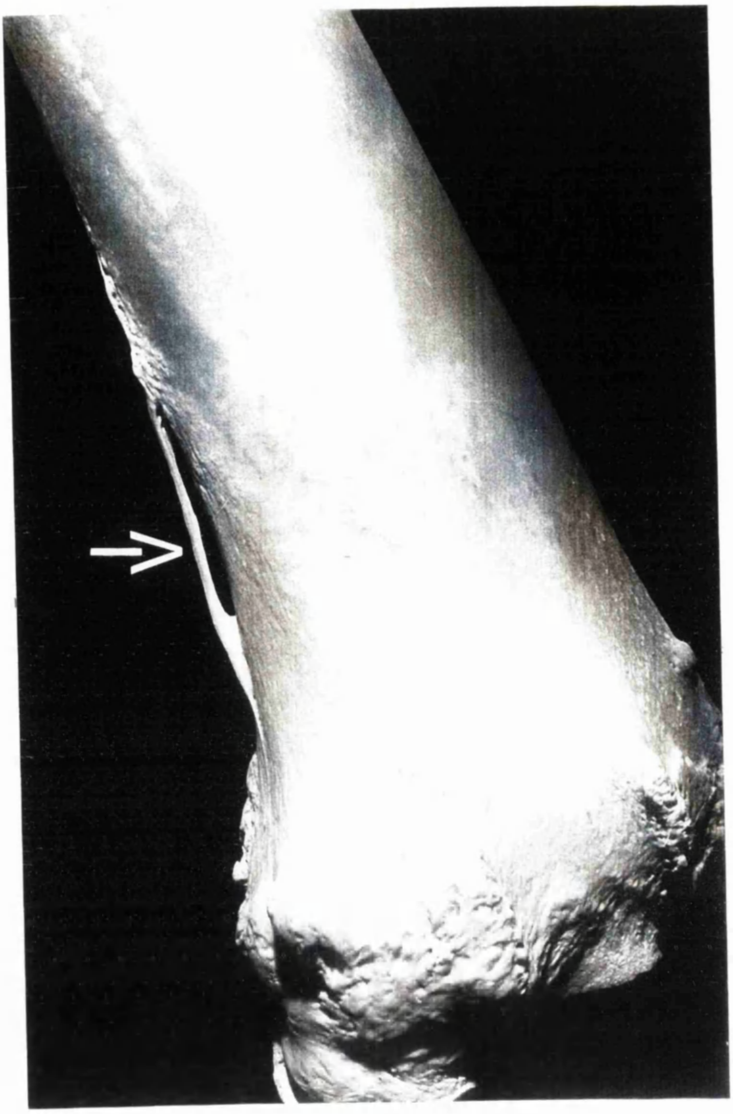


Figure 9:
A cross-section of the radius taken at mid-shaft.

M= Medial

L= Lateral

Cr.= Cranial

Cd.= Caudal

Of further interest is the report (Bertone, Turner and Park 1985) of the successful treatment of foals with angular limb deformities at the carpus after six months of age with hemicircumferential periosteal transection and periosteal stripping. Six months is near the time of physiological closure of the distal radial physis (Fretz 1980; Fretz, Cymbuluk and Pharr 1984).

ix) Transfixation of the Lateral Styloid Process

In a unique approach to the surgical treatment of carpal valgus deformities arising from the level of the growth complex, Heinze (1977c) proposed the technique of transfixing the lateral styloid process to the epiphyseal body.

The lateral styloid process is a developmental remnant of the vestigial equine ulna. It lies at the level of the distal radial epiphysis (figure 10) and represents a separate centre of ossification fusing with the distal end of the radius between 4 to 7 months of age (Heinze 1977c; Auer, Smallwood, Morris, Martens, McCall et al 1982; Auer, Martens and Morris 1983; Mase 1987).

Heinze reasoned that instability at this point could lead to the advent of a carpal valgus as well as rotational deformities. In his procedure a single vertical bone screw (4.5 mm ASIF) is placed either in lag or non-lag screw fashion, so as to transfix the lateral styloid process. This treatment was reported by Heinze (1977c) to be used successfully in 5 cases of carpal valgus, all less than 90 days of age with a 12 and 14 degree deviations. Little more is heard of this procedure other than brief mentions by other authors (Auer, Martens and Morris 1983; Turner 1986; Stashak 1987) as a historical oddity which is not to be recommended.

Interestingly, some 10 years after its initial report, Mase (1987) also recognised the phenomena of carpal valgus seemingly due to lateral instability of the styloid process. In a study of radial maturation and it's relationship in skeletal pathology of seventy foals, Mase comments on the strut-like support of the fused lateral styloid process and suggests that Heinze's work is worthy of further consideration.

x) <u>Transfixation of the Lateral Malleolus of the Tibia</u>

Heinze (1977c) proposed the technique of transfixation of the lateral "non-fused" malleolus of the tibia for the correction of tarsal valgus deformities not involving the cuboidal tarsal bones. The rationale behind the procedure is the same to that of the similar procedure previously discussed whereby the styloid process of the distal ulna is transfixed for correction of carpal valgus and/or rotational (supination) deformities of the forelimb. In a radiographic study of the developing equine tarsus (Smallwood, Auer, Martens, Morris, McCall et al 1984) the lateral malleolus of the tibia was said to be fused by 182 days of age. The earliest these authors noted was 57 days (6% of total cases). Heinze (1991 pers. comm.) acknowledged that to date (11/91) he has not carried out this procedure but he remains undoubting as to it's effectiveness citing that it was opportunity which prevented the application of the technique.

xi) <u>Osteotomy Techniques</u>

The actual use of closed wedge osteotomy in equine clinical cases has been described in the literature for the correction of diaphyseal angular deformities (White 1983) and fetlock varus angular limb deformities (Fretz and McIlwraith 1983). Few other reports of actual clinical cases treated by this means appear however, the topic is reviewed in length in the current standard equine surgical texts (Auer 1990, 1991) and in two current papers over-viewing current treatments for angular limb deformities in foals (Auer 1988, DeBowes 1991).

Diaphyseal angular limb deformities has been described as being an extremely rare limb deformity arising in the diaphyseal region of the third metacarpal or third metatarsal bone (White 1983). Because the site of origin of these deformities is not associated with a growth complex, correction is only possible via osteotomy techniques. In the particular series of cases, White (1983) described the successful treatment of 2 foals with diaphyseal angular deformities and the loss of the third case due to ischaemia of the operated limb. The 2 successful cases were said to have survived for useful performance.

Due to the physiological closure of the growth complex of the distal metacarpal/metatarsal bone by 120 days (Fretz 1980; Campbell and Lee 1981; Fretz, Cymbuluk and Pharr 1984) correction of an angular limb deformity arising at this level is not possible after this date by means of growth manipulation. Fretz and McIlwraith (1983) reported on a series of 5 foals aged greater than 120 days, which they "successfully" treated using a closed osteotomy.

For their case selection they used as criteria the fore mentioned age (>120 days), an eight degree or greater angular limb deformity, and an animal without any evidence of lameness or degenerative disease.

Their measure of success appears to have been an animal which was pasture sound, however, one animal was noted to be working as a stock horse at 3 years of age.

Since the time (1983) of these 2 reports of clinical cases, other osteotomy techniques have been presented in texts of equine surgery, however, no mention of their application to clinical material appears. These osteotomies are the open wedge, half wedge osteotomy and inversion of wedge, dome and step osteotomies, the step osteotomy being undertaken in either the frontal or sagittal plane.

The reader is referred to these works for further discussion of the techniques and their relative merits and drawbacks.

xii) <u>Salvage Arthrodesis</u>

Auer, Martens and Morris (1982) suggest that in severe cases of carpal angular deformities arthrodesis of the middle carpal joint may be warranted as a salvage procedure with a view towards further breeding purposes. This may be done following or in conjunction with a temporary transphyseal bridging technique to the distal radius whereby a second deformity is created to correct the limb axis (Auer, Martens and Morris 1982). These authors however, note that this axial correction may in turn perpetuate the degenerative joint disease. This belief is concurred by Wyn-Jones (1988). Little consideration of salvage arthrodesis is noted elsewhere in the literature.

1. Materials and Methods

The following case series represents a selection of clinical cases of angular limb deformities referred to Glasgow University Veterinary School (G.U.V.S.) between May 1988 to August 1991. They are presented to illustrate both the variable presentation of angular limb deformities and to exemplify some of the various treatments currently in use at G.U.V.S. The cases are presented both in brief case reports and in tabulated form (Table 3). Where possible, follow-up was by return to G.U.V.S. for re-evaluation both clinically and radiographically. This however, often proved difficult due to the lack of owner cooperation. In such instances, follow-up information was obtained by telephone conversation to the owner and/or referring veterinary surgeon. The follow-up period was quite variable and in some cases incomplete.

The anamnesis of these cases at presentation was based largely on the protocol of Stashak (1987) and the clinical examination of these cases was also carried out in a similar fashion to that of Stashak (1987).

Radiography was done in every case. The procedures which were followed in the methodology of their taking and the subsequent analysis of the radiographs has been reviewed. The radiography was carried out with a Triplex Optimac (Siemens, Stockholm), maximum kV and mAs 200 and 640 respectively. Dupont Cronex Quanta Fast Detail rare earth screens were used (Dupont, Wilmington) with Dupont Cronex 10 film. All films were processed automatically, using a Kodak RP X-Omatic model 101 processor (Kodak, Rochester).

In those cases treated surgically routine haematology and biochemistry was done. Occasionally, additional samples were also taken for non-routine mineral analysis (eg copper and zinc). Further mineral analysis was limited due to the reluctance of the G.U.V.S. laboratories to check for the levels of molybdenum, manganese and iron. The thyroid T-4 levels were checked in only one case (No. 117764) which had been on a diet with heavy supplementation using a seaweed product.

TABLE 3 Case Presentation

Foal No.	Breed	Sex	Age at onset (wk)	Age at Treatment (mo)	Age at Follow-up (mo)	Limb	Type of ALD	Angle of Deviation	Type of Treatment	2nd treatment	Amount of correction	Lameness at presentation	Lameness at followup	Use	Owner satisfactio	Other problems
108130	TBX	Male	B	3 weeks	26	RF	Carpus valgus	20 degrees	HCTP+PS splint	staples	5 degrees	yes	Ataxic	Hunter	no	Flexor deformity windswept foal later Ataxia 26 mo, P.M.=N.A.D.
						LH	Carpal varus	20 degrees	splint	hoof trim	almost straight					
108368	TB	Female	B	1	3	LH	Varus fetlock	9 degrees	conservative		almost straight	yes	none			Sickle hock conformation prox mt4
108480	TB	Female	B(?)	3	6	LF	Carpal valgus	?	HCTP+PS	-	-	no (2nd treatment)	none		moderate	blemish
							Fetlock valgus	18 degrees	HCTP+PS	HCTP+PS screws & wires	10 degrees					+ Rotation deformity
108538	TB-X	Male	B	2	3 years	LH + RH	Tarsal valgus		conservative		LH > RH	none	Pasture sound	Hunter	yes	Twin Collapsed T3 + TC tarsal bones
109082	QH	Male	6 wk	3	3 years	LF	Carpal valgus	9 degrees	HCTP+PS and screws & wires		3 degrees	yes	none	pleasure	yes	ALD developed secondary to lameness
							fetlock valgus	16 degrees			9 degrees					
						RF	fetlock valgus	11 degrees	HCTP+PS and screws+ wires		6 degrees					

TABLE 3 (continued) Case Presentation

Foal No.	Breed	Sex	Age at onset (wk)	Age at Treatment (mo)	Age at Followup (mo)	Limb	Type of ALD	Angle of Deviation	Type of Treatment	2nd treatment	Amount of correction	Lameness at presentation	Lameness at followup	Use	Owner satisfaction	Other problems
111160	Trotter	Male	B	3 weeks		RH LH	tarsal valgus fetlock varus	 10 degrees	HCTP+PS HCTP+PS		 5 degrees	none	none	trotter	yes	Seroma/blemish formation at distal tibia
115007	TB	Male	B	1	12	LF	Carpal valgus	18 degrees	HCTP+PS and medial ext. shoe	-	straight	none	none	Hunter Jumper	yes	Metaphyseal osteochondrosis Mild physitis (Distal Radial) LF>RF at follow-up.
115136	Han-x	Female	B	4	16	LF	Carpal varus	7 degrees	lat. ext.shoe 8 weeks		straight	yes	none	Hunter Jumper	yes	Mild physitis
117095	Con-x	Female	B	1	4	RF LF	Carpal valgus	11 degrees 6 degrees	HCTP+PS	-	straight	none	none	show	yes	? Developing physitis?
117764	App.	Male	B	5 weeks	3.5	RF LF RF	Carpal Valgus fetlock varus	23 degrees 23 degrees 11 degrees	conservative mgt. conservative mgt.		worse some improvement much improved	yes	yes	endurance		

Abbreviations used:

TB = Thoroughbred
QH = Quarterhorse
Han = Hanoveran
Con = Connamara
App. = Appaloosa

HCTP = Hemicircumferential of the periosteum
PS = Periosteal strip
B = Birth
NAD=No Abnormalities Detected

Clinical Case No. 1

Case number 108130 a three week old thoroughbred-cross colt presented as having a carpal valgus, right limb, and a rapidly increasing carpal varus, left limb, along with a concurrent flexural deformity and a ruptured common digital extensor tendon, left forelimb (see frontpiece). The foal was deemed small for its size however, the owner reported the gestation to have been "normal". No comment was made in the original case report as to the presence or absence of peri-articular laxity. Lameness was appreciated in the left forelimb. The owner reported that the condition was present since birth and was rapidly deteriorating.

Radiology confirmed the clinical impression of the deformities with a geometric analysis demonstrating a 22 degree valgus deviation of the rightfore and a 15 degree varus deviation of the leftfore. The point of intersection in both cases laid at the level of the distal radial epiphysis. The most notable radiographic finding was a discrepancy in the degree of ossification of the carpi, whereby the bones of the right carpus were clearly further ossified than those of the left (figures 10, 11, 12 and 13). Some degree of epiphysial "wedging" was appreciable as well physial ectasia in the right distal radius, whereas an overall appearance of incomplete ossification in the carpus of the left limb (Adams and Poulos Grade 3, Adams and Poulos 1988, Adams 1990) was apparent.

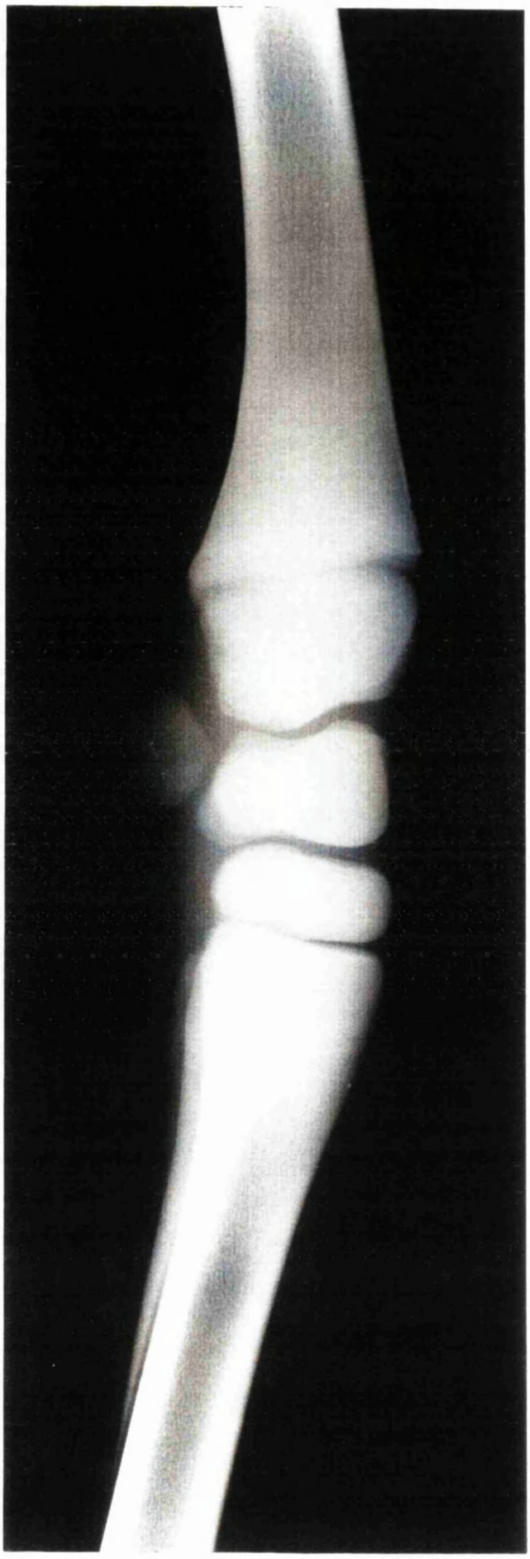


Figure 10 Figure 11

Figures 10 and 11: Lateral-medial views of left (figure 10) and right (figure 11) carpi of case no. 1. Both radiographs were taken at the same time. Note the differing degree of ossification. The lateral styloid process is clearly visible in figure 10.

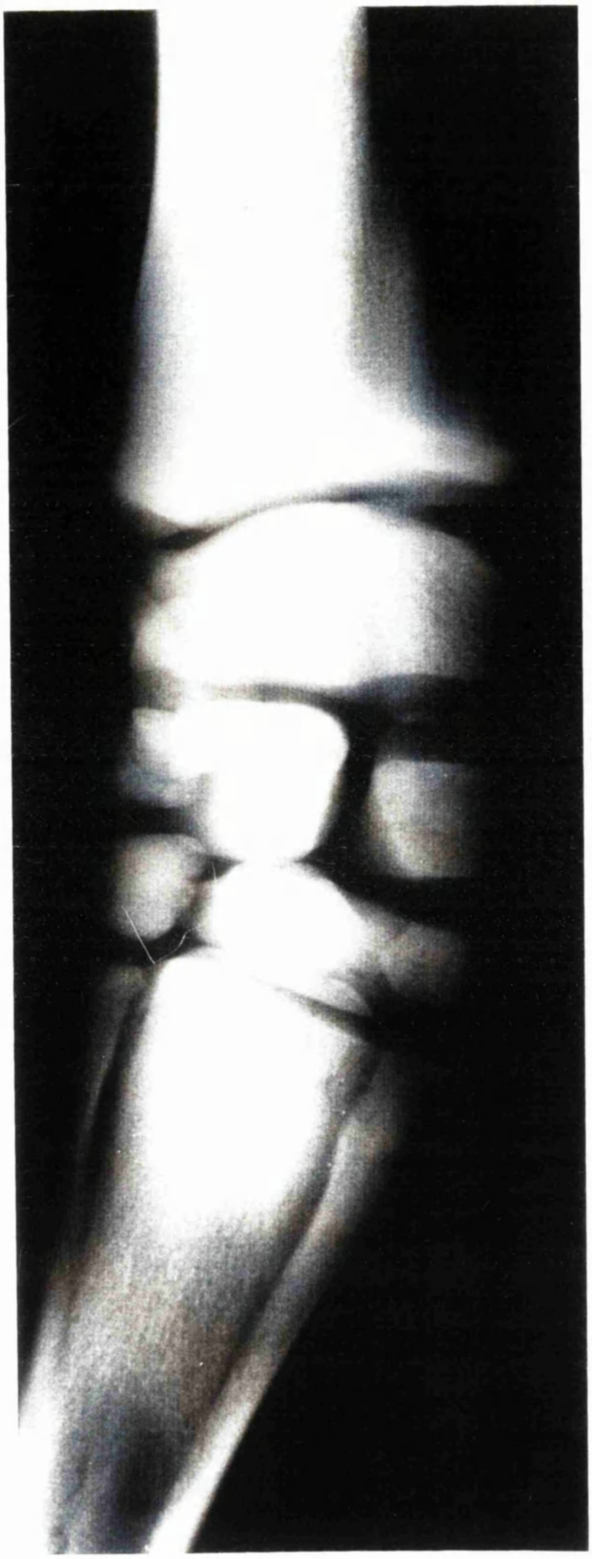


Figure 12

Figure 13

Figures 12 and 13: Craniocaudal views of the right (figure 12) and left (figure 13) carpi of Case 1. Both radiographs were taken at the same time. Note differing degree of ossification.

Treatment was to have consisted of hemicircumferential transection and strip of the periosteum at the level of the distal radius (lateral aspect of rightfore and medial aspect leftfore) along with corrective hoof trimming. Due to an anaesthetic crisis it was not possible to do both procedures during a single anaesthetic, therefore only the right forelimb was done at that time. Upon recovery from the anaesthetic, a splint and toecap were placed on the left forelimb.

The carpal valgus (R.F.) continued to rapidly worsen, presumably due to, or augmented by the concurrent lameness in the contralateral limb. The flexural deformity abated within a week's time hence the splint and toecap were removed. A marked instability was now noted in the right carpus, because of this, the limb was placed in a splint. Pressure sores began to develop by the second week of splinting. At this time it was decided to carry out a transphyseal bridging technique using two staples across the medial aspect of the right distal radial physis. This was without complications. Surgery was carried out only to the rightfore limb. A splint and toecap were removed at this time as that the flexural deformity was now resolved. Corrective balanced hoof trimming was now used aas the sole treatment of the carpal varus deformity. The staples were removed 6 weeks later at which time the carpal valgus (R.F.) was deemed to be approximately 5 degrees and the carpal varus unapparent. The foal was discharged with instructions to continue with regular balanced hoof trimming and judicious exercise.

Clinical Case No.2

Case number 108368 a four week old thoroughbred filly with a history of a left hindlimb deformity of the hock with ensuing lameness. The owner reported that the gestation was normal and that the abnormality was present at birth.

On examination it was noted that the foal had a tendency to rest the afflicted limb (L.H.) more so than the contralateral limb. A "sickle-hock" conformation with a false curb due to an excessively prominent proximal aspect of the fourth metatarsus (Mt4) was apparent. The most notable finding a reasonably severe fetlock varus of the left hindlimb. Manipulation failed to demonstrate an increase of peri-articular laxity, pain or resentment.

Radiographs were taken employing latero-medial and dorsoplantar/craniocaudal views of the left hock and left hind fetlock. There were no tarsal bone abnormalities detected, however, there was obvious "bowing" and proximal migration of the head of Mt4. The radiographs of the fetlock confirmed the clinical findings of a fetlock varus which determined to be approximately 9 degrees. The radiographs also demonstrated a metaphyseal and accompanying epiphyseal flare at the growth complex. A marked degree of sclerotic change at this level was also noted.

The findings were discussed with the owner along with possible treatment regimes. For economic reasons, conservative management was opted for. This consisted of balanced hoof trimming every four weeks along with restricted exercise until satisfactory results were acheived. On re-examination at three months of age, the conformation of the hock was much improved and the varus deformity was almost straight. There was no pain or resentment on either palpation or manipulation, nor was any lameness demonstrated. Radiographically the degree of metaphyseal and epiphyseal flare was diminished as were the sclerotic changes. The foal was discharged with routine instructions of regular balanced hoof trimming along with judicious exercise.

Clinical Case No. 3

Case number 108480 a three month old thoroughbred filly who was presented with a history of a left carpal and left forelimb fetlock valgus which was treated earlier at a public stud via a distal radial and distal cannon lateral hemicircumferential periosteal transection and strip. The history as given did not address any predisposing aetiological factors such as gestation length.

On examination the foal was noted to be well grown and that the carpal valgus was now insignificant. A mild rotational deformity was evident as was a scar of the previous periosteal transection and strip proximal to the left carpus. There was a moderate fetlock valgus (L.F.) and a considerable reaction at the site of the periosteal transection and strip at the lateral aspect of the distal metacarpal (Mc III) growth plate. There was no pain, heat or lameness present.

Radiographs of the leftfore fetlock confirmed a fetlock valgus of approximately 18 degrees. The physis was still "open" radiographically, but there was some evidence of closure. Metaphyseal and epiphyseal flare were evident, as were accompanying sclerotic changes and a marked ectasia of the physis.

Given these findings along with the age of the foal, it was decided to undertake a temporary transphyseal bridging technique as well as a periosteal transection and strip to correct the deviation. Screws and wires were used. These were removed three months later at which time the deviation was deemed to be approximately 8 degrees. Given the animal's age and the time of physeal closure at this site, this result was considered to be all that could be acheived. Balanced hoof trimming and restricted exercise were utilised throughout the management of this case. Further post-operative followup was not possible.

Clinical Case No. 4

Case number 108538 a two month old thoroughbred-cross colt with a severe bilateral tarsal valgus. The colt was a surviving twin.

On examination it was noted that the right leg was deviated slightly more than the left. The deviation appeared to arise primarily from the tarsometatarsal region. The foal was very narrow in it's hocks so much so that the medial malleoi of both hindlegs were knocking together. There was no distension of the tibial tarsal joints of either limb, however, there was an obvious sickle hock conformation to both limbs with a false curb formation. No lameness was detected nor was there any pain on either palpation or manipulation. Both hocks appeared to have a normal range of motion, and no instability was noted.

Lateral to medial and dorsoplantar radiographs were taken of both hocks. The lateral-medial views demonstrated collapsed central and third metatarsal bones in both tarsi with a prolapse of bony material dorsally as well as a bowing and proximal migration of the head of Mt4. There was obvious bony reaction around the prolapsed tarsal bones and some reaction within the intertarsal joints (figure 14). There were also changes at the level of the distal tibial physis whereby metaphyseal and epiphyseal flaring, ectasia and surrounding bony sclerosis were apparent. The changes were greater in the right hindlimb than in the left.

Figure 14: Case no. 4, Lateral-medial view of left hock at presentation. Note collapse of central and third tarsal bones along with prolapse of boney material.

These findings were discussed with the owner along with a poor prognosis with respect to intended use (ie; riding horse). The owner, however, elected for treatment in the form of conservative mangement.

Over the course of the next 6 months the foal returned to G.U.V.S. on four occasions to have the animal's condition reassessed both clinically and radiographically. During this period the foal remained sound, albeit under a limited exercise regime. The gait was seen to be altered such that whereby the breakover point was shifted to the medial aspect of the hoof (R.H. > L.H.) yielding a peculiar "rolling" action to the hindlimb gait. The owner was advised to have the horse shod with hindshoes which have an increased medial web in an effort to shift the axis of breakover to centre. This was done when the animal was at seven months of age and it continued to be shod such for the next year. To date the horse is pasture sound. The tarsal valgus although diminished is still evident. The most astonishing change was that seen radiographically (figure 15) which demonstrated a high degree of bony resorption and remodeling without the rampant development of degenerative joint disease as might have been expected.

Figure 15: Case number 4 - Lateral-medial view of the left hock six months post-presentation. Note remodelling of central and third tarsal bones (c.f. figure 13).

Clinical Case No. 5

Hospital case number 109082 a nine week old quarterhorse filly with a left fore carpal and fetlock valgus and a right fore fetlock valgus which the owner reported as being acquired at approximately six weeks of age. The history was such that the foal was noted to have been lame at that time (ie; aged six weeks) on the right forelimb. This lameness was attributed, by the referring veterinary surgeon, to be due to a "firm hot swelling on the dorsal surface of the mid-cannon". A diagnosis of "traumatic tendinitis" was made and the referring veterinary surgeon elected to place the limb in a plaster cast extending from the level of the coronary band to the level of the distal carpus. The limb remained in a plaster cast for the next nine weeks. At the seventh week of the treatment the referring veterinary surgeon noted a developing angular limb deformity in the contralateral limb (L.F.) and decided to place this limb in a similar cast. The foal was presented to G.U.V.S. at four months of age with both forelimbs in a Robert-Jones type bandages which ran from the level of the coronary bands to the distal carpi. Upon removal to the bandages valgus deformities were noted at the level of both fore fetlocks and at the left carpus. A fair degree of flexor tendon laxity in both forelimbs was apparent. This was presumably, secondary to the prolonged bandaging/casting of the limbs.

The radiographic findings confirmed those of the clinical examination. The points of intersection of all three deviations laid at the level of the epiphyses and the angulation was determined to be a 9 degree carpal valgus and a 16 degree fetlock valgus in the leftfore and a 11 degree fetlock valgus rightfore.

Given the advancing age of the foal it was decided to carry out both a hemicircumferential periosteal transection and strip and temporary transphyseal bridging techniques together at the appropriate sites. Screws and wires were used in the bridging technique. The recovery was uneventful and the implants were removed two months later. Radiographs at the time of removal demonstrated the angles of both the fetlock deviations to be approximately 5 degrees and that of the left carpus to be 6 degrees. The horse was reported to be pasture sound (October 1991) and the owner was intending to put the mare to stud.

Clinical Case No. 6

Case number 111160 a three week old male trotter with a history of an angular limb deformity of the right hindlimb present since birth which has been progressively worsening. The owner reported that the gestation was normal and that this was the only foal of a group affected with an angular limb deformity.

On examination the foal was judged to be slightly heavier bodied than would be expected for a foal of it's age and breed. A severe tarsal valgus was apparent on the right hindlimb as was a moderate fetlock varus of the left hind. There was no lameness, heat or pain in either of the regions and no instability in the associated joints.

Radiographs of the tarsal region revealed no abnormality of the tarsal bones themselves, however, at the level of the distal tibial growth plate some degree of metaphyseal flaring and sclerosis as well as ectasia was noted. Radiographs of the lefthind fetlock confirmed the angular deformity to be a 10 degree varus involving the distal metatarsal growth complex.

It was decided to perform a hemicircumferential periosteal transection and strip on the distal tibia of the right hindleg and the distal cannon of the left hindleg. Recovery and aftercare was uneventful except for the formation of a large seroma over the operation site of the righthind. This resolved with only a minor blemish formation.

The colt was seen again at G.U.V.S., eleven weeks later. The angular limb deformities appeared to be clinically resolved at this time. There was no pain or resentment on palpation or manipulation. There was no appreciable lameness.

Radiographs confirmed the clinical findings. A mild periosteal reaction was visible on the lateral malleolus (R.H.) only in the craniocaudal view. This was regarded only as an incidental finding, secondary to the periosteal transection and strip.

As a three year old entering training the colt was regarded by the owner to be sound and the deviations resolved.

Clinical Case No. 7

Case number 115007 a one month old thoroughbred colt with a left carpal valgus present since birth which was gradually worsening. The owner reported that the foal had previously been lame on the leftfore but the lameness had resolved itself without interference. The foal was kept in a large field with others and was said to be extremely active.

Examination confirmed the carpal valgus deformity (L.F.). The colt was not lame, but there was an obvious firm swelling on the medial aspect of the distal radial growth plate (L.F.), this was without pain, heat or resentment to palpation. A tentative diagnosis of a carpal valgus deformity (L.F.) with concomitant physitis was made.

Radiographs provided further confirmation of the deformity and accompanying physitis. On measuring the angulation it was found to be approximately 18 degrees with an intersection point at the level of the distal radial physis. The most unusual feature of the radiographs was however, the presence of changes at the level of the medial aspect of the left fore distal radial metaphyseal region which are consistent with a diagnosis of osteochondrosis (Stashak 1987, DeBowes 1991 pers. comm.) see figure 6.

A hemicircumferential periosteal strip and elevation was carried out at the level of lateral aspect of the distal radius. The hoof was trimmed and balanced and a medial extension shoe fabricated from plastic (figure 16) was glued on.

Figure 16: Application of an extension shoe.

The medial extension shoe was kept on the hoof for the next four weeks during which time the foal was under box rest. A restricted exercise regime was implemented thereafter. The recovery was uneventful and at follow-up at twelve months of age the limb was essentially normal however there was a mild rotational "deformity" emanating high in the limb. There was also a mild physitis at the distal radii, the left being more prominent, there was no lameness, pain, heat or resentment to palpation. The previously described osteochondritic lesion was no longer radiographically apparent.

Clinical Case No.8

Case number 115136 a four month old Hanovarian-cross filly with a history since birth, of an mild angular limb deformity of the leftfore which had also been associated with enlargement of the distal radial physis.

On examination the foal was noted to be well grown if not overly large for her age. The owner reported that she was on a highly supplemented diet and that the mare was also a "heavy milker". There was a marked metaphyseal flaring at the level of the distal radial physis (left greater than right). These were non-painful on both palpation and manipulation. There was no apparent lameness. A diagnosis of mild carpal varus of the left foreleg with a concurrent distal radial physitis in both limbs was tentatively made.

Radiographs confirmed the diagnosis of a carpal varus (L.F.) of approximately 7 degrees with evidence of physitis. A pivot point at the level of distal radial physis was seen. Given these findings conservative management was opted for along with the use of a plastic lateral extension shoe. The owner was also given advice with respect to the foal's dietary needs and blood samples were taken for full biochemical profiles including copper and zinc; the results of these were within acceptable ranges.

The foal was seen at six months of age and again at sixteen months. The angular deformity was reduced (from 7 degrees to 4 degrees) and the physitis appeared to be less aggressive.

There was no appreciable lameness present at the times of representation and no pain or resentment to either palpation or manipulation.

Clinical Case No. 9

Case number 117095 a one month old Connamara-cross filly with bilateral carpal deformities present since birth, which the owner reported to be rapidly increasing in severity. On examination the foal was noted to be well grown, heavy bodied and very active. The owner reported of a normal gestation period and that the foal was not receiving heavy dietary supplementation. It was also reported to be the only foal affected as such, on the farm. The foal was not lame and there was no pain or excessive joint laxity on palpation and manipulation of the carpi and associated structures.

Radiographic examination confirmed the clinical findings and demonstrated the deformities to be largely seated at the level of the distal radial physes. The angulation was determined to be 11 and 6 degrees for the right and left limbs respectively.

A bilateral periosteal transection and strip was performed without event. The hooves were trimmed and balanced and the foal was later discharged with instructions for restricted exercise, regular balanced hoof trimming on a frequent basis (every 4-6 weeks) and program of dietary awareness (ie care not to overfeed).

Follow-up was last at four months of age by means of telephone conversation with the referring veterinary surgeon, who reported the limbs to be "straight", however, it appeared from the description, to be developing a physitis at the level of the distal radii. Radiographic confirmation was not possible.

Clinical Case No.10

Case number 117764 a five week old appaloosa colt born with bilateral carpal valgus deformities and a fetlock varus deformity of the right hind limb. The owner believed that the condition had improved yet elected to have the colt seen by G.U.V.S. as that it had also been recently complicated by a dog bite to the righthind (R.H.).

On examination severe carpal valgus of both limbs was noted with that of the right fore (R.F.) being slightly worse than that of the left fore (L.F.). There was a moderate degree of outward rotation (supination) in the R.F. as well. The animal was also noted to have fetlock varus (R.H.) and there was some thickening over the fetlock and cannon region which the owners reported to be associated with the dog bite. Clinical examination of the joints of the affected limbs did not demonstrate any degree of joint laxity or pain however the colt was slightly lame at the walk on the left fore.

Radiographs verified the clinical presentation. Chief amongst the radiographic findings of the carpi, were epiphyseal wedging as well as marked wedging of the third carpal bone in both carpi. The angulation was determined to be approximately 23 degrees in both carpi with the pivot-points being located within the distal radial epiphysis. The radiographs of the fetlock varus (R.H.) demonstrated an epiphyseal wedging effect along with some degree of metaphyseal flare. The angulation was approximately 11 degrees with a pivot point at the distal metaphysis of the third metatarsal bone.

These findings were explained to the owner along with the possible treatments, foremost amongst which was surgical intervention. A poor to guarded prognosis with respect to intended use (endurance racing) was also given. Due to economic constraints the owner opted for conservative management despite the poor prognosis. This management consisted of restricted exercise, balanced hoof trimming and feed ration formulation. It should be noted that blood samples were taken for biochemical analysis inclusive of zinc and copper. The latter was especially of interest since the animal had been receiving a heavy supplementation of sea-weed. The findings of these tests were inconclusive.

At follow-up two months after the initial presentation, the varus deformity had improved immensely however there had been a deterioration of that of the R.F. carpal valgus. A positive joint trust and accompanying lameness was present in this limb (R.F.). A minor improvement was noted in the left fore limb (figures 17, 18 and 19). The owners wished to continue with conservative management, despite the prognosis.

The dog bite resolved without complication.

Figure 17

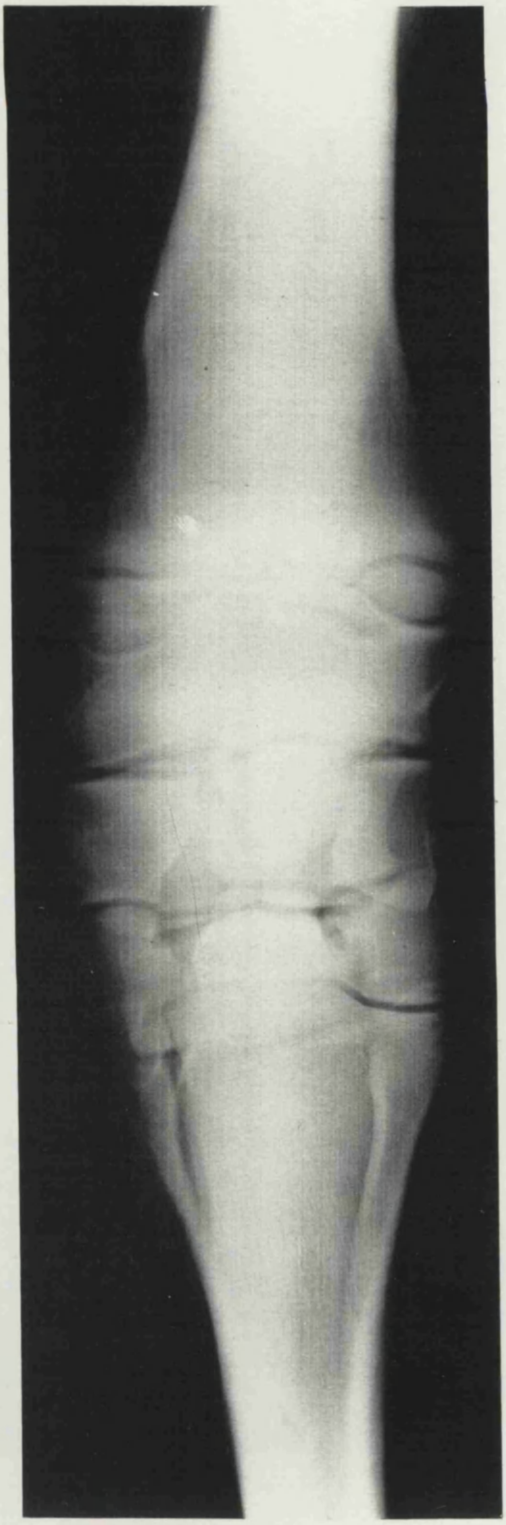
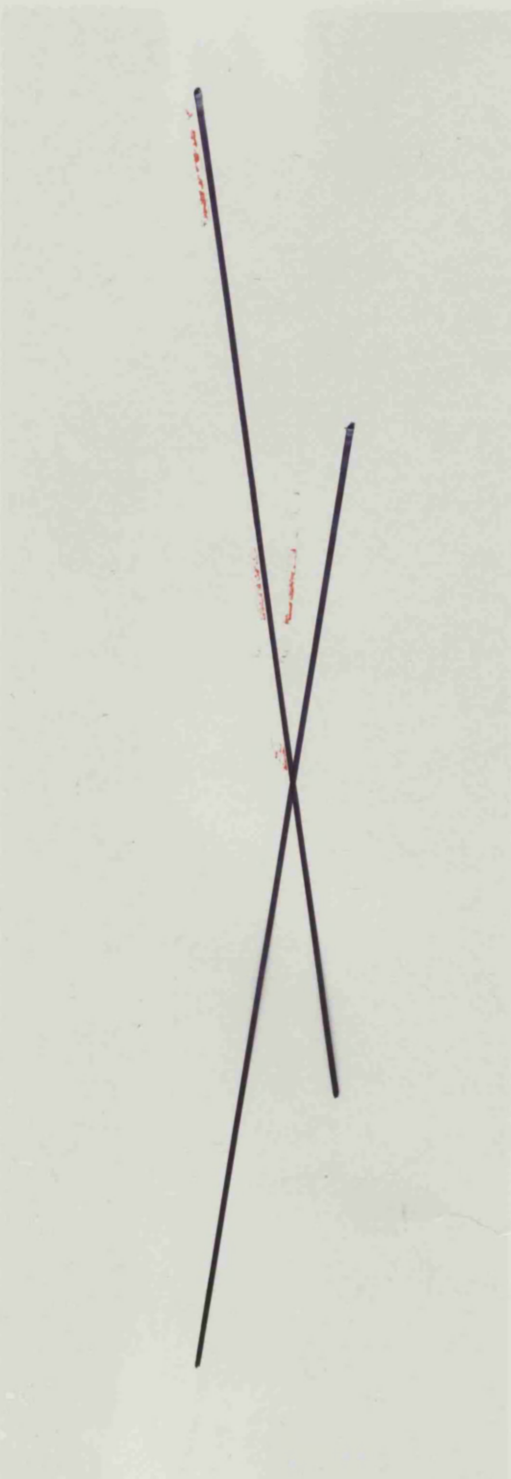
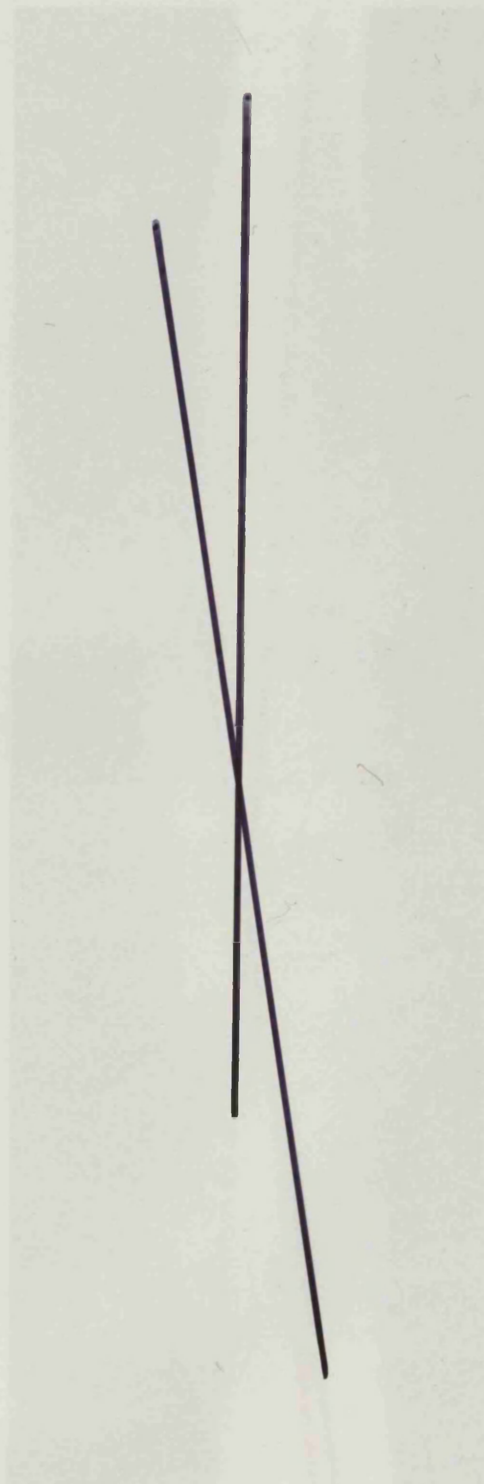


Figure 18

Figures 17 and 18: Craniocaudal views of right (figure17) and left (figure 18) carpi of case 10. Both radiographs were taken at the same time. Note the differing angulation and pivot points achieved on overlays A and B. See text for discussion.





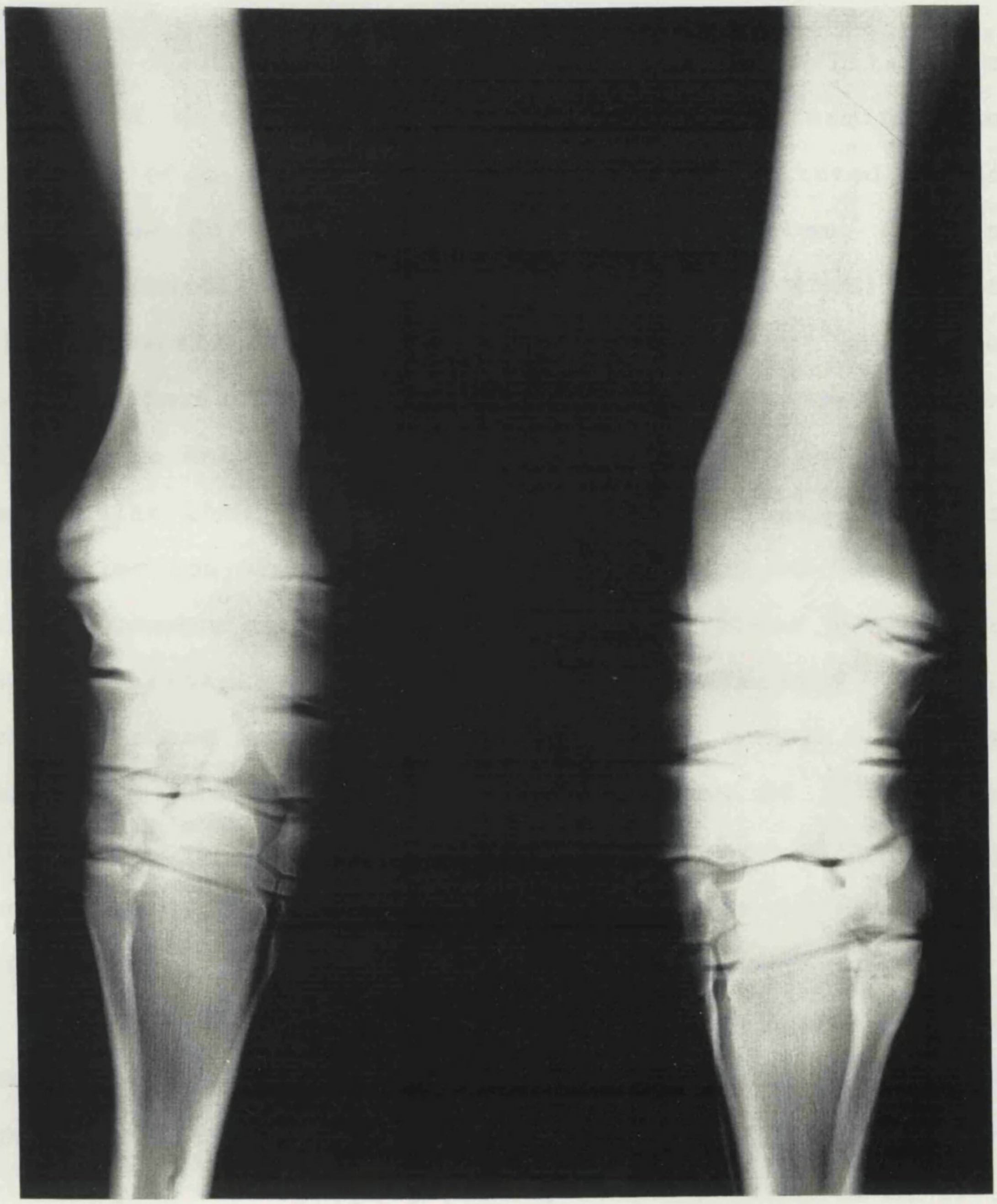


Figure 19: Case 10. The "Nancy View", compare the angulation of the above to that of figures 17 and 18. These radiographs were all taken on the same occasion. Every effort was made to position the foal such as to be truly representative of the clinical picture.

Discussion

The aim of this treatise was to review the literature pertinent to the condition of angular limb deformities and in light of this, to review the treatment instituted in such cases seen at G.U.V.S. as well as their outcome. In doing this an immediate need to adopt a standard protocol of both the anamensis and the clinical examination of this cases became apparent and was implemented. It also became apparent that there exist many areas of the management and treatment of angular limb deformities which remain unclear as to both the selection of treatment and the probable outcome. Often the treatment and management regimes utilised at G.U.V.S. and by clinicians elsewhere, are multifaceted. This in itself is not incorrect, but there exists a need for a more concrete knowledge and quantification of the actual individual contribution of each component. This in turn would aid the clinician in the selection of particular technique or procedure and the probable outcome.

Clinical cases 1,4, and ten of this dissertation, are examples whereby conservative management achieved favourable results. The results of case 4 were fairly remarkable and contrary to what was prognosed by others (Shaver et al 1979, Turner 1986). Adams (1990) stated the need for continued studies as to the effects of restricted exercise. The outcome of these previously described cases augments this claim.

Exploration of the results achievable by the use of extension shoes also requires more attention. The biomechanical forces achieved with extension shoes needs to be evaluated. Only one author (Wyn-Jones 1988) offers any kind of explanation of their underlying effects (figure 20). He fails though, to substantiate this with experimental or clinical data or even references thereto. The work of Firth, Schamhardt and Hartman (1988) throws the whole concept of the "balanced hoof" into some question, hence too, the forces generated by extension shoes. It should be noted that this is the sole publication as such to date. This in turn baits further work which could either replicate their results or to lead it into refute or question.

With respect to the re-emergence of dynamic orthotic devices; further case series results need to be published to uphold the claims of those manufactures as to their efficiency and lack of complications (eg; pressure necrosis and acquired flexural deformities).

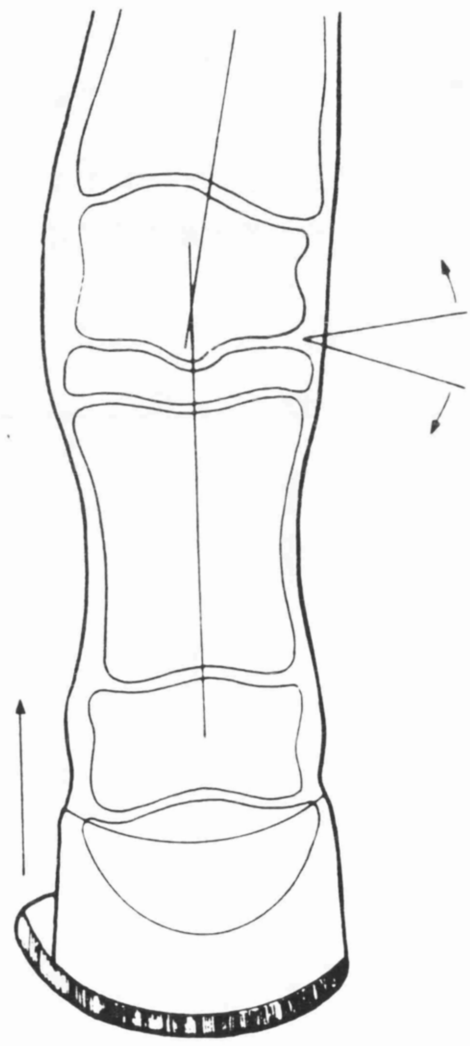
As an interesting post-script to Case No. 1, the animal at 26 months of age at which time the owner reported the animal as having had bouts of ataxia. It was also noted to be poorly grown. A mild degree of carpal valgus (R.F.) and varus (L.F.) were still clinically appreciable. Examination failed to demonstrate any gait or neurological deficit. Radiographs of the cervical vertebrae did not demonstrate any malformations although some evidence of increased height of the articular processes was suggested, but not agreed upon by conferring clinicians. The owner elected to have the horse euthanased and a post mortem performed. The only notable findings of this were a moderate degree of intestinal and hepatic parasitism and erosions of the articular cartilage of both elbows. It is interesting to speculate on the possibility of an inter-relationship of the different components of developmental orthopaedic disease these being angular limb deformity, osteochondrosis and cervical vertebral malformation in this particular case (Wagner, Grant, Watrous, Appel and Blythe 1985) reported on a possible heritable relationship between the latter two conditions in a group of twelve mares with known cervical vertebral instability bred to stallions similarly affected. These authors also noted an increase incidence of physitis and flexural deformities. There was no report of angular limb deformities in the twenty-two resulting offspring and it would be mere conjecture to suggest a direct heritability at this stage of the aetiological knowledge behind angular limb deformity.

Throughout the literature we are reminded that the radiographic examination is of tremendous value. This is undeniable, yet there exists no definitive description of the procedure of the geometric analysis of the radiographs. The descriptions which are given (O'Brien and Meagher 1971, Fretz 1980, Auer, Martens and Morris 1982, 1983) are largely given as line drawings. In those illustrations utilising actual radiographs (Auer, Martens and Morris 1983) it is not clear as to where the authors were plotting the mid-points of the radial shaft. It became apparent in the analysis of radiographs at G.U.V.S., that the radiographic shadow of the radius is not evenly opaque. This is the result of the elliptical cross-sectional architecture of the radius and the differing bone density existing medial-lateral (figure 9). If the mid-points of the radius are taken as those of the most radio-opaque image as appears to have been done by Auer et al (1983), the angulation as well as the point of intersection differs greatly from those determined utilising the mid-points lying in the true centre of the whole radiographic shadow (see figures 17, 18 and 19). This in turn creates the need for the development of a universally agreed standard with respect to the geometric analysis. This is especially so, if the angle of deviation and amount of correction possible prior to physeal closure, are taken as both indices of the treatment and the prognosis.

In summation, a wealth of material has been published on the subject of angular limb deformities, the largest part of which addresses surgical treatment, whereas very little information has been published on the conservative management of these cases. There also exists a large need for continued research into the aetiopathogenesis of angular limb deformities. Evidence suggests that this research should be concerted or inclusive of developmental orthopaedic diseases as a whole rather than being limited simply to the single condition.

Lastly, some accord must be reached in the aforementioned problems of the radiographic analysis if such analyses are to be used both as indices of treatment prognosis and as a means of dialogue or nomenclature between veterinary surgeons, students and clients.

Figure 20 :
The biomechanics of the extension shoe. "Fitting a shoe full on the convex side of the deviation will produce a straightening effect by reversing the stress concentration which exists on the concave side and by opening up the fetlock joint as illustrated". (Wyn-Jones 1988) used with permission of Blackwell Scientific Publications, Oxford.



Bibliography

ADAMS, O.R. 1966. Lameness. In Lameness in horses 2nd. ed., Philadelphia, Lea and Febiger p.168-174.

ADAMS, O.R. 1974. Lameness.In Lameness in horses 3rd.ed., Philadelphia, Lea and Febiger p.171-181 and p.217-219.

ADAMS, R. 1990. Non-infectious orthopedic problems. In Koterba, A.M., Drummond, W.H. and Kosch, P.C. (ed.s): Equine clinical neonatology. Philadelphia, Lea and Febiger, p. 333-336.

ADAMS, R. and Poulos, P. 1987. Radiographic evaluation of the carpal and tarsal regions of neonatal foals. In Proc. of 33rd Ann. Mtg. Am. Assoc. of Equine Practnr. 33:677-682.

ADAMS, R. and Poulos, P. 1988. A skeletal ossification index for neonatal foals. Veterinary Radiology 29:217-222.

AUER, J.A. 1982. Periosteal transection for correction of angular limb deformities. In Proc. 28th Ann. Mtg. Am. Assoc. of Equine Practnr. 28:223-243 .

AUER, J.A. 1985. Periosteal transection of the proximal phalanx in foals with angular limb deformity of the metacarpo / metatarsaophalangeal area. J. Am. Vet. Med. Assoc. 187:496-499.

Auer, J.A. 1988. Current treatment methods for angular limb deformity problems in foals. In Proc. 34th Ann. Mtg. Am. Assoc. of Equine Practnr. 34:263-282.

AUER, J.A. 1990. Appendicular deviations. In White, N.A. and Moore, J.N. (ed.s):In Current practice of equine surgery. Philadelphia, Lippincott, p. 482-500.

AUER J.A. 1991. Diseases of the musculoskeletal system. In Colahan, P.T., Mayhew, I.G., Merritt, A.M. and Moore, J.N. (ed.s):In Equine medicine and surgery 4th ed. Goleta CA., American Veterinary Publications, Inc., p. 1248-1253 and p. 1298-1307.

AUER, J.A. and Martens, R.J. 1980. Angular limb deformities in young foals. In Proc. 26th Ann. Mtg. Am. Assoc. of Equine Practnr. 26:81-86.

AUER, J.A. and Martens, R.J. 1982. Periosteal transection and periosteal stripping for corrections of angular limb deformities in foals. Am. J. Vet. Res. 43:1530-1534.

AUER, J.A., Martens, R.J. and Morris, E.L. 1982. Angular limb deformities in foals: Congenital factors. Compend. Contin. Ed. Pract. Vet. 4:330-339.

AUER, J.A., Martens, R.J. and Morris E.L. 1983. Angular deformities in foals: Developmental factors . Compend. Contin. Ed. Pract. Vet. 5:29-35.

AUER, J.A., Martens, R.J. and Williams, E.H. 1982. Periosteal transection for correction of angular limb deformities in foals. J. Am. Vet. Med. Assoc. 181:459-466.

AUER, J.A., Smallwood, J.E., Morris, E.L., Martens, R.J., McCall, V.H., Roenigk, W.J., and Boyd, C.L. 1982. The developing equine carpus from 6 month of age. Equine practice 4:35-55 .

BERTONE, A.L. Turner, A.S., and Park, R.D. 1985. Periosteal transection and stripping for treatment of angular limb deformities in foals: Clinical observations. J. Am. Vet. Med. Assoc. 187:145-152

BRAMLAGE, L.R. 1987. Clinical manifestations of disturbed bone formation in the horse. In Proc. 33rd Mtg. Am. Assoc. of Equine Practnr. 33:135-138.

BRAMLAGE, L.R. and Embertson, R.M. 1990. Observations on the evaluation and selection of foal limb deformities for surgical treatment. In Proc. 36th Ann. Mtg. Am. Assoc. of Equine Practnr. 36:273-279.

BRIDGES, C.H., Womak, J.E., Harris, E.D. and Scrutchfield, W.L. 1984. Considerations of copper metabolism in osteochondrosis of suckling foals. J. Am. Vet. Med. Assoc. 185:173-178.

BROWN, M.P. and MacCallum, E.J. 1975. A system of grading ossification in limbs of foals to assisst in radiologic interpretation. Am. J. Vet. Res. 36:655-661.

BROWN, M.P. and MacCallum, E.J. 1976. Observations on growth plates in limbs of foals. Vet. Rec. 98:443-446.

CAMPBELL, J.R. 1977. Bone growth in foals and epiphyseal compression. Equine Vet. J. q:116-121.

CAMPBELL, J.R. and Lee, R. 1981. Radiological estimation of differential growth rates of the long bones of foals. Equine Vet. J. 13:247-250.

DEBOWES, R.M. 1990. Carpal and tarsal cuboidal bone anomalies. In White, N.A. and Moore, J.N. (ed.s): Current practice of equine surgery. Philadelphia, Lippincott, p.501-503.

DEBOWES, R.M. 1991. Management of angular limb deformities in foals. In Proc. 4th Ann. European Mtg. Am. Coll. Vet. Surgeons 4:211-214.

DELAHANTY, D.D. and Gibbons, R. 1953. Traumatic epiphysitis in a young foal with metacarpus Vara. J. Am. Vet. Med. Assoc. 123:31-32.

DENNY, H.R. 1989. Growth disturbances in foals. In Treatment of equine fractures. Wright, London, 1989 p.14-24.

ELLIS, D.R. 1976. Growth plate defects in foals - Correspondence,
Vet. Record 98:225.

Ellis, D.R. 1981. Correction of angular limb deformities in foals. In Practice, 3:20-23.

FACKELMAN, G.E. and Frölich, D. 1972. The current status of ASIF technique in Large Animals. In Proc. 18th Ann. Mtg. Am. Assoc. of Equine Practnr. 18:325-328.

FACKELMAN, G.E., Reid, C.F., Leitch, M. and Cimprich, R. 1975. Angular limb deformities in foals. In Proc. 21st Ann. Mtg. Am. Assoc. of Equine Practnr. 21:161-166.

FARLEY, M. 1989. Fixing the unfixable. Thoroughbred of California 2:50-59.

FIRTH, E.C. and Poulos, P.W. 1987. Development of the epiphysis, metaphysis and traphysis in the foal. In Proc. 33rd. Ann. Mtg. Am. Assoc. of Equine Practnr. 33:787 -794.

FIRTH, E.C. and Schamhardt, H.C. and Hartman, W. 1988. Measurements of bone strain in foals with altered foot balance.
Am. J. Vet. Res. 49:261-265.

FRETZ, P.B. 1980. Angular limb deformities in foals. Vet. Clin. North Am. (Large Anim. Pract.) 2:125-148.

FRETZ, P.B., Turner, A.S. and Pharr, J. 1978. Retrospective comparison of two surgical techniques for correction of angular deformities in foals. J. Am. Vet. Med. Assoc. 172:281-286.

FRETZ, P.B., Pharr, J.W., McIlwraith, C.W., Piermattei, D.L., Turner, A.S. and Auer, J.A. 1982. Varus vs. valgus. In Letters. J. Am. Vet. Med. Assoc. 181:636-637.

FRETZ, P.B. and Donecker, J.M. 1983. Surgical correction of angular limb deformities in foals: A retrospective study. J. Am. Vet. Med. Assoc. 183:529-532.

FRETZ, P.B. and McIlwraith, C.W. 1983. Wedge osteotomy as a treatment for angular deformity of the fetlock in horses. J. Am. Vet. Med. Assoc. 182:245-250.

FRETZ, P.B., Cymbuluk, N.F. and Pharr, J.W. 1984. Quantitative analysis of longbone growth in the horse. J. Am. Vet. Res. 45:1602-1609.

Frost, H.M. 1988. Structural adaptations to mechanical usage. A proposed "Three-way Rule" for Bone Modelling. Vet. Comp. Ortho. Trauma. 2:80-85.

GABEL, A.A., Knight, D.A., Reed, S.M., Puttz, J.A., Paver, J.D., Bramlage, L.R. and Tyznik, W.J. 1987. Comparison of incidence and severity of developmental orthopaedic disease on 17 farms before and after adjustment of ration. In Proc. 33rd. Mtg. Am. of Equine Practnr. 33:163-170.

GETTY, R. 1975. Sisson and Grossman's The anatomy of the domestic animals 5th ed. Philadelphia, W.B. Saunders Co.

GLADE, M.J. and Belling, T.H. 1986. A dietary aetiology for osteochondrotic cartilage. J. Equine Vet. Science. 3:151-155.

GREEN, D.A. 1961. A review of studies on the growth rate of the horse. Brit. Vet. J. 117:181-191.

GREEN, D.A. 1969. A study of growth rate in TB foals. Brit. Vet. J. 125:539-545.

GUFFY, M.M. and Coffman, J.R. 1969. The variability of angular deformity of the carpus in foals. In Proc. of 15th. Ann. Mtg. Am. Assoc. of Equine Practnr. 15:47-58.

HEINZE, C.D. 1963. Epiphyseal stapling. In Proc. 9th. Ann. Mtg. Am. Assoc. of Equine Practnr. 9:203-216.

HEINZE, C.D. 1966. Epiphyseal stapling in the horse: An effective surgical technique for correcting angular limb deformities. Med. Vet. Pract. 47:40-44.

HEINZE, C.D. 1969. Epiphyseal stapling - A surgical technique for correcting angular limb deformities. In Proc. 15th. Ann. Mtg. Am. Assoc. of Equine Practnr. 15:59-73.

HEINZE, C.D. 1977a. Etiology of angular deformities. In Proc. 23rd. Ann. Mtg. Am. Assoc. of Equine Practnr. 23:289.

HEINZE, C.D. 1977b. An updating on physeal stapling. In Proc. 23rd. Ann. Mtg. Am. Assoc. of Equine Practnr. 23:289-294.

HEINZE, C.D. 1977c. Transfixation of the lateral styloid process- a method for early correction of carpus valgus. In Proc. 23rd. Ann. Mtg. Am. Assoc. of Equine Practnr. 23:294-300.

HEINZE, C.D., Miller, W.E., Reed, W.O. and Rooney, J.R. 1965. Orthopaedic panel epiphyseal closure and stapling. In Proc. 11th. Ann. Mtg. Am. Assoc. of Equine Practnr. 11:273-293.

HINTZ, H.F. 1987. Factors which influence developmental orthopaedic disease. In Proc. 33rd. Ann. Mtg. Am. Assoc. of Equine Practnr. 33:159-162.

HOUGHTON, G.R. and Dekel, S. 1979. The periosteal control of longbone growth, Acta Orthop. Scand. 50:635-637.

KIRK, M.D. 1979. Osteochondritis disease with epiphyseal separation and unilateral arrest in the distal radius of the growing horse: A case report. Journal of Equine Medicine and Surgery 3:394-398.

KNIGHT, D.A., Gabel, A.A., Reed, S.M., Embertson, R.M., Tyznik, W.J. and Bramlage, L.R. 1985. Correlation of dietary mineral to incidence and severity of metabolic bone disease in Ohio and Kentucky. In Proc. 31st. Ann. Mtg. Am. Assoc. of Equine Practnr. 31:445-461.

KNIGHT, D.A., Weisbrode, S.E., Schmal, L.M. and Gabel, A.A. 1987. Copper supplementation and cartilage lesions in foals. In Proc. 33rd. Mtg. Am. Assoc. of Equine Practnr. 33:191-194.

KRONFIELD, D.S. and Donoghue, S. 1987. Metabolic convergence in developmental orthopaedic disease. In Proc. 33rd. Mtg. Am. Assoc. of Equine Practnr. 33:195-202.

KRPAN, M.K. 1990. Rotational limb deformities. In White, N.A. and Moore, J.N. (ed.s): In Current practice of equine surgery, Philadelphia , Lippincott, 1990 p. 504-509.

KRPAN, M.K., White, K.K., Grant,B.D., Sande, R.D., Gallina, M. and Newbrey, J.W. 1985. The development and evaluation of a modification of the transphyseal bridging technique as a means of influencing bone growth of the distal metacarpal physis in the horse. In Am. Coll. Vet. Surgeon Abstracts, Vet. Surgery, 14:58.

LEITCH, M.M. 1979. Angular limb deformities arising at the carpal region in foals. Compen. Contin. Ed. Pract. Vet. 1:539-543.

LEITCH, M.M. 1985. Musculoskeletal disorders in neonatal foals. Vet. Clin. North Am. (Equine Pract.) 1:189-207.

LEWIS, L.D. 1987. Nutrition in Musculoskeletal Development and Disease, in Stashak, T.S. (ed.): Adams' lameness in horses, 4th ed. Philadelphia, Lea and Febiger. p.276-292.

LUCAS, D.M. 1991. A role for practical nutrition in the management of developmental orthopaedic disease. Equine Vet. Educ. 3:76-79.

MARTENS, R.J. and Auer, J.A. 1980. Hematogenous septic arthritis and osteomyelitis in the foal. In Proc. 26th Ann. Mtg. Am. Assoc. of Equine Practnr. 26:47-63.

MASE, C.A. 1987. Observations on radial maturation in foals as they relate to skeletal pathology. In Proc. 33rd. Ann. Mtg. Am. Assoc. of Equine Practnr. 33:439-449.

MASON, T.A. 1981. A high incidence of congenital angular limb deformities in a group of foals. Vet. Rec. 109:93-94.

McILWRAITH, C.W. 1982. Angular limb deformities in foals. In Mansmann, R.A. and McAllister, E.S. (ed.s). In Equine Medicine and Surgery, 3rd. ed. Santa Barbara, American Veterinary Publications 1982, p.1098-1109.

McILWRAITH, C.W. 1987. Disease of joints, tendons, ligaments and related structures. In Stashak, T.S. (ed.) : In Adams' lameness in horses 4th. ed. Philadephia, Lea, and Febiger 1987, p.339-485.

McILWRAITH, C.W. and James, L.F. 1983. Limb deformities in foals Associated with Ingestion of Locoweed by mares. J. Am. Vet. Med. Assoc. 181:255-258.

McILWRAITH, C.W. and Turner, A.S. 1987a. Orthopaedic surgery: Hemicircumferential transection and periosteal stripping. In Equine Surgery: Advanced Techniques. Philadelphia, Lea and Febiger, p.128-132.

McILWRAITH, C.W. and Turner, A.S. 1987b. Orthopaedic surgery: Temporary transphyseal Bridging. In Equine Surgery: Advanced Techniques. Philadelphia, Lea and Febiger. p. 120-127.

McLAUGHLIN, B.G., Doige, C.E., Fretz, P.B. and Pharr, J.W. 1981. Carpal bone lesions associated with angular limb deformities in foals. J. Am. Vet. Med. Assoc. 178:224-230.

McLAUGHLIN, B.G. and Doige, C.E. 1982. A study of ossification of carpal and tarsal bones in normal and hypothyroid foals. Can. Vet. J. 23:164-168.

MORGEN, J.P. 1967. Necrosis of the third tarsal bone of the horse. J. Am. Vet. Med. Assoc. 151:1334-1342.

NICKEL, R., Schummer, A., Seiferle, E., Frewein, J., Wilkens, H. and Willie, K.H. 1986. The locomotor system of the domestic mammals. Berlin, Verlag Paul Parey.

O'BRIEN, T.R. and Meagher, D.M. 1971. X-IRRADIATION of the distal radial epiphysis for the correction of forelimb angulation in the foal. In Proc. 17th. Ann. Mtg. Am. Assoc. of Equine Practnr. 17:253-263.

PHARR, J.W. and Fretz, P.B. 1981. Radiographic findings in foals with angular limb deformities. J. Am. Vet. Med. Assoc. 179:812-817.

POOL, R.R. 1987. Developmental orthopaedic disease in the horse: Normal and abnormal bone formation. In Proc. 33rd. Ann. Mtg. Am. Assoc. of Equine Practnr. 33:143-158.

REED, S.M., Knight, D.A., Weisbrode, S.E. and Stewart, R.H. 1987. The relationship of cervical vertebral malformation to developmental orthopaedic disease. In Proc. 33rd. Ann. Mtg. Am. Assoc. of Equine Practnr. 33:139-142.

SALTER, R.B. and Harris, W.R. 1963. Injuries involving the epiphyseal plate. Jour. Bone Joint Surg. 45-A. p. 587-622.

SHAMIS, L.D. and Auer, J.A. 1985. Complete ulnas and fibulas in a pony foal. J. Am. Vet. Med. Assoc. 186:802-804.

SHARER, J.R., Fretz, P.B., Doige, C.E. and Williams, D.M. 1979. Skeletal manifestations of suspected hypothyroidism in foals. J.of Equine Med. and Surgery 3:269-275.

SISSONS, S. and Grossman, J.D. 1948. The anatomy of the domestic animals 3rd. ed., Philadelphia, W.B. Saunders Co.

SMALLWOOD, J.E., Auer, J.A., Martens, R.J., Morris, E.L., McCall, V.H., Roenigk, W.J. and Boyd, C.L. 1984. The developing equine tarsus from birth to six months of age. Equine Pract. 6:7-48.

STASHAK, T.S. 1987. Lameness, in Stashak, T.S. (ed.): Adams' lameness in horses 4th. ed. Philadelphia, Lea and Febiger, p.486-785.

STROMBERG, B. 1978. A review of the salient features of osteochondrosis in the horse. Equine Vet.J. 11:211-214.

TURNER, A.S. 1986. Management of angular limb deformities in foals. The University of Sydney, The Post-graduate Committee in Vet. Science. In Proc. no.83: Equine Surgery 82:73-92.

TURNER, A.S. 1987. Diseases of bones and related structures, in Stashak,T.S. (ed.): In Adams' lameness in horses 4th. ed. Philadelphia, Lea and Febiger. p.293-338.

TURNER, A.S. and Fretz, P.B. 1977. A comparison of surgical techniques and associated complications of transphyseal bridging in foals. In Proc. 23rd. Ann. Mtg. Am. Assoc. of Equine Practnr. 23:275-287.

VAUGHAN, L.C. 1976. Growth plate defects in foals. Vet. Record 98:165-168.

WAGNER, P.C. and Watrous, B.J. 1991. Equine pediatric orthopedics; part 6 - Angular limb deformities. Equine Pract. 13:24-31.

WAGNER, P.C., Grant, B.D., Watrous, B.J., Appell, L.H. and Blythe, L.L. 1985. A study of the instability of cervical malformation in horses. In Proc. 31st. Ann. Mtg. Am. Assoc. of Equine Practnr. 31:43-50.

WHITE, K.K. 1983. Diaphyseal angular deformities in 3 foals. J. Am. Vet. Med. Assoc. 182:272-279.

WYN-JONES, G. 1988. Deformities of the appendicular skeleton, in Equine lameness. Oxford, Blackwell Scientific Publications. p.194-223.