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Hints on nutrition for optimal growth

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Summary
The aim of rearing foals may be to sell on or to produce at home, but ultimately the aim should be to achieve a sound, healthy and successful athlete for whatever level and type of equestrian use. Establishing a sound foundation during a foal’s development is crucial if we are to realise its full potential. The foal’s skeleton begins to develop early in pregnancy and is approximately 95% functionally mature by the end of the foal’s first year, at which time the foal has grown to about 90% of its adult height. Dietary nutrients provide the building blocks to support this rapid growth and therefore choosing an appropriate feeding programme is vital.

Many factors influence the growth and development of foals, but nutrition is one that we can more easily influence and therefore we should try and get as close to optimum as possible. We are increasingly realising that how we feed and manage our pregnant and lactating mares, as well as their young stock, can have a profound effect on health and welfare in both the short and long term. Some of the main issues which can be assisted by appropriate nutrition include:

- Bone development.
- Digestive health.
- Immune status.
- Behavioural development.

In addition, we now believe that good nutrition supports not only overall health and vitality now, but also future health and longevity.

Introduction
The overall goal for the mare is to have a live foal, which in turn develops into a healthy adult. Nutrition of the mare has perhaps been thought to be much less important than that of the foal. However, in the horse as well as in man, the important role that nutrition, via the mother, may have in the subsequent health of any offspring is increasingly being recognised (Harris 2003; Rossdale 2004, Tauson et al 2006).

If time is not a major factor, then young stock can be allowed to grow and mature at an acceptable rate. This may be complicated if the goal is to produce, for example, for weanling/yearling sales, in-hand showing, or 2- and 3-year-old racing animals. In these cases, the goal may be optimal growth if not maximal growth, with as few developmental and health problems as possible. One of the main potential pitfalls is unsoundness resulting from developmental orthopaedic disorders (DOD) (McIlwraith 2001, 2005) including osteochondrosis (OC). OC is a defect in endochondral ossification that can result in a number of different manifestations, depending on the site of the endochondral ossification defect’, one manifestation of which is osteochondritis dissecans (OCD) of cartilaginous origin. It has been suggested that the clinical signs of OC occur only after a progression of events that begin with a disturbance in the normal development of the cartilage (sometimes referred to as dyschondroplasia; DCP) leading to OC. At this point physical stresses are superimposed, leading to clinical signs. It is also thought possible that the initial defects/lesions may heal or develop into OCD or subchondral bone cysts. Due to the multifactorial nature of DOD, no single cause is likely to result in expression. Factors that may contribute include genetic pre-disposition, biomechanical trauma, mechanical stress through inappropriate exercise, obesity, rapid growth and inappropriate or imbalanced nutrition. Different combinations may be involved in different cases (Harris et al. 2005). Environmental or managerial factors probably determine whether expression occurs (i.e. provide the final triggering factor[s]). Nutrition is one potential factor involved in DOD which we can more easily influence (Harris et al. 2005), and adequately fortifying and properly balancing diets for the young growing horse can therefore be very important.

Growth patterns
Inappropriate growth rates may result in performance limitations, for a variety of reasons, later in life. In other species, such as the pig, dog and sheep, evidence of increased osteochondral lesions has been found in breeds with rapid growth rates compared with the slower-growing breeds (Wolter 1996). In the horse, a number of studies have linked rapid growth rates (and often by inference excessive feed/energy intake) with an increased incidence of DOD (Cymbaluk et al. 1990; Ruff et al. 1993; Pagan and Jackson 1996; Harris et al. 2005). Rapid growth rate may affect maturation of bone directly or indirectly due to disturbances in nutritional supply and hormonal balance or mechanical overload. Growth
rate reflects a combination of genetics and nutrition and, although a direct relationship between growth rate and DOD is not always seen (Harris et al. 2005), there does appear to be a benefit in trying to maintain smooth growth curves without abrupt changes in growth rate (Staniar 2005; Wingfield Digby 2005).

By the seventh month of gestation, the foetus will be less than 20% of its birth weight (Meyer and Ahlswede 1978). However, by this time significant placental development will have occurred and the greatest increase in crown-rump length occurs in mid-gestation. Although the majority of studies have suggested that embryonic development and foetal growth require no additional nutrients throughout the first 8 months of pregnancy, feeding a good balanced diet during this initial period is still important. Foetal growth obviously accelerates markedly during the last three months of gestation from around 0.08 to –0.33 kg/day (Meyer and Ahlswede 1978; Martin-Rosset 2004). Over 80% of the magnesium (Mg) and 90% of the calcium and phosphorus content are deposited in the 8th–11th months (Coenen 2000). Nearly half the copper, zinc and manganese (Mn) accumulation occurs, for example, in the 10th month. Appropriate nutrition of the mare during this period is crucial. Interestingly, it is being appreciated that, at least in other species, intrauterine effects including growth retardation may increase the likelihood of developing certain performance limiting conditions in later life (Rossdale 2004).

Birth weight is around 7–13% adult bodyweight and this can be affected by many factors, such as age of the mare, time of year, duration of pregnancy, how many pregnancies the mare has had, etc (Martin-Rosset 2004). This can be important because, in general, the mature number of cells in many tissues has been achieved by birth or shortly afterwards and certainly by puberty; so mature weight is, to a large extent (apart from, for example, the extent of fat deposition), linked to birth weight (Martin-Rosset 2004). Average daily gain (depending on nutrient intake) tends to be higher at any particular age for the heavy breeds (up to 50% more) and lower for ponies. Growth patterns, however, are thought to be similar across the breeds (especially when expressed as percentage of adult bodyweight), although the heavy breeds tend to mature later than the lighter Thoroughbred (TB) (Martin-Rosset 2004), whereas ponies tend to mature earlier and so seem to ‘grow faster’. Post natal growth, however, tends to be very rapid in all breeds, with TB foals being around 5 times their birth weight by the time of weaning, and by ~12 months of age reaching around 60–70% mature weight, 90%+ mature height and ~95% eventual bone growth. Compensation for moderate restrictions in growth can be made to a limited extent, but the capacity decreases with age (Martin-Rosset 2004). In general, once the initial neonatal period of very rapid growth has been completed, differences in growth rate have little influence on mature size. Intensive growth in spring and summer has often been reported in yearlings, perhaps due to feeding of low levels of energy in the winter period and then some compensatory growth with better pasture/light patterns (Staniar 2005).

Growth rate in the suckling foal depends predominantly on the milk production of the mare during early lactation and on available supplemental nutrients during mid to late lactation. Growth rate of the weanling will be affected by its genetic potential in particular, as well as its growth rate while suckling, level of weaning stress and nutrient intake (protein and energy). Maximal growth rate is obtained if young stock are fed a balanced diet containing high levels of energy and good quality protein, although the influence of feeding level becomes less as the horse gets older (Martin-Rosset 2004). Foals growing at a rapid rate deposit greater quantities of bone, muscle and, in particular, adipose tissue than their slower-growing counterparts, and therefore need more minerals and amino acids in particular Ca, P plus lysine. The adipose tissue content of horses varies most with age, breed, sex and nutrient intake (Martin-Rosset 2004). There is some evidence to suggest that there are positive effects on foal growth of the mare being in good condition at foaling (at the onset of lactation), especially when mares are fed in limited amounts after foaling, as it appears that the reconstitution of body reserves in the mare may take priority over foal growth (Doreau et al. 1988). In a recent study faster growing foals in Kentucky were found in mares that were gaining weight, and higher BCS were seen in foals from the mares with the higher BCS (Pagan pers. Comm). BUT time of year seemed to have a major influence in that the January/February foaling mares apparently lost weight in the first month of lactation and their foals were smaller at birth and grew slower initially but by 150 days were the same size as the later born foals. This resulted from a very rapid period of growth around 90 days of age, which was most likely associated with the availability of good quality grass at this time. This period of slow and then rapid compensatory growth may not be ideal. Similar effects have been reported in the foals of mares fed restricted energy or protein levels during pregnancy and then adequate amounts during lactation – they were not necessarily smaller at birth but grew more slowly during the 1st month but by 6 months of age had the same overall weight gain as foals from mares that had not been restricted during late pregnancy (Martin-Rosset pers. comm.).
### Monitoring: in order to check the pattern of growth:

- Weigh fortnightly/monthly or use equations designed for use in the growing animal (see Staniar et al 2004) – do not use adult equations especially in young foals and weanlings.
- Measure height at withers.
- Determine average daily gain (ADG).
- Determine condition score regularly.

**With the aim of**

- A steady increase in size and bodyweight (accepting that there is usually a slowing down especially over the first winter)
- Avoiding extremely rapid growth rates.
- Avoiding rapid compensatory growth spurts.
- Avoiding getting too fat or heavy.

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### Suckling foal

This is the period of most rapid growth rate (approximately 110-kg gain in the first 3 months in TB foals). It is crucial that the foal receives adequate nutrition throughout this period. Milk is the only significant food that a suckling foal receives throughout the first week of life; it is normally the major source of nutrients until the foal is at least 2 months of age, and for many until 4–5 months of age. Foals often start eating concentrate feed by picking at their mother’s feed at as early as 2–3 weeks of age. Suckling foals eat about 2.5–3.5% of their bodyweight as fed (at 90% dry matter [DM]), which is divided between the mare’s milk, pasture or hay and supplemental concentrate feed. The amount of concentrate feed required increases with age and the requirement for rapid growth.

It has been estimated that the percentage fat in a foal changes from around 5% during the first week to around 9% by 2 months of age. This influences the total energy required for weight gain during this period which increases, as the fat percentage of the weight gain increases, from around 2.1Mcal Net Energy/kg live weight gain at 4 days of age, to 2.6Mcal NE/kg live weight gain at 83 days to 3.4Mcal NE/kg live weight gain at 132 days (Martin-Rosset pers comm.).

### Weaning and the weanling

Age at weaning does not appear to influence significantly mature height and weight, but nutrition around this time can be crucial. If foals are not used to eating solid feed before they are weaned, they will tend to show more prolonged decrease in average daily gain (ADG) post weaning which will often be followed by an undesirable compensatory growth spurt. Time of year may make a difference according to the nutritive value and availability of grass or other forage (Pagan 1998).

Unless there are special circumstances where early weaning is needed or advantageous, it appears best to keep the foal with the mare until at least 5 months of age. Early weaning can result in greater initial growth rates if higher levels of concentrate are being fed, but these differences are usually overcome later on. Clearly, the longer that weaning is delayed the less of an insult it becomes. Not only will digestive function be more developed, but the animal will also be more independent. Weaning stress can be considerable and in order to minimise it feeding and managemental practices need to be optimised. The type of diet fed appears to influence behaviour around this time, with apparent advantages in providing fat- and fibre-rich feeds rather than the traditional starch- and sugar-based types (Holland et al. 1996; Harris 2005; Nicol et al. 2005). The method of weaning used can also have a significant effect on the degree of weaning stress experienced by the foal. Gradual methods seem to be far preferable to abrupt ones (Holland et al. 1996).

### First and second year of life

Typical weight gains for yearlings range from about 0.75-1.25 lbs/day depending on breed and prior feeding and developmental history. Yearlings appetite is around 2-3% BW as fed, but can be very variable. Maximum recommended is 60% non-forage (again lower concentrate intakes are preferable for many horses and ponies). If on good lush pasture may only require a vitamin and mineral supplement. Otherwise around 1-1.2 to 1.7 kg/100 kg BW as supplementary feed especially when being fed grass hay and/or poor quality pasture may be necessary.

Yearlings fed for rapid gains during suckling and weanling phases and fed for rapid gains as yearlings will tend to

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become obese especially fillies. Yearlings, which have been underfed previously, may need to be fed for rapid growth similar to weanlings according to BW rather than age. BUT care must be taken with respect to potentially increasing the risk of DOD if this is undertaken. Colts tend to grow into their yearling year at slightly higher rates than fillies. Colts often need to be fed sufficient additional feed to account for higher gains of around 0.2-0.3 lbs/day extra as well as higher maintenance requirements due to the larger amount of voluntary activity in yearling colts kept in groups.

Long yearlings appetite is typically around 2-2.75% BW. Suggested that the maximum amount of non forage feed is 50-60% of the total diet approximately 1.0-1.35 kg/100 kg BW. As with the yearlings the amounts of feed 2 year olds should be fed depend on how close they are to reaching their mature weights, which in turn depends on previous feeding and developmental history. Gains of around 0.25 lbs/day and 100 lbs/yr. are likely to be typical of light breeds under most conditions but may need to be modified.

Obviously it may also be necessary to take in to account any requirements for exercise/training.

Nutrient Requirements

It is important to realise when using, for example, tables based on the requirements as stated by the NRC (Anon 2007) that these are minimums and that allowances need to be made for different circumstances and individuals (Harris 2003). All animals require water, energy, protein, minerals and vitamins in balance and in the appropriate amounts from suitable sources. However, the essential or critical nutrients, which need to be considered first in balancing diets, will differ for different animals at different stages. In horses the list of critical nutrients for growth (excluding water), as we currently understand it, is relatively small.

- Energy sources
- Protein (especially amino acids - lysine and possibly threonine).
- Minerals - Macro: - Ca/P and possibly magnesium
  - Cu/Zn. and possibly manganese
- Also need to consider Selenium, Iodine, and Vitamins A & E.

Water is often the forgotten nutrient and the requirements will vary according to the environmental temperature but foals should have access to clean fresh water from around 2 weeks of age.

Energy Intake

Energy requirements per kg bodyweight gain increase with age (due to the changing proportions of tissues). For a guide to requirements, see the NRC guidelines (Anon 2007) and Coenen (2000). Restricting nutrient intakes to levels, close to those recommended by the NRC earlier in 1978, did not reduce the length or height of the horses, but did reduce weight gain and heart girth in yearlings, which was thought to be linked to energy intake (Ott and Asquith 1985). A number of studies have suggested that a high intake of energy may result in an increased incidence of DOD (see Harris et al. 2005), including a study by Savage et al. (1993a) in which feeding 129% NRC (anon 1989) digestible energy (DE) requirements to foals from 130 days of age resulted in an increased incidence of lesions compared with the control group (fed 100% DE) or those fed 126% of the NRC recommendations (Anon 1989) for protein. Multiple DCP lesions were found on gross post mortem examination in 11 foals fed the high DE diet, one the high protein diet and one the control diet. However, it should be noted that there has been concern that the lesions produced by some of these studies are not directly comparable to those found in the field, and many field studies have reported foals being fed much higher energy intakes without an apparent increase in clinical incidence (Kronfeld 1990). This may perhaps be linked to the background level of predisposition within individuals, nature of the energy being provided, concomitant exercise level and the overall balance of the diet.

Energy source may be as important as the amount

Modern feeding and managerial practices have considerable influence on the health and welfare of horses (Davidson and Harris 2002). This is perhaps most noticeable in the growing horse, especially when under commercial conditions where the goal may be ‘production’ for early sale. In particular, this results in mares and foals either being kept on artificially enhanced pastures or being fed one or two large meals a day and the foals being weaned early (at 3–5 months compared with ~9 months in the wild). In such cases, the diet typically consist of feedstuffs with a greatly reduced water content and often radically different nutritional profile from the diet that they would be able or would choose to select in the wild as a non-ruminant herbivore.

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It has been suggested that diets that intrinsically produce high glycaemic peaks, or individual horses that respond to certain diets to produce high glycaemic peaks (and subsequent effects on insulin and other hormones) may have an increased risk of developing DOD (Glade and Belling 1986; Ralston 1995, 1996; Pagan 2001; Harris and Kronfeld 2003). Such diets have the potential to establish a feeding-fasting cycle, which is a perturbation from the hormonal patterns seen in grazing animals. This, in turn, may adversely influence bone development, as the cyclical changes in glucose and/or insulin may influence bone maturation via effects on the somatotropic axis, including growth hormone, thyroxine and triiodothyronine as well as insulin-like growth factor I (Harris et al. 2005). Feeding diets that provide the same energy intake but are derived primarily from oils and fibres rather than starch and sugars (Figure 1) may modulate these changes (Kronfeld et al. 2001; Staniar et al. 2001; Hoffman et al. 2003). In Thoroughbred weanlings adapted to a sugar and starch diet lower insulin sensitivity was found as compared to weanlings adapted to a feed rich in fat and fiber, and it is currently unknown what effect this may have on long term health (Treiber et al 2005) although in other species it is not thought to be desirable.

Figure 1. Glucose and Insulin responses over 24hrs following the provision of two meals of feeds rich either in starch and sugar (SS) or fat and fibre (FF) compared with animals out at summer pasture with no supplemental feeds (Staniar et al unpublished data)
Protein Requirements
Both energy and protein intake must be adequate to promote optimal growth. It is important to provide sufficient protein at all stages of growth and development e.g. to support foetal development in the mare as well as tissue, especially muscle, development in the foal and growing athlete. As for energy, however, it may not only be the amount of protein that is important but the make-up of the protein – i.e. the amino acid profile or quality of the protein that is key (see below). Meeting dietary protein requirements therefore depends on the protein concentration of the diet as well as feed intake (which may be influenced by the level of exercise) and amino acid content of the diet.

Protein requirements for growth in horses obviously depend on age, size and rate of growth as well as the nature of the feed being fed (i.e. its quality). As foals and weanlings grow the proportion of their weight gain that is muscle decreases and that of fat increases, which is the reason why the protein requirements of young weanlings are proportionally higher than those of the yearling and adult horses in light work. Recommended figures of around 3 g CP/kg BW/day for yearlings and 4 g CP/kg BW/day for weanlings would be reasonable – depending on the quality of the feedstuff.

Amino Acids
Protein quality, as defined as available amino acid content, has a positive effect on growth of the weaned foal both directly and via the mare (Ott 2004). Lysine is believed to be the first limiting amino acid in typical horse rations (Ott et al. 1981) and if the lysine requirement is met, unless synthetic amino acids are used to supplement the diet, it is believed that the requirement for other amino acids will most likely be met. However, due to the variability in the availability of lysine from forage it has been suggested that at least 70% of the lysine requirements are met by the non-forage proportion (Gibbs and Potter 2002). A threonine intake of >80% of lysine levels is thought to be of value (Graham et al. 1994; Staniar et al. 2001). Like energy, therefore, the source of protein may be important. e.g. soybean protein has been suggested to be used more efficiently for growth than alfalfa protein (Ott 2004). In general terms based on the literature lysine intakes of around 170 mg/kg BW per day for weanlings and slightly less that this at around 160 mg/kg BW per day for yearlings would seem to ensure more than adequate provision.

Despite being linked in many people’s minds, no studies have conclusively shown adverse effects of high or low protein intakes on the incidence of DOD in the horse. In fact, most studies have shown no effect of increasing protein on the incidence (Schryver et al. 1987; Savage et al. 1993a, see Harris et al 2005).

Nutritional support for the immune system
The epitheliochorial equine placenta prevents in utero transfer of immunoglobulins from dam to foetus before birth. Except for trace amounts of IgM, newborn foals are agammaglobulinaemic. The foal therefore relies primarily on acquired immunity until ~3–4 months of age, at which time globulins from the mare are virtually undetectable. The foal starts producing its own gamma globulins at ~4 weeks of age in normal foals and around 2 weeks of age in colostrum-deprived foals. It is therefore essential that the newborn foal receives sufficient immunoglobulin-containing colostrum, ideally from its dam, in the first 12 (~24) h of life. Recent research has suggested that dietary supplementation of vitamin E (160 IU/kg DM intake/day) and selenium (3 mg/day/500kg mare) to the mare in late gestation may beneficially influence colostrum concentrations of immunoglobulins (Table 1) (Hoffman et al. 1999; Janicki et al. 2000).

Table 1: Colostral Immunoglobulins, mg/dL: Pre-suckled concentrations at foaling (Hoffman et al 1999)

<table>
<thead>
<tr>
<th>Immunoglobulin conc. in the colostrum mg/dL</th>
<th>+ Additional Vitamin E (total intake ~160iu/kg DM feed).</th>
<th>Control</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>IgG</td>
<td>19,010 ± 1000</td>
<td>9,020 ± 2350</td>
<td>.0001</td>
</tr>
<tr>
<td>IgA</td>
<td>1,760 ± 462</td>
<td>951 ± 197</td>
<td>.002</td>
</tr>
<tr>
<td>IgM</td>
<td>152 ± 21</td>
<td>115 ± 6</td>
<td>.006</td>
</tr>
</tbody>
</table>
**Vitamin and mineral nutrition**

**Vitamins**

Seasonal fluctuations may occur in vitamin and mineral status, which are often, but not totally, linked to variations within the diet (Maenpaa et al. 1988). It is, however, important to understand the decline in vitamin content that occurs in preserved forages, as this influences the need for supplemental support. For example, naturally occurring β-carotene is thought to be unstable in preserved forages (McDowell 1989) and fresh forage is therefore recommended. Where this is not possible supplemental sources of vitamin A are required, especially as a low β-carotene intake may increase the risk of a reduced conception rate (Coenen and Vervuert 2004). As with certain other vitamins, the nature of the supplementary source is important; for example, although the water-soluble form of synthetic β-carotene has been shown to increase serum β-carotene concentrations, it has been suggested not to be effective at influencing vitamin A status in mares (Griewe-Crandell et al. 1997). This is very important with respect to vitamin A, as there is believed to be minimal transference across the placenta and foals can be born with a relative vitamin A deficiency, especially if mares are fed a vitamin A deficient diet, colostrum levels are low or if the foal fails to suckle adequately.

In the past, where available, the incidence and severity of clinical deficiency in the horse (or other species where not available for the horse) has often been used as a guide to vitamin and mineral requirements (Anon 1989). This, however, does not automatically help define the optimal requirements. For example, the first estimate of vitamin E requirements given by the NRC in 1978 was based on the concentrations needed to maintain erythrocyte stability in vitamin E deficient foals (Stowe 1968), but this may not reflect optimal intakes to support other aspects such as immune development. Similarly, information obtained from studies conducted in growing ponies deprived of daylight (El Shorafa et al. 1979) was used to estimate the current vitamin D requirements for growing horses. Often blood levels per se do not accurately represent status and alternative techniques have therefore been employed, e.g. the retinol response test (RDR) as an indicator of liver vitamin A storage, which is a more sensitive indicator of vitamin A status than serum retinol concentrations (Griewe-Crandell et al. 1997). This technique suggests that the current NRC (Anon 2007) recommendations for mares are too low even though no signs of any clinical problems were noted with animals fed at this level. Overall, for the majority of vitamins and trace elements, the requirements have not been fully evaluated and guidance based on available scientific evidence, as well as experience, is currently recommended.

> It is important to remember that a Vitamin E deficiency can be associated with Vitamin E and selenium responsive myodegeneration – ‘white muscle disease’. Vitamin E deficiency may also lead to depressed immune status, poor performance, reduced fertility and fetal death. Equine Motor Neurone Disease is believed to occur due at least in part to a lack of Vitamin E, which may predispose the type I oxidative neurones to oxidative injury and death. It tends to occur more commonly in horses which are either stabled or with access to dirt paddocks and only fed grass hay with a high grain ration.

An important consideration regarding vitamin supplementation is the risk of toxicity, e.g. excess vitamin D may be associated with calcification of soft tissue and death (Anon 1989, 2007).

Suggested intakes of the main fat soluble vitamins are illustrated in Table 2 (I.U/Kg dry matter of feed - assuming a DM intake of around 2% early pregnancy and 2.5% otherwise), although these need to be modified with individual circumstances.

**Table 2:** Guide to recommended levels of Fat-soluble vitamins (need to be adjusted according to individual circumstances).

<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Pregnancy/Lactation</th>
<th>Growth</th>
<th>Max recommended</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>6 000</td>
<td>4000</td>
<td>20,000</td>
</tr>
<tr>
<td>D</td>
<td>800</td>
<td>900-1000</td>
<td>2200</td>
</tr>
<tr>
<td>E</td>
<td>160</td>
<td>160</td>
<td>1000</td>
</tr>
</tbody>
</table>
B vitamin requirements
Thiamine and riboflavin are given recommended levels by the NRC (Anon 2007), which are as follows:

- Thiamine at 0.075 mg/kg BW per day for growing foals; (approximately 3mg/kg DM intake with a 2.5% BW intake - however, levels of up to 5 mg/kg DM feed intake per day have been recommended by others).
- Riboflavin at 0.05mg/kg BW per day for growing horses (approximately 2 mg/kg DM with a 2.5%BW intake - however, levels at approximately twice this have been recommended by some authors).

Suggested levels for folic acid are around 1.7 mg/kg DM for young growing horses with the greatest demands. Vitamin B12 levels of 15 µg/kg feed ‘as fed’ for young growing horses have also been suggested.

Minerals and trace elements
It is perhaps important to remind ourselves that calcium makes up about 35% of bone structure and the skeleton represents around 99% of total body calcium stores; approximately 85% of the total body phosphorus is present in the bones and teeth and bone contains about 60-70% of the body stores of magnesium. It is not therefore surprising that these three minerals are important in the formation of skeletal tissue. Over 80% of the magnesium (Mg) and 90% of the calcium and phosphorus content are deposited in the 8th–11th months of gestation (Coenen 2000). Although the mare can utilise to some extent her own reserves it is important that we do not forget to provide throughout the breeding cycle adequate (but not excessive) amounts of calcium, phosphorus plus magnesium in balance with each other (e.g. Ca: P ratio of ideally between 1.5 – 2 :1).

In an epidemiological study by Knight et al. (1985) carried out on a single occasion on 19 breeding farms in the USA with 384 yearlings, the highest problem scores were associated with low or deficient intakes of Ca and P or extreme ratios between these. However, to date there does not appear to be any clear evidence of a link between excess Ca or marginal P intakes and DOD (Harris et al. 2005). In one study high intakes of P appeared to result in an increased incidence of DCP lesions (Savage et al. 1993b), but little work has been carried out on the effects of P on cartilage development. The amount of exercise given to the foals in that study was intentionally limited and this may have played a role (Harris et al. 2005). No adverse effects of Mg have been reported in relation to the incidence of DOD, but little direct work has been done on this in the horse despite the fact that Mg may compete for Cu binding sites and excessive Mg may inhibit PTH secretion (Ellis 2001). It appears that growing horses fed a low dietary cation-anion difference ration (suggested in the short term to potentially increase calcium loss in the urine) over an extended period of time can compensate for the increased loss of calcium in their urine; to date such diets have not been shown to affect growth, although they are not necessarily to be encouraged (Baker 2004).

Trace elements - especially Copper, iodine and selenium

Copper
A copper-containing enzyme, lysyl oxidase, is involved in the X-linking of protein chains in elastin and collagen of cartilage. Disruption of these X-links due to copper deficiency may result in biomechanically weakened cartilage and increase the risk of DOD A number of studies have suggested a relationship between copper and zinc in the diet and DOD (see Harris et al 2005). However, more recent work confirms that copper supplementation may not be the ‘magic bullet’ suggested by some in the past as far as DOD is concerned, but a reduced copper intake/absorption particularly during gestation could possibly either be permissive to the development of DOD under certain conditions or reduce the ability to repair lesions (van Weeren et al. 2003). Further research is needed in this area on a much larger scale. Currently, therefore, it is believed to be important to maintain copper and zinc intake and balance throughout gestation and growth (Harris et al. 2005).

Iodine
An essential nutrient for reproduction and normal physiological function in the horse. T4 and T3 (thyroxine and triiodothyronine) contain iodine. Iodine deficiency (due to inadequate intake by the mare or the ingestion of goitrogenic substances) and excess may lead to goitre. Excess iodine is also a possible cause of bony abnormalities in foals. Excesses are commonly caused by feeding large amounts of seaweed meal, or supplementation with excessive potassium iodide or iodate. The upper limit recommended by the NRC for iodine (5mg/kg DM) is based on the non-pregnant non-lactating mare. The author actually recommends much less than this at less than 3mg/100kg BW for the pregnant or lactating mare and ideally not more than 1mg/100kgBW. NB because iodine is concentrated across the placenta and in the milk the most vulnerable are foals from highly supplemented mares.
Selenium
Selenium is very important in antioxidant defence. Selenium deficiency is seen particularly in foals of mares grazing selenium-deficient pastures. This may lead to nutritionally associated myopathy (white muscle disease), which occurs in both skeletal and cardiac muscle. The margin of safety for selenium is however, relatively narrow and selenium toxicity (selenosis) can occur. The signs include hair loss on the mane and tail and sloughing of the hooves. This is seen in areas of seleniferous soils and when supplementation is miscalculated. There is a current European limitation to the amount of selenium that can be fed to horses (around 4mg/kg DM) which approximates to around 1mg/100kg BW as fed. As there is some anecdotal evidence that levels above this may increase the risk of certain foot conditions it is recommended that selenium is not provided to any animal at more than 1mg/100kg BW.

There is some, but limited transfer of selenium across the placenta and via the milk. More alkaline soil and lower rainfalls leads to higher soil content and therefore acidic soils are more likely to be deficient but there is little relationship between soil and plant levels. There are areas which are selenium deficient and many natural feedstuffs and forages are low in selenium.

Selenium supplementation is therefore very important. Recent work has suggested that supplementation at higher levels than those currently recommended by the NRC (i.e. at 0.2-0.3mg/kg DM) may help improve the colostral antibody concentration in a similar way to the Vitamin E described above.

Table 3: A guide to the recommended concentrations of trace elements in the diet, mg/kg dry matter. (Modified from the NRC 2007). These will need to be adjusted to suit individual circumstances, growth rate and appetite etc.

<table>
<thead>
<tr>
<th>Trace element</th>
<th>Pregnancy/lactation</th>
<th>Growth</th>
<th>Max upper limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu (copper)</td>
<td>15 -20</td>
<td>15-20</td>
<td>250 – less in growing horses if zinc not elevated</td>
</tr>
<tr>
<td>Zn (zinc)</td>
<td>60-80</td>
<td>60-80</td>
<td>500 Zn : Cu ratio of diet currently recommended should be 3-4:1</td>
</tr>
<tr>
<td>Mn (manganese)</td>
<td>60</td>
<td>60</td>
<td>400</td>
</tr>
<tr>
<td>Fe (iron)</td>
<td>50</td>
<td>50</td>
<td>500 - lower in very young animals</td>
</tr>
<tr>
<td>Se (selenium)</td>
<td>0.2 –0.3</td>
<td>0.2</td>
<td>2 – see text for recommended limits</td>
</tr>
<tr>
<td>Co(cobalt)</td>
<td>0.1</td>
<td>0.1</td>
<td>25</td>
</tr>
<tr>
<td>I (iodine)</td>
<td>0.3</td>
<td>0.2</td>
<td>5 – adult non pregnant mare - see text for pregnant and lactating mare recommended limits</td>
</tr>
</tbody>
</table>

There is as yet no body of scientific evidence that clearly supports the need to provide certain trace elements in an organic form although some suggest improved availability under certain circumstances. It is currently advised by the author of the present article that not more than 30% of total intake of trace elements is provided in this form (Table 3).

What about nutrients to improve bone ‘strength’
Obviously it is important to provide sufficient and balanced amounts of the key vitamins, minerals and trace elements involved in bone growth especially calcium, phosphorus, copper and zinc as well as sufficient energy and protein. But what about more unusual nutrients? Silicon is one such nutrient of potential interest where safety and efficacy is still unproven. Although Silicon is considered by some to be a trace element, others refer to it as an ultra trace element. The soluble form of silicon (Si (OH) 4 or orthosilicic acid) is thought to be health beneficial and is the most readily available source of silicon at least for humans (>50% available: Sripanyakorn et al 2005). Recent work comparing the availability of silicon from Sodium Zeolite (synthetic) or a more natural form of silicon (Azomite A) suggested that the Si source also effected Si utilisation and/or absorption in the horse as those fed the synthetic source had higher plasma...
silicon concentrations during the period of supplementation whereas those on the natural source had a lower level but this does not appear to have been a cross over trial and further work in animals at different ages and workloads would be useful (Mazzella et al 2005).

Silicon is a normal constituent of natural drinking water or is derived from certain plants as ‘phytolithic silica’, which can be broken down and absorbed in the gastrointestinal tract of humans (Sripanyakorn et al 2005). In man factors such as ageing and the reduction of oestrogen levels appear to reduce the ability to absorb silicon as does exercise – suggesting that athletes may require increased amounts in the diet (Perez-granados & Vaquero 2002). However, minimum recommended levels have not been established for man or other animals although levels have been suggested at 10-25 mg for adult humans under normal circumstances and 30 – 35 when exercising (Sripanyakorn et al 2005, Perez-granados & Vaquero 2002). Silicon deficiency (perhaps associated with the depletion of other nutrients) in some animal studies has however, been linked with abnormal connective and bone tissue metabolism and may result in delays in growth, bone deformations and abnormal skeletal development (Perez-granados & Vaquero 2002, Sripanyakorn et al 2005).

Whilst, little is known of the role of dietary silicon in bone health of both humans and horses, it is thought that soluble silicate may be advantageous in promoting collagen formation and therefore be of benefit for hair, skin and nails in particular. Research suggests that dietary silicon intake is positively correlated with bone mineral density (BMD) at four hip sites in men and pre-menopausal women (Jugdaohsingh et al, 2004). This positive correlation was not found in postmenopausal women. Interestingly this study suggests that some of the effects seen for moderate consumption of alcoholic beverages on bone mineral density may be due to silicon intake! Most of the work suggests that any effect of silicon on bone may be through stimulation of bone formation although a few suggest it may also have an effect by inhibiting bone re-absorption (Sripanyakorn et al 2005).

Work using human osteoblast cells suggested that the addition of Zeolite A, a Si containing compound, would significantly increase osteoblast proliferation and differentiation and in 1992. Frey et al (1992) used 60 quarter horses to determine the ability for various levels of SZA) to increase plasma silicon levels in addition to increasing radiographic bone density. Feeding the SZA resulting in an increase (P<05) in plasma silicon concentrations (though this was not consistently correlated with dose there appeared to be a possible trend), thus, suggesting that SZA was a bioavailable source of silicon for the horse. Radiographs of the anterior-posterior of the third metacarpal were taken at the start of the trial and at 56-day intervals with bone density being expressed as radiographic aluminium equivalents (RBAE). Whilst the RBAE gain seen during the first 56 days of trial was the largest, there was no significant difference in RBAE between levels of SZA fed over the 168-day trial as a whole. Further to this study, Nielsen et al (1993) went on to look at the addition for 30 days of varying amounts of SZA to the diet of 18month old quarter horses in training. Results confirmed the findings of the Frey et al (1992) study in that plasma silicon concentrations were increased in all horses fed SZA (irrespective of amount fed) when compared to the control group. A correlation of 0.54 was seen between plasma silicon concentrations and distance travelled, during training and racing cycles, before injury, which may suggest that SZA may help to prevent injury in athletic horses BUT further work is needed to confirm this. Increased plasma silicon concentrations were not seen to be detrimental to performance as faster average race times were seen in treated horses though this was not significant when looking across all distances. In 2001, the effect of supplemental dietary silicon (sodium zeolite A: SZA) on plasma and milk silicon concentrations of lactating mares and the subsequent effect on plasma silicon concentrations in nursing foals was investigated (Lang et al, 2001). All supplemented mares and supplemented mares milk had higher levels (P<0.01) of plasma silicon and silicon concentrations by days 30 and 45 respectively. Foals of mares supplemented also had higher plasma silicon levels (P<0.01) concentrations by day 45. While supplemental silicon did not influence bone metabolism (plasma silicon concentrations were not seen to be higher in supplemented foals until the last study day) (P>0.36), trends were observed in postpartum mares (P<0.10). Results therefore indicated that supplemental dietary silicon may indicate an increase in both milk and plasma silicon levels in mares and foals. Lang et al in 2001b reported on a study in twenty yearlings (ten Quarter Horses and ten Arabsians) half of which were given 2% of the total diet as SZA, and the others no such supplement. Supplemented yearlings had higher plasma Si concentrations than the controls by day 15, and remained higher when subsequently sampled during the 45 days of the trial. There were no differences between treatment groups for osteocalcin or pyridinoline and deoxypyridinoline crosslinks concentrations however, ICTP concentrations were lower in the supplemented yearlings on day 45 when compared to the control group which the authors suggested might mean that there was decreased bone resorption, which might in turn provide for greater net bone formation - BUT this is currently unproven.

BUT, what about safety? In a report on the Safe Upper Levels for Vitamins and Minerals (May 2003) from the Expert Group on Vitamins and Minerals from the FSA it says ‘few data are available on the oral toxicity of silicon in humans and no acute or chronic toxicity data have been identified. The occurrence of silica
stones has been reported in patients on long term antacid therapy with magnesium trisilicate.’ ‘No significant toxicity or mortality has been reported in animals given doses of up to 3g/kg BW/day.’ But ‘growth rates were reduced and the concentrations of certain other minerals in the plasma and tissues were affected in rats fed 500ppm (equivalent to approximately 50mg/kg BW for young rats).’ Work recently reported (Turner et al 2005) in calves (which might not be the ideal model for the horse) that were either fed 0.5% BW of Sodium Zeolite A or not with their milk replacer showed no effect on the weight of average daily gain, but there was an increase in the levels of deoxypyridinoline in the supplemented calves (unlike the decrease noted in the horse study above) which tended to have longer metacarpi although there was no effect on mechanical properties. Whilst this might mean that silicon may aid the rapid repair of subclinical injuries rather than prevent damage as suggested by the authors – such differential alterations of growth patterns in the horse may not be desirable. *Future work on the role of silicon in the horse is obviously needed – before any real conclusions can be given.*

**Conclusions**

Although providing appropriate nutrition, during pregnancy and throughout lactation to the mare as well as, to the foal itself can obviously not guarantee a healthy and successful adult, there is increasing evidence in other species as well as the horse to suggest that it might have short-, medium- and long-term advantages and may help to reduce the risk of certain unwanted conditions. While the above provides a guide and some hints, it may be advantageous to obtain expert nutritional advice in order to ensure the most optimal nutrition at these key periods.

**Key nutritional facts to consider:**

1. Provide water from around 2-3 weeks of age
2. Introduce the foal to concentrates from about 2-4 weeks of age, either allowing it to nibble the mother’s feed, or by using a specialist foal starter feed.
3. From around 2-3 months of age often need to increase the level of supplementary feed (fed in addition to forage) as the quality and quantity of the mare’s milk decreases (as a guide aim between 0.2 – 0.45kg of supplementary feed/month of age until weaning depending on the breed, individual, rate of growth and type of feed).
4. The foal at weaning must be able and accustomed to eating solid supplementary feed. Consider gradual weaning processes (as less stressful).
5. The foal will require proportionally less protein and amino acids but more energy as it grows (as an increasing proportion of the daily gain is fat and less is muscle).
6. In the first year post weaning, non-forage/concentrate or supplemental feed intake should not exceed 70% of total daily intake. For many horses and ponies, far lower concentrate intakes may be preferable, and more commonly found.
7. It may be useful to allow up to 20% extra energy requirements for youngstock kept in-groups or outside. Males tend to require more energy than females.
8. Protein quality is important (intake of key amino acids such as lysine and threonine e.g. ~170mg lysine/kg BW/day for weanlings and ~160mg/kg BW yearlings).
9. Vitamins and minerals need to be provided, in adequate amounts (e.g. foals are born relatively vitamin A-deficient) and in balance with each other (consider the balance of copper to zinc [Cu: Zn] and calcium to phosphorus [Ca: P] in particular). Ensure adequate trace mineral intake to mares at all stages of gestation and lactation as well as growing foals (even when pasture forage appears to be providing adequate protein and energy.)
10. Foals growing at a rapid rate deposit greater quantities of bone, muscle and fat than their slower growing counterparts – so need more minerals and amino acids to support this growth
11. Be careful of excessive iron supplementation (especially in very young foals where it can be fatal) ; iron deficiency is extremely rare unless there is severe or chronic blood loss.
12. Energy sources are increasingly thought to be crucial; there is increasing
evidence that using alternatives to traditional feeds (i.e. using fibre and oil
based diets with starch plus sugar levels less than 15% and oil contents
around 10%, that produce low insulin and glucose responses post ingestion
and contain specifically chosen fibre sources to support digestion system
health) may provide a number of advantages including:

- Improved gastric health.
- Improved behavioural development.
- Maintenance of insulin sensitivity.
- Superior support for sound bone development (see below).

13. Appropriate antioxidant supplementation may be more important than
previously thought, particular attention should be paid to vitamin E
(160iu/kg DM intake) and selenium (Se : 0.2-0.3mg/kgDM intake) intake
during the last 3 months of gestation for potential effects on the immune
status of the foal as well as protection against muscular problems.

14. Increased support for sound bone development. Due to the multifactorial
nature of developmental orthopaedic disease (DOD), no single cause is
likely to result in expression. Factors that may contribute include genetic
pre-disposition, biomechanical trauma, mechanical stress through
inappropriate exercise, obesity, rapid growth and inappropriate or
imbalanced nutrition. Different combinations may be involved in different
cases. Environmental or managemental factors probably determine whether
expression occurs (i.e. provide the final triggering factor[s]). It is therefore
important to try to limit those nutritional and managemental factors that may
increase the risk, and the following should be considered:

- Raising copper intakes: while adequate copper supplementation is
  unlikely to be the only answer to DOD, it is important to maintain
  appropriate and balanced copper intakes in the gestating mare as well as
  the growing foal (aim for between 15 – 20mg Copper/kg DM intake).
- Controlling phosphorus intakes: while there does not appear to be any
clear evidence of a link between excess Ca and DOD or marginal P
intakes and DOD, high intakes of P appear to result in an increased
incidence of lesions and therefore careful attention should be given to
the P intake as well as the Ca: P balance (should aim for a ratio of
between 1.5 – 2:1 Ca : P). Note that too little P will also not be
beneficial.
- Changing energy sources: diets which intrinsically produce high
glycaemic peaks, or individual horses that respond to certain diets to
produce high glycaemic peaks (and subsequent effects on insulin and
other hormones), may have an increased risk of developing DOD.
Feeding diets, which provide the same energy intake but are derived
primarily from oils and fibres rather than starch and sugars may
modulate these changes.
- Although this may reflect the nature of the energy source, it is still
advisable to avoid excessive energy intakes allowing foals to become
overweight.
- Management practices that avoid as far as possible periods of slow
then rapid compensatory growth periods, and encourage appropriate
pasture turnout are advisable.

For further information on specifics see Anon (2007), Coenen (2000) and Harris
(2004).
References


Jugdahsingh R, Tucker KL, Qio N, Cupples LA, Kiel DP, Powell JJ 2004, Dietary silicon intake is positively associated with bone mineral density in men and premenopausal women of Framingham Offspring cohort J of Bone and mineral research 19(2) 297-307


