GHENT UNIVERSITY

FACULTY OF VETERINARY MEDICINE

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“NATURAL FEEDING STRATEGIES FOR SPORT HORSES”; A “CONTRADICTIO IN TERMINIS”?

By

Nathalie HILMO

Promotors: Prof. Dr. M. Hesta
D. van Doorn, PhD

Literature review as a part of
a Master’s Dissertation

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PREFACE

I would like to express my very great appreciation to my promotor Prof. M. Hesta for providing me this subject and for her guidance through my literature study. I wish to gratefully acknowledge my second promotor, D. van Doorn, PhD, for his enthusiastic advice and ideas. Mrs M. Locher provided me with very valuable literature.
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LIST OF ABBREVIATIONS

ADF = Acid detergent fibre (the fibrous, least-digestible portion of roughage)

ATP = Adenosine-5'-triphosphate = A coenzyme for transport of chemical energy within cells for metabolism. Used as a molecular unit of intracellular energy.

BW = Bodyweight

CH = Carbohydrates

CT = Cheek teeth

DE = Digestible energy (GE minus fecal energy left after a feedstuff has passed through the animal)

DEm = Digestible energy requirements for maintenance

DM = Dry matter

GE = Gross energy = total heat that could be released

GIT = Gastrointestinal tract

ME= Metabolisable energy = DE minus energy lost in the gases and urine produced

MRT = Mean retention time= expression of time the digesta are kept in the gastrointestinal tract

NDF = Neutral detergent fibre. NDF measures most of the structural components in plant cells (i.e. lignin, hemicellulose and cellulose), but not pectin.

NE = Net energy (NE=ME minus heat lost through ingestion, digestion and metabolizing of feed).

NE = ME x k, where k represents the efficiency in conversion of energy substrates to ATP

VEP = “Voeder Eenheid Paard” = feed unit horse

VFA = Volatile Fatty Acid

VFI = Voluntary Feed Intake

ABSTRACT

The aim of this study is to discuss whether current feeding practices are a contradiction to the natural feeding of the horse, and the possible implications on equine health and welfare. The digestive system of the horse has distinct characteristics allowing digestion of a fibrous diet. In the foregut mainly enzymatic digestion occurs, but with a limited capacity. The voluminous hindgut receives the undigested part of the digesta where microbial degradation by the resident bacterial flora occurs. The cellulolytic flora allows digestion and utilization of structural carbohydrates by fermentation. In contrast, the traditional diet and feeding management is adapted to meet the increased energy requirements for performance, and supplementation with concentrate such as grain has become normal practice. The amount of non-structural carbohydrates can easily exceed the enzymatic digestive capacity of the small intestine and increase the amount that reaches the hindgut. By the changes in available substrate, a shift of the bacterial flora from mainly cellulolytic to amylolytic occurs. These changes of the microbial flora are associated with digestive and systemic disturbances such as colic and laminitis. As forage occupies a major part of the time of a free ranging horse, limiting forage may lead to boredom and behavioural problems. The limitation of roughage also decreases wear of the teeth, and as the horses' teeth erupt continuously, sharp enamel points may be formed. Thus, the discrepancy between the natural feeding and current feeding practices may have important implications on equine health and welfare.

Key words: Feeding – Fermentation – Horse – Starch – Welfare

DUTCH SUMMARY

Zijn de huidige voedingsstrategieën bij sportpaarden in contradictie met het natuurlijke voedingsgedrag van het paard? Het gastro-intestinale stelsel van het paard wordt gekenmerkt door een kleine maag en een groot cecum en colon die vertering van een vezelrijk dieet toelaten. Tijdens het kauwen wordt speeksel gesecreteerd dat het zuur in de maag buffert. De lage pH van de maag wordt veroorzaakt door continue secretie van zoutzuur. Amylase in het speeksel en de bacteriële flora van de maag initiëren de vertering tot op zekere hoogte. De dunne darm van het paard is relatief kort en vormt de belangrijkste plaats van enzymatische vertering van hydroliseerbare koolhydraten. Evenwel zorgt een hoge concentratie aan amylase in het speeksel en de dunne darm voor een gelimiteerde enzymatische verteringcapaciteit van zetmeel in de dunne darm. De passage door de dunne darm is vrij snel, tot 30 cm/min, en het materiaal dat hier niet geabsorbeerd wordt, bereikt de cecum en colon waar het voor 75-80% van de totale passagetijd door het gehele gastro-intestinale systeem verblijft. De cecum en colon van het paard is zeer volumineus, waar de aanwezige bacteriële flora vertering van koolhydraten toelaat via fermentatie. De samenstelling van de bacteriële flora wordt beïnvloedt door de aanwezige substraten in het lumen van de cecum en colon. Om te voorzien in hun nutritionele behoeften via het natuurlijke dieet, wordt tot 16 uur per dag gespendeerd aan grazen. In contrast is het traditionele dieet en voedingsmanagement aangepast om te voorzien in de hogere energiebehoefte van het paard, veroorzaakt door de prestaties die het paard moet leveren. De aandacht is gefocust op de lage hoeveelheid energie in gras en hooi, en supplementatie met energierijke voeding zoals graan behoort tot het normale management. Een praktisch aspect van het voedingsmanagement van het stalpaard is maaltijdvoederen en gerestricteerd ruwvoederdieet. Aangezien het paard minder moet kauwen om een hoog geconcentreerd dieet op te nemen wordt minder tijd besteed aan het opnemen van voeder. Deze discrepantie tussen de natuurlijke voedingsgewoonten en het huidige voedingsmanagement heeft potentieel belangrijke gevolgen voor de gezondheid en het welzijn van het paard. Aangezien paarden een grote motivatie hebben om te foerageren, kan de beperking van de tijd dat het paard effectief aan het eten is, leiden tot frustratie en eventueel tot wangedrag en stereotypieën. Bijgevolg kunnen de stereotypen een indicatie zijn voor een gecompromiteerd welzijn van het paard. Door de continue eruptie van de tanden bij het paard, kan de verminderde slijtage door een geconcentreerd dieet leiden tot abnormaliteiten van de tanden met verdere gevolgen voor de vertering, aangezien tegelijk het kauwen zal verminderen. Of emailpunten een natuurlijk fenomeen zijn, of veroorzaakt worden door het dieet kan bediscussiëerd worden. Verder kunnen tandproblemen leiden tot of bijdragen tot verstoringen in het spijsverteringssysteem ten gevolge van onvoldoende kauwen. Aangezien geconcentreerd voeder tot minder kauwen leidt en hierdoor minder totale speekselsecretie, wordt het continu gesecreteerde zoutzuur in de maag minder gebufferd, waardoor een zuur milieu gecreëerd wordt met maagulcers als gevolg. Maaltijdvoederen is ook een predisponerende factor, aangezien er geen buffering van de maag pH plaatsvindt tussen de maaltijden. Intragastrische fermentatie door hoge beschikbaarheid van zetmeel, leidt tot vorming van vluchtige vetzuren waardoor de pH verder daalt. Ook stress en inspanning spelen een rol in de erosie. De gelimiteerde capaciteit van de dunne darm om zetmeel te verteren, toont aan dat gestegen hoeveelheden van zetmeel in het voeder zal leiden tot verhoogde hoeveelheden die het cecum en colon zullen bereiken. Overmatige consumptie van concentraten rijk aan koolhydraten samen met milieufactoren en mogelijks genetische predisposities, modificiëren de graad van voorkomen en ernst van intestinale problemen, vaak gezien als koliek. De overmaat aan zetmeel die ontsnapt aan de enzymatische vertering in de dunne darm, ondergaat een snelle fermentatie in de achterdarm, waardoor de productie van kortketenige vluchtige vetzuren stijgt en de pH daalt. Een snelle shift van de microbiële flora van cellulolytisch naar lactaat producerende bacteriën kan leiden tot intestinale en systemische verstoringen. Een ander potentiëel gevolg van ingestie van te grote hoeveelheden koolhydraten is het ontwikkelen van laminitis. Het dieet rijk aan zetmeel draagt bij tot, naast obesitas en hyperinsulinemie,

een toestand waarbij een inflammatie van de hoefwandlamellen voorkomt. Lyse van bacteriën met vrijlaten van toxische componenten kan tot een septische toxinemie leiden, met inflammatie tot gevolg. Ontstekingsmediatoren dragen verder bij tot destructie van de hoefwandlamellen met verlies van hun functie als verbinding tussen de hoefwand en de distale phalanx. Radiografisch kan dit zichtbaar zijn door een loslating van de hoefwand met inzinking en rotatie van de distale phalanx in de hoefkapsel. Studies hebben aangetoond dat normale groei, prestaties en gezondheid kunnnen bereikt en behouden worden met een dieet dat enkel uit ruwvoer bestaat, of met een minimale supplementatie van concentraat. Om het mogelijk te maken de energetische behoeften te dekken, moet energierijk voer gegeven worden. Ondanks dit feit, bestaat het huidige voedingsmanagement uit het voederen van ruwvoeder laag aan energie, en supplementatie met concentraten gebaseerd op granen. Uit de literatuur blijkt dat alternatieve voedingsmaatregelen mogelijk zijn, die beter zijn voor de gezondheid en welzijn van het paard. Ruwvoer met hoger energieinhoud zou toch voor de nodige energie kunnen zorgen. Daar paarden goed vet kunnen verteren zou het gebruik van vetten in het dieet een mogelijke oplossing kunnen zijn om de snel fermenteerbare koolhydraten te verminderen. Het verwerken van granen heeft ook een positieve invloed op de vertering ervan. Het doel van deze studie was om een de vraag te beantwoorden of de huidige voedingspraktijken in contradictie zijn met het natuurlijke voedingsgedrag van het paard, en de mogelijke gevolgen daarvan. Er blijkt geen twijfel te bestaan over het feit dat de huidige voedingspraktijken bij sportpaarden ver van natuurlijk zijn. Het beperken van ruwvoer en het overmatig voederen met zetmeel lijken potentieel nadelige gevolgen te hebben op de gezondheid en welzijn van het paard. Het aanpassen van het dieet naar meer ruwvoer en minder koolhydratenrijke granen is een belangrijk aangrijpingspunt om deze problemen te proberen op te lossen. Uiteraard moet het energiebehoefte van het paard gedekt worden. Uit de litteratuur blijkt dat het voederen van meer energierijke ruwvoeders een mogelijke oplossing is.

INTRODUCTION

Requirements for higher quality and energy content of the horse's diet came along with domestication due to the increasing demand for horses to perform. From being a free ranging feral animal, the horse has been used for farming and further for racing and other equine sports. Although it began more than 5000 years ago, this is just a brief period in evolutionary terms. This means that even though the horse had to adapt to a new life and diet, the characteristics of the digestive system has not undergone the same development.

"Sport horses" include a wide range of breeds performing different kinds of activities in disciplines such as endurance, racing, jumping and dressage. To cover its increasing energetic demands, the equine athlete is traditionally fed diets rich in readily fermentable carbohydrates. Although this is common practice, research has shown that large amounts of these carbohydrates are associated with health issues. An improved knowledge of the horses' natural and current diet and ingestive behaviour would create an understanding of how the discrepancy might influence health and welfare of the horse. A lot of knowledge exists in the literature, however unawareness might be responsible for the problems experienced.

On the basis of these observations, the following research question was developed:

Are current feeding strategies for sport horses a contradiction to the natural feeding of the horse?

In order to answer the research question, this paper will investigate why these problems are experienced, how they occur and how they impact the health and welfare of the horse on the basis of discrepancies between natural and current feeding practices. In chapter one the digestive system of the horse is presented as this is the foundation for understanding why current feeding practices might contradict the natural feeding of the horse. Further, chapter two will identify what the natural feeding of the horse consists of in terms of feed and ingestive behaviour. Chapter three continues with researching current feeding practices, with focus on feeding concentrates. Finally, chapter four utilize the findings in chapters two and three in order to identify potential consequences of disproportions between natural and current feeding practices. Answering the research question and creating knowledge is paramount, as feeding practices can have serious impacts on equine health and welfare.

This paper is a traditional literature review, synthesising scientific papers mainly from, but not limited to, "Web of Knowledge", "Science Direct", "PubMed" and "Google Scholar", focusing on an exploratory qualitative analysis. Typical search words used are: "colic", "diet", "digestion", "feeding", "feeding management", "fermentation", "pasture", "roughage", "starch" and "welfare".

The scope of this paper is to highlight the most commonly experienced issues associated with current feeding management of sport horses. The paper will focus on the current practice of feeding limited forage with supplementation of concentrates with high amounts of readily fermentable carbohydrates. Many of the issues discussed in this paper are multifactorial, however the contribution of other etiologies than carbohydrates are only briefly mentioned and considered, which constitute a possible limitation. Another limitation is that this paper compares studies without considering the different study methods or quality.

LITERATURE REVIEW

1. The digestive system of the horse

Insight into the characteristics of the digestive system of the horse is important for understanding the mechanisms behind dysfunctions and for optimizing feeding procedures to prevent these (Julliand and Merritt, 2013). The horse has evolved as a hindgut fermenter and its gastrointestinal tract is characterized by a small stomach and a large hindgut (Stevens and Hume, 1995; Botha et al., 2012). Distinctive characteristics in the digestive tract allow them to digest a fibrous diet (Jansson and Lindberg, 2012). The following text will describe the function of the digestive system of the horse with emphasis on carbohydrate digestion.

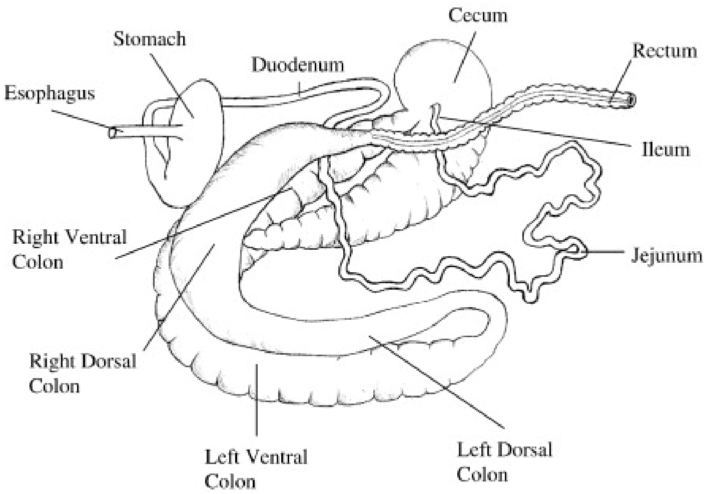

Fig. 1: Gastrointestinal tract of the horse
(Source: Van Weyenberg et al., 2006)

1.1. Oral cavity

The upper lip of the horse is very sensitive, strong and prehensile and is used to sort through feed to leave offending material behind, collect and manoeuvre it between the teeth (Frape, 2004). The muscular tongue passes the ingested material to the cheek teeth for grinding (Hembroff, 2006), after being torn by the incisors in case of forage.

The evolution of the horse as a grazing animal has resulted in a dental morphology characterized by a longer cheek tooth row, described by Clauss (2013) as molarisation of the premolar teeth, to form a large grinding surface. The development of high crowned (hypsodont) teeth which erupt continuously to compensate for wear, relates to feeding on abrasive feed (Easley et al., 2011). Further, this wear of the teeth is needed to maintain dental health.

Jernvall et al. (1996) conducted a study where they identified and compared molar crown types of both fossil and extant ungulates, and noted that horses have evolved a complex molar occlusion pattern. Frape (2004) explains the occurrence of these patterns by differences in hardness, and hereby different wear of the materials of which teeth are composed. This roughness of the teeth and further the circular and sideways movement of the jaw effectively grind the food, to reduce the particle size of the feeds and increase the surface area for digestive enzymes (Cunha, 1991). Clauss (2013) indicated that the particle size reduction achieved by the horse (and other equids) is very efficient, and greater than other large nonruminant herbivores.

Saliva is only secreted in the presence of food during mastication (Alexander F., 1966; Durham A., 2009; Luthersson et al., 2009; Elia et al., 2010). Al Jassim and Andrews (2009) indicated that 10-12 litres of saliva is secreted daily, while Merritt and Julliand (2013) report that the total amount secreted may reach 35 – 40 litres, and Moeller et al. (2008) report a flow of up to 50 mL/min. The saliva of the horse mainly consist of water (>99%) (Alexander F., 1966), and seems to have little or no digestive enzyme activity. Hereby, carbohydrates will undergo very limited hydrolysis during mastication due to the low amount of amylase (Julliand et al., 2006; Hoffmann, 2009). Among other, the function of saliva seems to be lubrication of feed and buffering of the acidic gastric content (Al Jassim and Andrews, 2009; Elia et al., 2010). The concentration of buffering bicarbonate in saliva of the horse seems to be directly proportional to the rate of secretion (Alexander, 1966), and was measured by Alexander (1966) to be 50 mEq/L, which is lower compared to cattle (127 mEq/L; Bailey and Balch, 1961). Also phosphate concentration is lower in the horse (0.29mmol/L; van Doorn et al, 2011) than in cattle (23 mEq/L or 7.67 mmol/L; Bailey and Balch, 1961).

1.2. Stomach and small intestines

The equine stomach has a capacity of 5–15 litres which is relatively small when compared to the large volume of the hindgut (Auer and Stick, 2012). Where the oesophagus enters the stomach, a strong sphincter prevents gastric content to flow back in a retrograde direction, which makes the horse incapable of vomiting (Al Jassim and Andrews, 2009). Subsequently, overeating may lead to gastric dilatation and even rupture, when horses for instance accidentally get access to unlimited amounts of feed (Robb, 1892; Henderson, 2013). The stomach of the horse is adapted to frequently receive small amounts of feed (NRC, 2007). The majority of feed rapidly passes through, after being held in the stomach for two to six hours (Van Weyenberg et al., 2005) and the stomach is normally rarely completely empty, because of decreased contractions when less feed enters the stomach (Santos et al., 2011; Jansson, 2013).

The equine stomach is separated into two regions by a line of demarcation called the margo plicatus. The most proximal region is covered by nonglandular stratified squamous mucosa, and the distal by glandular mucosa. The gastric fill line is typically the margo plicatus, which implicates that the proximal squamous mucosa does not intensively come in contact with digesta, in contrast to the glandular area. (Hembroff, 2006; Auer and Stick, 2012). Further, Merritt and Julliand (2013) report that the gastric content of an adult horse has a variable pH depending on where in the stomach it is situated. This is in contrast to most other monogastric animals and the foal, where the digesta is more uniformly mixed with acid. The lower density content at the top will have a higher pH due to the buffering effect of saliva and less exposition to gastric acid, than the higher density content in the lower part where the opposite occurs. The described situation is only applicable when roughage is available on a free-choice basis.

Hydrochloric acid is continuously produced and secreted by gastric parietal cells (Cambell-Thompson and Merritt, 1990; Lester, 2004; Hembroff D.A., 2006; Hothersall and Nicoll, 2009), and is up-regulated by the intake of feed (Merritt, 2003)
An in vitro study conducted by Morrissey et al. (2008) demonstrated that both the glandular and nonglandular gastric mucosae of the horse secrete prostaglandin E2, which is one of the protective factors of the gastric mucosa against gastric ulcers (See chapter 4.4).

Alexander and Davies (1963) and Jansson (2013) report that the bacterial flora of the stomach and small intestine consist of streptococci, lactobacilli and lactate utilizing bacteria, which indicates that fermentation occurs (Coenen et al., 2006). In the stomach this bacterial growth occurs in the proximal part where the pH is highest (Frape, 2004). Müller et al. (2008) reported that the microbial flora in the foregut is mainly amylolytic, indicating an impact on starch and fructans degradation and insignificant plant cell wall degradation. Nevertheless, this amylolytic capacity is limited and dependent on diet. The pH of the gastric content falls approaching the pylorus distal in the stomach, preventing bacterial fermentation.

The digesta subsequently enters the small intestine. The horse has a relatively short small intestine, with a total length of 21-25m in length. It can be divided into three parts from cranial to caudal; the duodenum, jejunum, and ileum (Budras et al., 2009). The small intestine is the major site of digestion of hydrolysable carbohydrates, protein and fat. In the duodenum the digesta is mixed with bile salts that are continuously produced and secreted by the liver, with the function of emulsifying and digesting fats together with lipase (Jansson, 2013). The pancreas continuously secretes digestive enzymes into the duodenum, such as peptidase, lipase and carbohydrase to assist the digestion of proteins and carbohydrates (Hembroff, 2006; Gore et al., 2008). The secretion is profuse and reported by Merritt (2013) to be 20-25 litres per day in an average adult horse. The basal secretion can increase by a factor of four to five in response to different stimuli, such as the presence of food in the stomach and hydrochloric acid arriving in the duodenum (Frape, 2004).

The alkaline character of the pancreatic juices buffers the acid pH of the digesta that passes from the stomach, creating favorable conditions for establishing a fermentative bacteria population that contribute to the digestion of carbohydrates in the small intestine (Al Jassim and Andrews, 2009). An adequate retention time is also acquired for the colonization by the microbial flora (Hoffman, 2009). Still, fermentation predominantly occurs in the hindgut.

The digestion of carbohydrates is started prior to arrival in the small intestine. Hydrolysis is initiated by α-amylases in saliva, but only to a limited degree due to its low concentration (Julliand et al., 2006; Hoffmann, 2009). In the stomach some fermentation occurs (Alexander and Davies, 1963; Coenen et al., 2006) and gastric acid hydrolyzes carbohydrates to an extent (Hoffman, 2009). Subsequently, the small intestinal enzymes continue on the process of hydrolysis. These enzymes can only break down carbohydrates built up by monomer units linked by α-linkages. β-linkages are hydrolyzed by the hindgut flora (Shirazi-Beechey, 2008). Further, also the pancreatic juice has a low α-amylase concentration (5-6%; Frape, 2004) compared to other monogastric species, contributing to the limited ability of the horse to digest starch pre-caecally. This was shown in a study conducted by Richards et al. (2004) where exogenous α-amylase was added to the feed and the results on starch digestibility was examined. Compared to the control horses where no amylase was added, the starch digestion in the small intestine was increased significantly.

Polysaccharides are hydrolyzed yielding oligosaccharides and disaccharides. These are further hydrolyzed by disaccharidases (sucrose, maltase and lactase) secreted by the intestinal brush border mucosal cells into glucose. In contrast to amylase, maltase has a very high activity in the small intestine of the horse (Dyer et al., 2002). From the intestinal lumen, glucose is transported through the enterocytes into the systemic circulation, ready for metabolization to yield ATP as energy for different tissues.

The transit of digesta through the small intestine is quite rapid, with a movement of up to 30 cm/min (Gerring and Hunt, 1986). The time the digesta are kept in the gastrointestinal tract is expressed by the mean retention time (MRT), with different values troughout the gastrointestinal tract (GIT). The MRT and the digestibility of starch can be evaluated by the mobile bag technique in caecally cannulated horses (Julliand et al., 2006; Van Weyenberg, 2009; Rosenfeld and Austbø, 2009; Ghoorchi et al., 2013). The mobile nylon bags are filled with grains in different forms (micronized, ground, extruded or pelleted) dependent on the performed experiment, and provided with a magnet. In combination with a meal, the bags are intubated through a nasogastric tube, and can be captured with a magnet through the caecal cannula (to evaluate precaecal digestibility or passage rate) or collected from the feces (to evaluate total or cecal digestibility or passage rate). Contents of the bags are analyzed and the digestibilities in the different parts of the GIT are calculated for the different types of grains (Rosenfeld and Austbø, 2009). The MRT is influenced by a number of factors such as type of diet, feed processing (Julliand et al., 2006), feeding level and non-dietary factors such as exercise (Jansson, 2013) bodyweight and gestation (Van Weyenberg et al., 2006).

Merrit and Julliand (2013) report that the MRT for passage of digesta through the whole GIT ranges from 18 to 60 hours where most of the variability occurs in the hindgut. The MRT of the foregut was10-20% of the time needed to pass through the whole GIT, more specificly 6.8±1.2 h, with a minimum of 1.6 to a maximum of 9.9 hours (Julliand et al., 2006).

Drogoul et al. (2000) conducted a study where fistulated ponies where fed chopped, ground and pelleted hay to investigate digestibility and rate of passage of digesta. They found that the MRT when chopped hay was fed, was significantly longer than when the diet consisted of ground and pelleted hay, concluding that larger particles lead to a slower transit rate.

In conclusion, horses have a limited capacity to digest hydrolysable carbohydrates (e.g. simple sugars and starches) to hexoses (Hinchcliff et al., 2008). This is confirmed by the effect of increasing the amount of starch fed per meal. When the starch content increases, the digestibility tends to decrease. Kienzle (1994) reports that the digestibility of certain cereals are above 80% when the starch content of the meal is less than 2.0 g/kg bodyweight, and drops to less than 60% when the starch intake exceeds this “limit”. The remaining undigested starch will be passed on to the hindgut together with the structural carbohydrates that cannot be digested in the foregut.

1.3. Cecum and colon

Within 3 hours after feed consumption, most of the material remained unabsorbed reaches the hindgut (i.e. cecum and colon). Here the digesta will be held for 75-80% of the total retention time of the whole GIT (Ross et al., 1986). Al Jassim and Andrews (2009) estimated that the large intestine only comprises 30% of the total length, but as much as 64% of the volume. This is the final site for absorption of electrolytes and water, and the main site for microbial fermentation of structural carbohydrates from plants (Stevens and Hume, 1995). When the digesta are passed from the small intestine they enter the cecum, a blind sac of about 1 m long with a capacity of approximately 25-35 litres (Al Jassim and Andrews, 2009; Budras et al., 2009). After being held in the cecum the digesta continue to the colon, which can be divided into the ascending, transverse and descending part. The ascending part of the colon (i.e. large colon) is the most capacious part, and can hold a volume of about 80 litres. It is 4 metres long and folded in a double loop, divided by flexures. The voluminous characteristics in combination with the narrow flexures allow an important decrease in transit rate of the digesta (Budras et al., 2009).

When the undigested part of the digesta is passed from the ileum to cecum, it is moved from a mainly enzymatic mediated digestion in the small intestine, to a highly developed microbial fermentation in the hindgut, allowing release of absorbable materials and hereby utilization of energy stored in plants (Zeyner, 2003). As the horse and other animals do not produce enzymes capable of hydrolyzing complex carbohydrates (such as xylan, cellulose and hemicelluloses), they are dependent on microbial activity to digest these compounds (Al Jassim and Andrews, 2009). One of the main functions of the equine hindgut is to provide a suitable environment for colonization and fermentation by microbes, thus functioning as a fermentation vessel. To emphasize the importance of this microbial flora, there are ten times more bacteria in the hindgut of a horse than there are cells in its body, numbering about $0,5\times10^9$ to 5×10^9 /g content, forming more than half of the dry weight of the feces (Frape, 2004). High variation is found in counts and species between different individuals, intestinal compartment and time (Santos et al., 2011; Immerseel and Julliand, 2013).

Digestion of carbohydrates and protein mainly occurs in the small intestine, with absorption before the digesta reaches the hindgut. Santos et al. (2011) indicated that a large fraction of the material arriving in the hindgut consists of plant fibres. This implicates that the population of fibre-digesting (cellulolytic) bacteria is predominant compared to the proteolytic. Further, de Fombelle et al. (2003) reported that the proportion of cellulolytic bacteria among total anaerobes was several times higher in the cecum than in the colon. They point out that the situation is opposite for starch- and lactate-utilizing bacteria, which is greater in the colon than in the cecum. This might be caused by the fact that the colonic microflora is more influenced by fermentable carbohydrates than the cecum, due to the slower passage rate, resulting in adaptation of the flora (Santos et al., 2011). Merritt and Julliand (2013) report that the components remained undigested after passage through the small intestines, are fermented by this microbial flora with production of volatile fatty acids (VFA), microbial mass, gas and heat. The flora mainly consists of fungi and bacteria, with insignificant influence of protozoa. VFA (acetic, propionic and butyric acids) are absorbed from the hindgut, and transported in the blood circulation to different tissues to be used as a source of energy (Al Jassim and Andrews, 2009). The products of microbial degradation depend on the type of substrate available and on the present microbial flora. The composition of the community itself is also influenced by these substrates and the environment created in the hindgut lumen (Richards et al., 2006). An example of this mechanism is summarized by Frape (2004); when the amounts of starch reaching the hindgut are higher, this will cause an increase in amylolytic bacteria and suppress the cellulolytic and related bacteria.

Besides fermentation, the presence of these microbes contributes to prevention of colonization by unwanted microorganisms, providing a first line defense against pathogens. During stressful conditions or when diet is changed, an alteration in the population occurs, disturbing the balance between the flora and its host. These changes may be responsible for disorders such as colic and laminitis (Santos et al., 2011). Nevertheless, Immerseel and Julliand (2013) report that the potential loss of function when a shift in the microbial population occurs, may be intercepted by other species able to perform similar metabolic processes.

Passage of the digesta through the hindgut depends on gut motility. The fibrous part of digesta has a large holding capacity of water, and may serve as a fluid reservoir during dehydration (Meyer, 1987). Contractions of the cecum and colon are complex physiological events in the form of migrating myoelectrical complexes that give rise to rhythmic contractions. A first type of contractions move aboral and a second type propagate in the opposite, thus oral direction. A third type does not propagate in either direction. The overall result of these contractions is aboral movement of the digesta. Additional retrograde movements cause mixing that promotes fermentation and absorption. These movements in oral direction are limited within each compartment, preventing retrograde flow from one compartment to another (Van Weyenberg et al. 2006; Merritt and Julliand, 2013). As the chyme passes through the large colon, great volumes of water are absorbed, altering the consistency of the chyme from relatively fluid to more compact and dry fecal balls (Hembroff, 2012).

The digestive system of the horse has distinct characteristics allowing digestion of a fibrous diet. The small volume of the stomach indicates that the horse is adapted to receive small amounts of feed throughout the day. The fact that there is a limited capacity of enzymatic digestion in the foregut indicates that undigested material will be passed on and further be processed by the resident bacterial flora of the hindgut. The characteristics of the resident microbiota are dependent on the available substrate, and the stability of this flora is crucial for maintenance of good health. By the characteristics of the digestive tract, the natural feeding of the horse can further be explained.

2. Natural feeding of the horse

The characteristics of the digestive system determine the diet the horse has evolved to consume and its ingestive behaviour. In order to answer the question whether current feeding practices contradict the natural feeding, this chapter will give an overview of natural feeding in order to be able to compare it to current feeding practices.

2.1. Feeding behaviour

The horse evolved over millions of years as a grazing animal, with a digestive tract adapted to degrade and utilise high-fibre diet (Thorne et al., 2005; Santos et al., 2011). By their capability of processing large quantities of forage the horse could meet their nutrient demands, (McIlwraith and Rollin, 2011) and spend as much as 12 (Dulphy et al., 1997) to 16 (Masey et al, 2010) hours per day foraging, or 52 (Dulphy et al., 1997) to 70 (Boyd L., 1991) percent of their time.

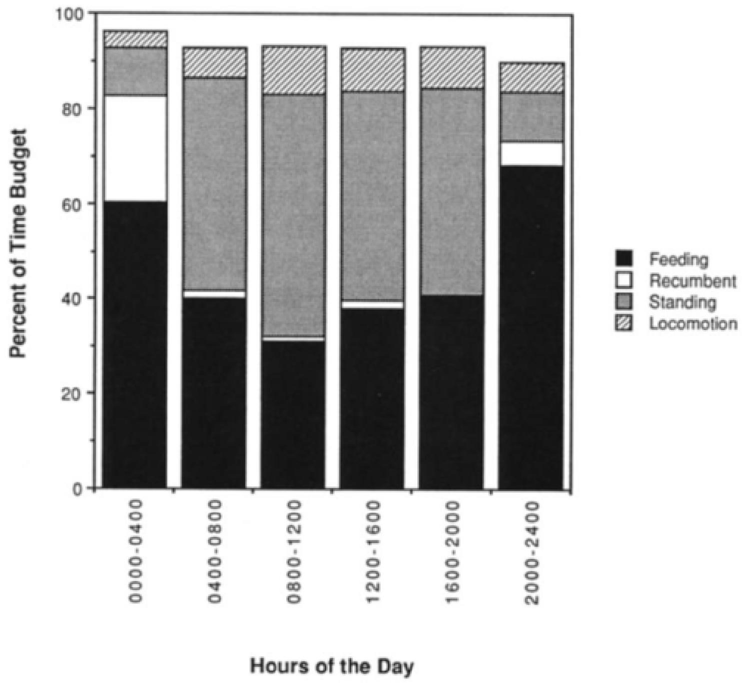

Fig. 2: Time budget of Przewalski horses. Percentage of time spent in 4 behaviours throughout the day *(Source: Boyd et al., 1988)*

Foraging time vary depending on internal factors such as metabolic requirements, age and sex of the animal (Bels, 2006; NRC, 2007). Daily and seasonal variations are observed (McDonnell, 2003). The available nutritional value of plant materials and other external factors such as weather, management, palatability, structure of the sward, monotony of the feed, social factors and size of the field influence the foraging time and pattern. A lower availability of forage increases the time spent foraging (Bels, 2006). However, the increased time spent grazing has an upper limit, presumably due to fatigue (Carson and Wood-Gush, 1983).

During a 24-hour period, the foraging is separated into different periods/meals, where 23 percent of the total time spent foraging occurs at night (Carson and Wood-Gush, 1983). Further, Grazing consists of two phases. The appetitive phase is the activity of seeking food, and the consumption is the ingestion itself. During both phases the horse constantly moves (Bels, 2006), taking one or two steps before taking the next bite (NRC, 2007). Arnold (1984) indicated that the time spent feeding was strongly negatively correlated to the time spent standing still. Consequently, free ranging horses will travel great distances during the day. Hampson et al. (2012) conducted a study where 12 mature feral horses were equipped with a GPS, monitoring their positional data and total distance travelled. The mean daily distance covered was 15.9 ± 1.9 km. (The distance travelled is also dependent on availability of water, where longer distances may be travelled to find sources of water in case of scarcity.) According to Jansson (2013) exercise may positively affect dry matter digestibility.

The correlation between amount of feed consumed and caloric concentration of the diet was studied by Laut et al. (1985). This study showed that horses adapt their intake of feed to the amount of energy of the feed. The response of caloric dilution by adding sawdust to the pelleted diet of ponies was observed. The ponies increased their daily total feed intake and thereby maintained their energy intake, until gut capacity became a limiting factor. The capacity of dry matter intake may be a limiting factor when the concentration of energy in forage is low. On the other hand, Dulphy et al. (1997) suggest that the seasonal variations in body condition contradict the horses' capability of compensating a low caloric diet. Overfeeding of palatable and high energy concentrates may lead to intake of excessive amounts of energy. The high prevalence of obese horses due to concentrated feeding also contradict the ability of the horse to limit its intake to the amount needed (NRC, 2007).

Kiley-Worthington (1987) reported that a horse of about 500 kg will eat around 13.5 kg of fibrous material over 24 hours, provided free access, with variation depending on physiological demands. The National Research council (2007) estimated that a horse on pasture will have a dry matter intake of between 1.5 and 3.1% of their body weight (BW) per day. A higher percentage of voluntary feed intake (VFI) (2.4-5.1%) was found in a study of forages consumed by feral horses, with a likely explanation of higher intake by lactating mares (Pratt-Phillips et al., 2011).

An average VFI rate was estimated by Dulphy et al. (1997) to 2.01-2.12 kg/100 kg bodyweight (BW) of some grass hays, and 1.28 kg/kg BW for straws. However, the intake rate of different types of hay was reported to be higher, and others low enough to provide suboptimal energy intakes, indicating that palatability plays a significant role in intake.

2.2. The natural diet of the horse

Wild horses and horses kept on pasture have nutritional wisdom which helps them to select their diet. This means that the animal avoids poisonous feed, and is able to compensate dietary surfeit or deficiency by seeking out or avoiding certain substances (Kiley-Worthington, 1987).

The diet of feral horses mainly consists of forage, with a lot of variation in composition; around 65 percent grasses and sedges, 25 percent shrubs and a small amount of forbs (NRC, 2007). NRC indicated that the choice of forage is more influenced by the stage growth of the plant rather than the species. Further, factors such as sward height, maturity and quality influence the choice of feed. The choice made is complex, changing with the metabolic status of the animal. In free ranging horses the VFI exerts a greater influence on feeding value than the nutrition value of the feed itself (Waghorn and Barry, 1987)

A study conducted by Pratt-Phillips et al. (2011) studied the nutritional values of forages consumed by feral horses of Shackleford Banks. During two years nutrient composition of plants were analyzed. Fecal samples were collected for microhistological analysis to estimate selection and proportions of plant species. Together, the composition of the diet of the feral horses was estimated. Fibre content and digestive energy was examined, besides mineral and crude protein.

Table 1: The approximate mean intake of acid detergent fibre (ADF) and digestive energy (DE) in the diet of the feral horses over four seasons.

Season	**ADF (%)**	**DE (Mcal/kg)**
Summer	41.4	1.91
Fall	39.4	1.88
Winter	45.5	1.77
Spring	42.4	1.92

(Adapted from: Pratt-Phillips et al., 2011)

According to Carson and Wood-Gush (1983), palatability plays an important role in the selection of feeds. Smell, taste and texture highly determine the rate of intake (Dulphy et al., 1997). A study conducted by Dulphy et al. (1997) investigated the ad libitum intake of dry forages by horses and sheep. They studied the intake of twelve different forages and the intake of these forages by six gelding saddle horses, each weighing approximately 500 kg and six texel rams, weighing approximately 70 kg. The forages were prepared in good conditions of harvesting and were well preserved. The forages were offered twice a day besides a mix of concentrate in two equal fractions before the meals. The quantities fed and what was not eaten where weighed every day. Samples were taken for chemical analysis in order to measure the dry matter content and the feeding activities were recorded. The measurements indicated that refusals were markedly richer in cell-wall components than the average content fed. Further, Dulphy et al. (1971) indicated that horses select short, young, fast-growing forage, with a preference for clover-rich seeds-mixture pasture with varieties of other types of grass. This was investigated in a study involving the intake of over 30 different plant species and seeds mixtures. Hoskin and Gee (2004) indicate that horses select a high sugar content, rather than low lignin content, emphasizing the role of palatability. Although refusal of forage richer in cell-wall components are markedly higher than grass (Dulphy et al., 1997), horses also consume more fibrous grass species that cattle reject (Carson and Wood-Gush, 1983). Compared to cattle the body condition of horses may be less negatively affected when grazing on the same low quality pasture (Clauss, 2013).

3. Current feeding practices of exercising horses

In this chapter current feeding practices of exercising horses will be discussed. Characteristics of the traditional diet, and hereby the ingestive behaviour of the horse will be emphasized.

The traditional diet and feeding management is adapted to meet the energy requirements for maintenance and performance (Willing et al., 2009), In addition, activities such as transport should be taken into account as it could add significantly to the total energy requirements of a sport horse. The amount of energy used during transport is comparable to walking, and may play a role in the energy requirements of competing horses (NRC, 2007). Further, practical considerations associated with the stabled horse have played a major role in development of current feeding practices (Harris, 1999).

3.1. Feeding management and ingestive behaviour

In order to cover the energetic needs and keep body condition of the horse in balance, attention is focused on the low amount of energy in pasture and hay, and supplementation with concentrate such as grain has become normal practice (Harris and Kronfeld, 2003). Intensively managed horses are often fed a high grain diet to cover the increased amount of energy needed for performance (Freire et al., 2009; Honoré and Uhlinger, 1994). Hinchcliff et al. (2008) indicated that another reason for feeding low-roughage diets among some trainers was to reduce the 'deadweight' as high-roughage diets could increase the weight of ingesta in the intestines, which is energetically disadvantageous. Harris (2009) found that fibre may provide energy during an endurance ride, but confirms the normal practice of limitation on forage, as less than 30% of the total energy of the diet of race horses is provided by forage.

Usually sport horses are stabled in individual boxes, separated from conspecifics in individual boxes (Carson and Wood-Gush, 1982). A practical aspect of feeding management of the stabled horse is meal feeding (Harris, 1999) and restricted forage diets, with little or no variation (Thorne et al., 2005; Higgins and Snyder, 2006; Freire et al., 2009; Santos et al., 2011). There is little or no choice in quantity and quality of the diet (Carson and Wood-Gush, 1982). Hoffman et al. (2009) found that sport horses in New England were typically meal fed at specific times during the day, with a mean number of 2.1 ± 0.7 meals per day. A study conducted by Fortier et al. (2013) of feeding practices of French Standardbred trotters showed that all trainers in this survey fed 3 meals a day of concentrate. Mostly (70%), hay was provided two times per day, while some provided it three times. Before a race the meals were eliminated, decreased or fed earlier. A survey of feeding management of the Australian racing Thoroughbred conducted by Richards et al. (2006) showed that >80% of the trainers fed their horses large meals twice per day. The survey by Richards et al. (2006) further showed that the Australian racing Thoroughbreds recieved 7.3 ± 0.23 kg of grain concentrate per day. Other studies among trainers of Thoroughbred race horses indicated a daily grain intake of 4,9-7,5 kg (Glade, 1983; Gallagher et al., 1992). Honoré and Uhlinger (1994) found that adult riding horses in central North Carolina received an average of 2.8 kg of grain daily (37% of total feed intake). Of the rations excessive in energy, they found a mean daily grain intake of 6.95 kg (79% of total feed intake).

The median turnout time of sport horses in New England found by Hoffman et al. (2009) was 2 hours per day. Horses are often kept in small yards with limited motivation to walk and will only travel an average of 1.1 km/day (Hampson et al., 2010). Similarly Hoffman et al. (2009) found that most of the owners gave their horses access to fresh grass with a median of 2 hours à day.

Consequently, the feeding behaviour of modern sport horses is less complex than free ranging horses (Carson and Wood-Gush, 1982). The common practice of feeding concentrates fed in meals has implications on the ingestive behaviour of the horse. Smaller particle size (compared to forage) gives a greater density and allows faster eating rate.

The feeding behaviour is characterized by fast consumption compared to forage due to its palatability and feed characteristics (NRC, 2007). It takes between 800 and 1200 chewing movements (Frape, 2004) during 15 minutes (Carson and Wood-Gush, 1983) to consume one kg of oats, in contrast to 3000 – 5000 chewing movements (Frape, 2004) in 65 min (Carson and Wood-Gush, 1983) to eat one kg of hay. Ellis et al. (2003) found that the number of chews per kg dry matter (DM) was 2199-2581, while Meyer et al. (1975) found 3000-3500 chews per kg DM. Ellis (2003) report that possible explanations for this discrepancy may be differences in the forage used, such as fibre size, but also type and size of the horses studied.

Carson and Wood-Gush (1983) found that horses fed hay spent 14.4 hours a day eating, while 6.5 hours were spent eating when oats were supplemented. Faster rate of chewing with less displacement of the lower jaw can explain the reduced time consuming concentrates. Hereby, horses fed diets relatively too high in grain and limitations on roughage significantly reduce the time spent foraging compared to free ranging (Thorne et al., 2005). Eating time and frequency of chewing depends on the type of roughage and on the physical form of the feeds (Dulphy et al., 1997). Overfeeding of palatable and high energy feed may lead to intake of excessive amounts of energy. This is emphasized by the high prevalence of obese horses among those fed concentrates (NRC, 2007).

3.2. Diet of exercising horses

Compared to non-working horses, the most profound nutritional effect of exercise of sport horses is an increase in dietary energy needs to cover the requirements for performance, besides being able to maintain bodyweight and condition (Geor, 2004). This is reflected in current feeding practices.

Besides performance, also body condition, environment and physiological status such as age, breed and fitness level, should be taken into consideration (Ellis, 1994). With increasing demands for performance, attention is focused on low energy in forages with increased supplementation of grain-based concentrates.

Although there are a wide range of diets fed to sport horses, they have a common major source of digestible energy; carbohydrates (NRC, 2007). CH can be divided into three fractions. Hydrolyzable CH (readily digestible and absorbable in the small intestine, such as mono- and disaccharides, some starches), rapidly fermented CH (rapid fermentation in the hindgut, such as fructans, pectins and resistant starches), slowly fermented CH (slower and incomplete fermentation, such as hemicellulose, cellulose and lignins). Challenges associated with current feeding practices are high concentrations of readily fermentable CH (Hoffman et al., 2001). In average grains contain 60% to 85% starch and about 3.2 to 3.9 Mcal/kg, hereby the term “concentrate” (NRC, 2007). Through the large amounts of carbohydrates, mixed feeds and grain are important sources of energy (Al Jassim and Andrews, 2009).

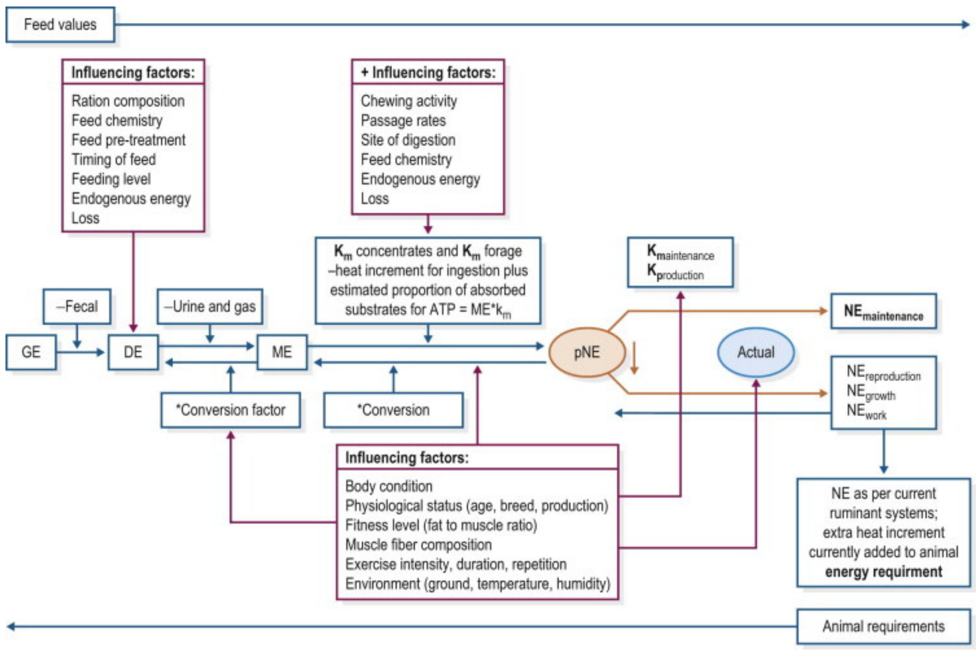

Fig. 3: Schematic overview of reaching the energy unit assigned to feed. See ABBREVIATIONS for figure explanation.
(Source: Ellis, 2013)

Calculation of the actual requirements in different countries is typically performed using different systems and methodologies. As an example, NRC (2007) proposed an estimate of the requirements during different intensity levels of exercise as a multiple of maintenance requirements.

Table 2: Estimated total daily digestible energy (DE) requirements for a 500 kg horse at five different levels of activity.

Intensity		**DE (Mcal/d)**
Maintenance	DEm[1]	16.7-18.2
Light	1.20 x DEm	20.0
Moderate	1,40 x DEm	23.3
Heavy	1.60 x DEm	26.6
Very heavy	1.90 x DEm	34.5

[1]DEm: Digestible energy requirements for maintenance.
(Adapted from: NRC, 2007)

Also other systems for calculations exist, such as the dutch EWpa system (the actualised net energy system for horses). In several systems the calculations of energy requirements are combined with feed values obtained from tables, allowing estimation of rations.

A study conducted by Hallebeek et al. (2000) compared the intake and requirement of protein and energy supply for event horses during training. Their study included 15 horses in training for the highest level of eventing. The intensity of training was measured by the time (in minutes) spent performing different levels of exercise. By the time spent walking, trotting, galloping and jumping in combination with the velocity of the different gaits, the energy requirement for work was calculated. The required energy was expressed in the unit VEP (Voeder eenheid paard = feed unit horse) as the net energy content. One thousand VEP is equivalent to the amount of energy the horse gets of 1 kg of dried barley; 9,41 MJ. (Lommelen et al., 2011). The requirements for maintenance were added to the total daily requirements. Further, the daily rations of feed were registered during one week, which all contained roughage and one or more type of concentrates, additionally some of the horses had access to pasture for a few hours per day. The components of the feed were analyzed, and the energy and protein content of the rations were calculated. The VEP intake was compared to the calculated VEP requirements (besides similar measurements for protein).

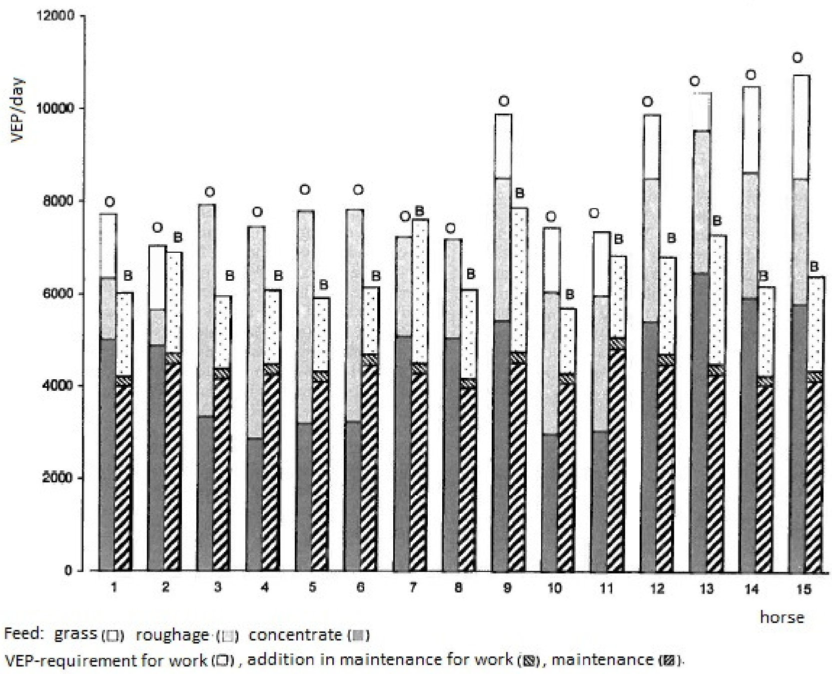

Fig. 4: Average daily intake ("O") and requirements ("B") for 15 event horses (during one week) *(Source: Hallebeek et al., 2010)*

The VEP intake was average 30 percent higher than the calculated requirements. The horses were all in energy balance, indicating that the VEP-intake was overestimated and/or the VEP-requirements were underestimated. This study illustrates the difficulties in calculation of rations, and the stability of the BW of the horses may be an applicable criteria in the evaluation of energy intake.

Further, knowledge can be a limiting factor in the development of rations for horses. Hoffman et al., (2009) conducted a survey of feeding practices of sport horses (dressage, pleasure and trail, jumping, 3-day eventing) in New England. The aim of their study was to investigate feeding practices, supplement use and knowledge among a subpopulation of horse owners. The horse owners enrolled in this study were those who brought their horses to the Large Animal Hospital at the Cummings School of Veterinary Medicine during two months in 2008. The owners were asked to answer some questions. The questions were designed to survey their feeding habits and supplement use, besides the health of their horse. Further, questions to assess knowledge of equine nutrition were added. They reported that all of the owners in this survey fed hay to their horses. Of these only 20% had analysed the content of the forage given. The horses were weighted and an average of 508 kg was found. The questions included the owners' approximation of the horses' BW, where a median of 545 kg was found, indicating an overestimation by the owners. Fifty percent estimated the amount of hay that should be fed to less than 2 percent of the horses' body weight, and forage rations less than optional were fed. Further, only 34 percent of the horses actually received the weight of hay their owners *thought* they were feeding, and 60 % recieved the amount of grain their owners intended to feed. Hereby, Hoffman et al. (2009) indicate that the owners' ability of calculating the proper amount of feed might be inadequate. Further, a study conducted by Honoré and Uhlinger (1994) found that quality and nutrient composition of grain and hay fed to pleasure and sport horses in the UK were extremely variable.

Hereby, almost all owners of sport horses feed grain or concentrate in addition to hay (96%; Hoffman et al., 2009, 87,4%; united states department of Agriculture, 90,1%; Baseline Reference of Equine Health and Management). The current practice in feeding roughage to sport horses is to use low energy late-cut forage. The high energy requirements are then fulfilled with energy-dense cereal-based concentrates, which commonly account for 40% of the diet (Redbo et al.,1998; Williamson et al, 2007)

Jansson and Lindberg (2012) conducted a study where they compared two feeding regimes in six Standardbred race horses. A standard mixed diet consisting of late-cut haylage supplemented with concentrates was compared to a high-energy forage only diet consisting of early-cut haylage. A comparison of the diets emphasize the discrepancy between a more natural forage-only diet and a traditionally fed mixed diet. The diets were estimated to be iso-caloric.

Table 3: Daily feed allowance, feed intake, nutrient and estimated metabolisable energy intake during the experiment on a forage-only and mixed forage-concentrate diet

	Forage-only	Forage-concentrate
Forage allowance (kg)	14.56 ± 0.04	7.00 ± 0.04
Forage intake (kg)	10.07 ± 0.09	4.88 ± 0.09
Concentrate allowance (kg)	0.29 ± 0.03	7.31 ± 0.03
Concentrate intake (kg)	0.29 ± 0.04	7.07 ± 0.04
NDF[1] intake (g)	6588 ± 507	3885 ± 270
Starch intake (g)	0	2503 ± 108
Water-soluble CH (g)	861 ± 66	605 ± 60
Energy intake (MJ)	110 ± 6	116 ± 6

[1]NDF = Neutral detergent fibre

(Adapted from: Jansson and Lindberg, 2012)

When concentrates were fed, less forage was consumed. Further, the higher fibre intake in the forage-only diet and the high starch intake in the traditional diet is emphasized. In this study body condition was similar in four of the six individuals, and two had higher body condition after receiving the mixed diet of forage and concentrate. No health problems were observed.

Also Muhonen et al. (2009) found that Standardbred horses in training can maintain body weight and condition on forage-only diets, where forage is early-cut and more energy-dense. As a large portion of sport and pleasure horses do not perform "intense activity", they could also do well on good quality grass or hay alone or with minimal concentrate (Hoffman et al., 2009). Despite this fact, Honoré and Uhlinger (1994) found that riding horses were fed concentrate rations approaching the ration of Thoroughbred race horses.

In the following example the effects of forage energy content on the proportions of hay and concentrate is illustrated. Both diets meet the energy requirements of a 500 kg horse with daily digestible energy (DE) needs of approximately 30 Mcal/day. This example assumes a daily dry matter (DM) intake of 11.5 kg or approximately 2.2% of bodyweight. LOW = hay with DE content of 1.5 Mcal/kg DM; High = hay with DE 2.0 Mcal/kg. The DE content of the energy concentrate is 3,3 Mcal/kg.

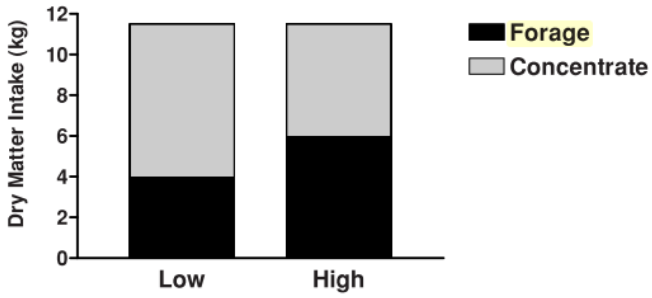

Fig. 5 : Effects of forage energy content on forage concentrate ratio
(Source: Geor, 2004).

The forage concentrate ratios in these two scenarios are:
LOW: 4 kg hay and 7.5 kg concentrate, or a ratio 35:65.
HIGH: 6 kg hay and 5.5 kg concentrate, or a ratio of 52:48.

Hotchkiss et al. (2007) reported that most horses in their Great Britain survey spent at least some time at pasture, but during the year hay and haylage were the most important available forage. There are seasonal variations in feeding practices due to the weather and the availability of pasture (Harris, 1999). In addition, most riding horses in moderate work are fed unprocessed grains, extruded feeds, complete feed pellets, commercially mixed sweet feed or combinations of these (United states department of Agriculture, 1998; Hoffman et al., 2009). Different supplements and palatability enhancers such as sugar, beet and molasses, are often added to the diet (Harris, 1999).

Current feeding practices of exercising horses are adapted to the high energetic demands and practical aspects concerning the stabled horse. Individual housing, limitations in forage, supplementation with concentrates, meal feeding and less time spent eating are main characteristics of current management.

4. Potential consequences of disproportion between concentrates and roughage

Cereal grains with a high starch content is not a part of the natural diet of the horse (Hubbard and Hansen, 1976), and the common practice to feed high-starch diets is associated with health problems (Ringmark et al., 2012). The previous chapters described the digestive system and the natural feeding of the horse, followed by characteristics of current feeding practices. With basis in discrepancies between natural and current feeding, this chapter will discuss some of the most common consequences associated with traditional diets characterized by a low roughage concentrate ratio.

According to Kiley-Worthington (1987) the horses' behaviour of nutritional wisdom works less well when they are fed concentrates compared to wild horses or horses kept on pasture. This is a consequence of a learning process where the horse learns that the food in the crib is good and does no harm. The horse will no longer show natural caution such as with taking small pieces initially. Also the deprivation between meals contributes to fast ingestion of the feed with less adaption of food intake to requirements. This, in combination with large concentrate meals, contradict the natural feeding habits of the horse.

4.1. Implications on behaviour and welfare of the horse

Higgins and Snyder (2006) report that feeding high concentrate diets with limitations on roughage may compromise the well-being of the horse by reducing the time foraging. Compulsive behaviours can be a direct result of deprivation of social interaction and the opportunity to graze, by giving the horse more idle time and less distraction from misbehaviour.

External environmental factors such as feeding management interact with internal factors such as motivation and discomfort and can cause stereotypical behaviour to occur. The type of activity performed can be an indication of the underlying motivation. Chewing, licking, crib-biting, wind-sucking and wood chewing are all thought to be related to eating (Kiley-Worthington, 1987). A strong motivation to forage was shown in a study conducted by Elia et al. (2010). Horses were highly motivated to work in order to get hay when access was limited. The discrepancy between strong motivation and limitation of forage are likely to result in frustrations, leading to abnormal behaviour (Kiley-Worthington, 1987). Wood-chewing is sometimes wrongly referred to as crib-biting by horse owners, however, Hothersall and Nicol (2009) report a study where 30.3% of young horses showed wood chewing, and of cribbing horses, 74% had shown wood-chewing previous to development of this compulsive behaviour. Cribbing is an example of stable vices classified as a stereotypy by its apparently functionless, repetitive character.

Further, studies show that development of unusual oral behaviour such as wood chewing, coprophagy (Frape, 2004; Higgins and Snyder, 2006), geophagia and even cribbing, can be caused by gastric inflammation and erosion (See also chapter 4.2.2). Hothersall and Nicol (2009) suggest that this unusual behaviour might be an adaptive attempt by the horse to reduce the acidity in the gastrointestinal tract. According to the National Research Council (NRC) (2007), the gastric pH is lower in cribbing horses (pH 3,3) compared to normal horses (pH 5,5). Cribbing stimulates the production of saliva, which can partly compensate the lower saliva production, though not sufficiently. Further, NRC announce that studies with antacid therapy lead to different results; positive results with reduction of cribbing as well as no effect on the duration or frequency were found. Nevertheless, conclusions were that predisposed horses on high-concentrate diets are more likely to develop vices such as wood chewing and cribbing as a result of the creation of an acid environment in the gastrointestinal tract. Coprophagy, geophagia and wood-chewing are not classified as stereotypes and seem rather to be responses to normal physiological or foraging needs (NRC, 2007).

Besides reduction of acidity, a study performed by McGravy (1997) showed that crib-biting is a coping mechanism that is also related to a decrease in oro-caecal transit time compared to normal horses. This positive correlation between crib-biting and transit time was found in horses with no-forage diets as well as with hay as a part of their diet. McGravy (1997) suggests that there is a triangular relationship between diet, gut activity and crib-biting.

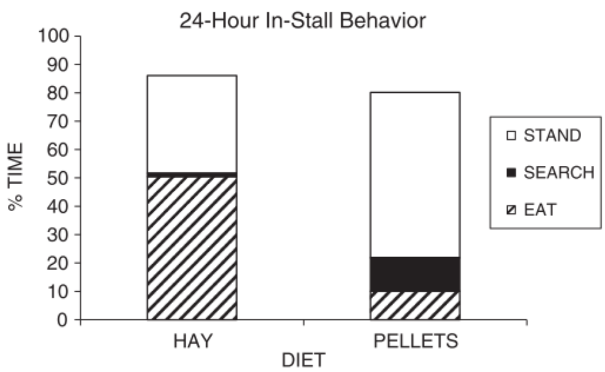

Fig. 6: The time budgets of horses fed a complete pelleted diet or hay ad libitum
(Source: Elia et al., 2010).

A review of crib-biting horses published by Wickens and Heleski (2010) found that many horse owners attempt to physically prevent their horses from performing this abnormal behaviour. This among other things includes removing biting objects, use of repellents, aversive methods and even surgical intervention. These methods simply prevent the symptoms and fail to treat the underlying causes. As this behaviour possibly serves a function of reducing boredom and discomfort of digestion, prevention compromises the welfare of the horses. The strong motivation to perform the activity is emphasized by the post-inhibitory rebound effect reported by McGravy (1997). The registered performance of stereotypy was increased after a 24 hour deprivation by wearing a tight collar. Physical prevention of other unusual oral behaviour only removes the symptoms. Even though the correlation between roughage and stereotypy is shown, other factors such as genetics, age, environmental factors and disease may play important roles (NRC, 1997).

As restriction of forage may increase vices such as wood-chewing, feeding palatable harvested long-stem fibre may reduce boredom and stress and enhance the welfare of horses (NRC, 2007).

4.2. Disturbances of the digestive system related to a low roughage concentrate ratio

Disturbances of the digestive system are often multifactorial or may have different possible etiologies. Some of the most common disturbances of the digestive system in relation to carbohydrate overfeeding and limited forage will be discussed.

4.2.1. Dental abnormalities

Dietary alterations associated with domestication are thought to be responsible for disorders associated with reduced wear of the teeth, such as formation of sharp enamel points on the cheek teeth (CT) (Dixon and Dacre, 2005). Mastication is important to process feed into small particles, as preparation for further digestion in the gastro-intestinal system (Julliand et al., 2006).

When the chewing cycle of a horse eating concentrate is compared to eating hay, an increased frequency and a lower total number, with less mediolateral mandibular displacement of the chewing movement is observed (Easley and Caddel, 1991). The length of the stems of roughage fed is positively correlated with the extent of the lateral movement of the mandible during mastication. Hereby, sharp enamel points are more probably to be formed when the horse is fed a high concentrate diet with limitations on roughage, due to reduced wear of the teeth (Easley and Caddel, 1991).

Some enamel folds normally protrude on the occlusal surface of the cheek teeth due to differences of wear between the harder enamel and softer cementum and dentine. The maxillary cheek teeth (CT) are wider than the mandibular (O’connor, 1950). This contributes to formation of enamel points on the buccal aspect (medially) on the mandibular CT and on the lingual aspect (laterally) on the maxillary (Dixon and Dacre, 2005).

The reduced displacement of the jaw may be caused by mechanical impediment or pain (Carmalt, 2007). The formation of enamel points will limit the movement of the mandibles additionally, leading to a vicious circle (Dixon et al., 2000; Dixon and dacre, 2005). Sharp points may be responsible for wounds in the mouth, with pain and less movement of the jaw, which further affect feed digestibility (Carmalt, 2007).

Further, dental disorders have an impact on feed digestibility in the intestines of the horse. A study conducted by Pagliosa et al. (2006) evaluated the influence of excessive enamel points on structural carbohydrates. They found that the digestibility of all the nutrients in this study increased after treatment of the enamel points, indicating that disorders of the teeth have a negative influence on the digestibility.

The role of dietary long-stemmed haylage was emphasized by a study conducted by Müller (2009). Chewing rate was slightly higher and the number of chews/kg DM was lower when horses were fed cut haylage compared to long-stemmed. Ellis (2003) found that particle size of feces was bigger when horses were fed chopped (3.5 cm mean particle size) compared to long-stemmed hay (>20 cm mean particle size), indicating that the particle size reduction during mastication is reduced when paricle size of the feed is reduced. Forage type does not affect the particle size distribution of feces (Ellis, 2003; Müller 2009), while individual differences may have an important impact (Udén, 1982).

On the other hand, sharp enamel points are also seen in free-ranging horses. O'Neill et al. (2010) performed a study to gain evidence that the prevalence of dental abnormalities in stable-kept horses is greater compared to free-living horses. A group of horses stabled on shavings with a diet of concentrate and limited access to forage was compared to horses kept on grassland with no supplementation with concentrates. After 9 months the dental condition and oral health of each horse was examined. Surprisingly they found that there was no difference in prevalence of sharp enamel points between free-ranging and stabled horses, suggesting that these are expected to occur. Other abnormalities such as exaggerated transverse ridges of the occlusal surface of the cheek teeth, focal overgrowth of the cheek teeth and periodontal disease were significantly higher in stabled than free-ranging horses. Their conclusion was that concentrate feeding opposed to forage are likely to adversely affect the dentition of the horse, by increasing the prevalence of dental abnormalities.

Dental overgrowth or other sources of pain in the mouth may lead to insufficient clearance of food in the mouth, with accumulation and predisposition for periodontal disorders (Dixon and Dacre, 2005).

Further, abnormal wear and other disorder of the teeth can lead to digestive problems and colic because of the limited ability of the hindgut to process the long strands of forage (Frape, 2004). Undigested grain particles and long strands of forage may be found in the feces, indicating insufficient particle size reduction, with following decreased digestion in the hindgut (Dixon and Dacre, 2005). Long feed particles due to ineffective chewing can also disrupt the passage of digesta causing impaction (Al Jassim and Andrews, 2009) (See chapter 4.2.3).

4.2.2. Gastric ulcers

Among disturbances of the gastrointestinal system associated with diet and current feeding practices, gastric ulceration has to be mentioned. Gastric ulcers are a group of disorders where the prevalence and severity is dependent on several factors (Andrews and Nadeau, 1999). Activity level, temperament, feed intake, diet, presence of clinical signs and housing are all parts of the multifactorial etiology of gastric ulceration (Hammond et al., 1986; Videla and Andrews, 2009). A higher prevalence is seen in stabled sport horses than horses kept on pasture. Videla and Andrews (2009) indicate that the higher prevalence might be caused by the association with exercise, meal feeding and feeding concentrates, as stabled horses typically are fed two large meals of grain daily. Further they emphasize that deprivation of feed between meals makes the horse consume its feed more rapidly.

The clinical signs of gastric ulcers are numerous and vague. Acute or recurrent colic, diarrhoea, rough hair coat, poor appetite, weight loss, depression, decreased performance, intermittent anorexia, and mild intermittent abdominal pain could be observed (Videla and Andrews, 2009).

Ulceration or erosion of the squamous mucosa is the most common form, and one of the most important gastrointestinal disorder of the performance horse (Vatistas et al., 1999; Lester, 2004), with a prevalence of 40-90 per cent in various studies (Murray et al., 1996; Vatistas et al., 1999; Andrews et al., 2005). The majority of gastric ulcerations occurs in the proximal nonglandular region (Hammond et al., 1996; Lester, 2004), due to its lack of protective mucus and bicarbonate (Videla and Andrews, 2009). The NRC (2007) suggests that diet and feeding management may alter the risk of development of erosions.

When there is an imbalance between protective factors (mucus, bicarbonate) of the gastric mucosa and ulcerogenic factors (hydrochloric acid, bile acids and pepsin), gastric ulcers may occur (Ethell et al., 2000; Lester, 2004). Repeated exposure of the squamous mucosa to high acidity contributes to formation of gastric ulcers (Videla and Andrews, 2009).

The prevalence of gastric ulcers is lower in horses kept on pasture compared to stabled horses with limitations in roughage and concentrate fed in meals (Videla and Andrews, 2009). During grazing there is a continuous flow of saliva buffering the ingesta; this in contrast to meal feeding of concentrates. As the number of chewing movements per kg concentrate is significantly lower than for chewing roughage, the production of buffering saliva is also lower (Frape, 2004). Elia et al. (2010) estimated that horses on a hay diet would chew 43 476 times per day, compared to 10 036 chews when eating a pellet diet. Subsequently, less chewing gives less opportunity to moisten the food with buffering saliva, causing a drop in pH and exposure of the mucosa to a more acidic environment (Murray and Eichorn, 1996). Besides less bicarbonate from saliva, this acidic environment is caused by the fact that the equine stomach continuously produces hydrochloric acid. Further, resident bacteria form short chain VFA by fermentation of readily fermentable carbohydrates, decreasing the stomach pH additionally. According to Al Jassim and Andrews (2009) exercise induces an increase in gastric acid production that may contribute to the lower pH. The corrosive capacity of the acidic environment contributes to formation of gastric ulcers (Argenzio et al., 1974). The role of lower saliva production in combination with continuous acid production is emphasized by the fact that meal feeding increases the prevalence of gastric ulcers. A study conducted by Feige et al. (2002) showed an increasing prevalence of gastric ulceration with a decreasing number of meals; the prevalence of gastric ulcers was 57,9% in horses fed three meals a day and as high as 75% of the horses fed only twice daily. The impact of feeding frequency on gastric ulcers was also demonstrated in a study conducted by Murray and Eichorn (1996). Alternation of 24-hour periods of feed deprivation and ad libitum access to hay over an 8-day period could induce ulceration of the squamous region of the stomach in healthy horses.

A study conducted by Metayer et al. (2004) showed that also the size of the meals fed plays an important role. The volume fed affects the extent of intragastric fermentation and hereby gastric fermentation. They saw that large meals (700g/100kg BW) had a higher gastric emptying rate than small meals (300g/100kg BW), but the percentage of emptying relative to the total mass was slower, indicating a longer retention time in the stomach. This allowed more fermentation by the resident bacteria, yielding VFA, favouring development of erosions. Similarly to stabled horses in general the high prevalence in race horses may be induced by the association with a typical high caloric diet, which is high in concentrate and low roughage (Hammond et al., 1986). The exercise itself can decrease the passage rate of feed through the stomach, allowing more fermentation to occur (Lester, 2004). According to Lorenzo-Figueras and Merritt (2002) also the increased abdominal pressure and decreased stomach volume during training is one of the most important factors increasing the exposure of the non-glandular mucosa to the acidic environment. Further, the high prevalence in stabled and intensively trained horses might also be associated with stress. A study conducted by Vatistas et al. (1999) showed that the stressful environment might contribute to ulceration of the gastric mucosa as all horses in their study developed gastric ulcers within 2 weeks of intensive training. Nevertheless, similar cortisol levels were found in horses not trained intensively. The entering of a new environment rather than the training itself might be the cause of stress and ulcers, as acclimatisation to the new environment led to decreased levels of cortisol. In stressful conditions sympathetic stimulation inhibits gastric bicarbonate secretion. Hereby, stress induce reduced mucosal defence and hereby enhancing the risk of ulceration (Lester, 2004). For the same reason temperament, more specifically a nervous disposition, may be associated with gastric ulcers (McClure et al., 1999).

According to NRC (2007) there is no definitive evidence of diet as one of the main causes of development of gastric ulcers. The influence of diet composition, meal size and feeding frequency on saliva production and further intragastric fermentation may play an important role in the risk of developing gastric ulcers.

4.2.3. Intestinal problems

The equine gastrointestinal tract is not evolutionary adapted to modern diets and feeding practices. This discrepancy may manifest in intestinal problems (Durham, 2009). Cereal feeding, restricted forage, bad forage quality as well as abrupt dietary changes, fasting periods, and irregular feeding times are factors that increase the risk of intestinal problems, leading to different types of colic (Cohen et al., 1999; Hudson et al., 2001; Archer and Proudman, 2006). This increased risk is caused by the changes of the microbial flora from cellulolytic to lactate producing bacteria (Drogoul et al., 2001; Julliand et al., 2001).

Excessive consumption of concentrates rich in CH in addition to environmental factors and possibly genetic predispositions alter the rate of occurrence and severity of colic (Shirazi-Beechey, 2008). A study conducted by Hudson et al. (2001) revealed an increased risk of colic by the factor six in horses fed more than 2.7 kg oats per day, compared to foraging horses. This indicates a discrepancy between the natural diet of the horse and modern feeding management with potential important consequences. Colic is the number one reason for euthanasia (Baker, 2012).

The prevalence of colic cases is significantly increased during spring, indicating that pasture is highly associated with intestinal problems (Steenhaut et al., 2000). Grasses can store large amounts of starches and fructans, making them a contributing factor in contribution to colic due to their rapid fermentable nature similar to concentrate (Durham, 2009). The often sudden access and the carbohydrate rich nature of young grass in the spring explains this influence by grazing to colic, in contrast to the general vision that grazing has a protective function on the digestive system of the horse (NRC, 2007).

The problems associated with starch occurs when the rapid fermentable CH content in the diet exceeds the digestive capacity of the small intestine. The excess of starch escaping enzymatic digestion in the small intestine enters the large intestine, where rapid fermentation of the non-structural carbohydrates occur, increasing short chain volatile fatty acid (VFA) production and lowering the pH. Proliferation of lactic acid producing bacteria is responsible for further decline in the pH (Al Jassim and Andrews, 2009). The pH can drop to four, compared to the normal 6.8-7.5 (Pollitt and Visser, 2010). This has an adverse effect on the resident bacterial population and short chain fatty acid absorption by the colon (Shirazi-Beechey, 2008). The fermentative acidosis predispose the horse to intestinal dysfunction (Julliand et al., 2001), making incomplete digestion in the small intestine one of the most important causal factors in dietary induced colic (Durham, 2009).

Lactic acid is poorly absorbed and accumulates in the lumen, attracting water, which can lead to osmotic diarrhoea and cecal distention (Clarke et al., 1990). On the other hand, Shirazi-Beechey (2008) indicated that the decrease in pH may be associated with decrease of fluid content, making the digesta more solid. The water content may also be decreased by the lower water holding capacity of the digesta when a concentrated diet is fed compared to a fibrous diet (Hintz et al., 1971). The physiological narrow flexures are predisposed sites for impaction. When the passage is blocked, the increased amount of gas produced during rapid fermentation is accumulated proximal to this blockage, leading to distention and pain (Clarke et al., 1990; Al Jassim and Andrews, 2009). Intestinal impaction is also associated with feeding forages of less than 2 cm particle length, and may be caused by decrease in particle size reduction due to the correlation with less effective mastication (Müller, 2009). Hay of poor quality, high in less fermentable CH, is another risk factor in ileal and colonic impaction (Hudson et al., 2001).

Dehydration of digesta and pain may cause dysmotility of the intestines, leading to increased distention of the colon, with displacement and volvulus as possible complications. A feared consequence is infarction of blood supply, causing ischemia and necrosis. These conditions altogether compromise the mucosal barrier of the hindgut, increasing the absorption of bacterial toxins and amines, predisposing to systemic problems (Shirazi-Beechey, 2008).

Durham (2009) suggested that five cases of colic could be expected per 100 horses each year. This is a serious condition that might even be fatal, and is a common cause of mortality of endurance horses (Fielding and Dechant, 2012).

4.3. Contribution to Laminitis

Laminitis is an inflammation of hoof wall lamellae, which is certainly seen in the acute phase of this disorder (Pollitt and Visser, 2010). In this subchapter the role of excessive amounts of readily fermentable carbohydrates in the contribution to development of laminitis will be discussed.

Besides an excess in carbohydrates other factors may play an important role in the pathogenesis of laminitis. Metabolic and endocrine factors in general and obesity, insulin resistance and hereby hyperinsulinemia in particular, are all associated with increased risk of development of laminitis (Frank et al., 2010).

Besides the intestinal problems discussed in the previous subchapter, unrestricted pasture or consumption of large amounts of cereal grain may lead to laminitis. After colic as number one, laminitis is the second most common reason for euthanasia (Baker, 2012). The type of grain and pre-feeding processing, besides digestion in the stomach and small intestine, are all factors that determine the amount of undigested starch reaching the hindgut. Further, the amount associated with onset of intestinal problems and laminitis varies between individuals (Pollitt and Visser, 2010). Besides sudden consumption of large amounts of CH rich feed, subthreshold doses consumed over a longer period of time may be responsible for subclinical cases ultimately manifested as clinical laminitis due to cumulative damage to the lamellae (Geor, 2010).

Climatic conditions, particulary during spring and summer favour rapid grass growth, with storage and accumulation of rapidly fermentable non-structural CH (fructans, simple sugars, or starches). Grazing under these conditions increase the risk, and is the main reason, of CH overload of the grazing horse. Thus, periods of high pasture fructan content appear to correlate with periods of increased incidence of laminitis. Further. the presence of insulin resistance alter the risk of development of laminitis (Johnson, 2002; Geor. 2010).

As discussed in chapter 4.3, a carbohydrate overload of the hindgut causes massive proliferation of hindgut gram-positive bacteria with rapid fermentation resulting in acidosis by the formation of lactic acid and other VFAs (Onishi et al., 2012). The Lactate produced during metabolic activities of the horse and other mammals is L-lactate, whereas D-lactate is a product of bacterial fermentation. Hereby, the concentration of D-lactate in the blood is an indicator of lactic fermentation in the hindgut (van Eps and Pollitt, 2006).

The bacterial overgrowth resulting in an acidic environment in the hindgut initiates increased permeability of the cecum and colon and other secondary events that may lead to laminitis (Pollitt and Visser, 2010). The possible role of migration of bacteria to the laminae was studied by Onishi et al., (2012). They collected laminae for bacterial analysis in horses with commercial fructans (such as oligofructose) induced laminitis. The difference in bacterial count was not significantly increased in the laminitis horses compared to the control group. Hereby, no association of the intra-intestinal bacterial overgrowth with translocation of viable bacteria to extra-intestinal tissues was found, although the cecal/colon lymphatic system was activated.

Rather than viable bacteria, Bailey et al. (2009) indicated that one of the most important consequences of the bacterial overgrowth is the death and lysis of large numbers of bacteria, and hereby release of toxic components such as cell wall components (endo- and exotoxins), as well as microbial genetic material. Absorption of these toxic components into the bloodstream may lead to severe illness of the horse with signs of cardiovascular shock (Pollitt and Visser, 2010).

MacKay et al., (1999) indicated that experimental administration of endotoxin solely failed to cause laminitis besides the fact that a range of drugs can effectively inhibit endotoxin, but fail to treat laminitis. Hereby, association of genuine endotoxinemia with laminitis onset is difficult to associate. The role of the bacterial overgrowth is undoubted, as administration of virginiamycin (antibiotic) followed by carbohydrate overload does not lead to development of laminitis in contrast to when an overload of carbohydrate is fed without administration of antibiotics. However, virginiamycin has to be present in the hindgut before arrival of CH to prevent laminitis, reducing the benefits of administration of antibiotics in the treatment of laminitis. (Pollitt, 1996).

It is believed that the systemic inflammation that occurs in response to CH overload initiates inflammation of lamellae similar to different disorders associated with gram-negative septicaemia (Geor, 2010). Endotoxins may prime inflammatory and hemodynamic mechanisms such as activation of platelets and further activation and migration of leukocytes. In normal horses, leukocytes are rarely found in the lamellar tissues in contrast to during this process where extravasation and infiltration of lamellae by leukocytes is seen. Inflammatory mediators are activated, contributing to inflammation (Bailey et al., 2009). The activity of mediators such as matrixmetalleproteinase, a basal membrane-degrading enzyme, results in lysis and detachment of the lamellar basal membrane. In a chronic phase this results in detachment between hoof and distal phalanx. Alterations in blood flow associated with inflammation, platelet activation and the presence of vasoactive amines absorbed from the hindgut may contribute to laminitis (Bailey et al., 2006).

Loss of function by the detachment of the lamellae may in a chronic phase allow displacement, rotation or sinking of the distal phalanx within the hoof capsule (Parks and O’Grady, 2003), causing lamellar injury and further loss of function. Activity performing stress on the already weakened attachment will cause further damage (Pollitt and Visser, 2010).

This process could be divided into stages with different grades of severity. There is a good correlation between damage seen microscopically and the degree of pain and lameness (Pollitt, 1996). Thus, when lameness is visible, destruction of the hoof wall lamella is already in progress, with a positive correlation with severity. Radiography for diagnosis and interpretation is an absolute necessity. Clinical signs combined radiography makes it possible to estimate the stage of this disorder with implications on treatment and prognosis. Although treatment is possible, there is no one proven treatment protocol (Baker, 2012), and the focus should be on prevention.

DISCUSSION

The aim of this paper was to answer the question whether and how current feeding practices contradict natural feeding of the horse, and the potential consequences.
With a background in function of the digestive system, the natural diet of the horse was discussed. Discrepancies between the natural and current feeding practices emphasized potential health and welfare issues.

Starch-rich concentrates are an important part of traditional diets, though not a part of the natural diet of the horse (Hubbard and Hansen, 1976). Limitations of the digestive system in the digestion of readily fermentable carbohydrates are associated with health problems (Ringmark et al., 2012).

As discussed, distinctive characteristics in the digestive tract allow horses to digest a fibrous diet (Jansson and Lindberg, 2012). By their capability of processing large quantities of forage the horses' could meet their nutrient demands (McIlwraith and Rollin, 2011) by spending as much as 12 (Dulphy et al., 1997) to 16 (Masey et al, 2010) hours per day foraging, or 52 (Dulphy et al., 1997) to 70 (Boyd L., 1991) percent of their time. As it takes 65 min to eat one kg of hay compared to 15 minutes to consume one kg of oats (Carson and Wood-Gush, 1983), consuming a concentrate rich diet occupies less time than a natural forage-rich diet. The fast ingestion of concentrated feed compared to forage is characterized by a faster rate of chewing due to its palatability and structure of the feed (NRC, 2007). Hereby, horses fed diets relatively too high in grain and limited on roughage significantly reduce the time spent foraging compared to free ranging (Thorne et al., 2005). Carson and Wood-Gush (1983) found that horses fed hay spent 14.4 hours a day eating, while 6.5 hours were spent eating when oats were supplemented. These numbers are not common for all concentrated or fibre rich feeds, but an illustration of the discrepancy in time spent eating a natural and a traditional diet. As seen in figure 2, the time budget of Przewalski horses is characterized by spending 30-70% of the time eating in the different time intervals throughout the day. This is comparable to figure 6 where 50% of the time is spent eating and searching for feed when the horse is on a diet of ad libitum hay. In contrast, figure 6 illustrates that only 20% of the time is spent eating and searching when on a complete pelleted diet. The reduced time spent foraging when diets with limitations on roughage are fed, compromise the welfare of the horse (Higgins and Snyder, 2006). Compulsive behaviours can be a direct result of deprivation of social interaction and the opportunity to graze, by giving the horse more idle time and less distraction from misbehaviour. The type of activity performed can be an indication of the underlying motivation. Chewing, licking, crib-biting, wind-sucking and wood chewing are all thought to be related to eating (Kiley-Worthington, 1987). As figure 6 illustrates that the time spent eating on a forage-only diet approaches the time spent foraging by the wild Przewalski horses, a diet consisting mainly of forage may be a solution to these problems by reducing boredom and stress and enhancing the welfare of the horses (NRC, 2007).

Besides the role of feed as occupancy, feeding on abrasive feed is needed to maintain dental health as the teeth of the horse erupt continuously (Easley et al., 2011). When hay is ingested it takes 3000 – 5000 chewing movements (Frape, 2004) to eat one kg. In a traditional diet, concentrates are fed, where it takes between 800 and 1200 chewing movements (Frape, 2004) to consume one kg of oats. Besides allowing a faster rate of chewing, less displacement of the lower jaw is observed when concentrated feeds are ingested (NRC, 2007). Dietary alterations associated with management of sport horses are thought to be responsible for disorders associated with reduced wear of the teeth, such as formation of sharp enamel points on the cheek teeth (Dixon and Dacre, 2005).

Sharp points may be responsible for wounds in the mouth, with pain and less movement of the jaw, which further affect feed digestibility (Carmalt, 2007). On the other hand, sharp enamel points are also seen in free-ranging horses, but the average incidence of dental problems in general is increased in the stabled horses compared to the free ranging horses (O'Neill et al.,2010).

Further, the decreased chewing has implications on the production of saliva as it is only secreted in the presence of food during mastication (Alexander F., 1966; Durham A., 2009; Luthersson et al., 2009; Elia et al., 2010). Among others, the function of saliva seems to be lubrication of feed and buffering of the acidic gastric content (Al Jassim and Andrews, 2009; Elia et al., 2010). Further, hydrochloric acid is continuously produced and secreted in the stomach (Hembroff D.A., 2006; Hothersall and Nicoll, 2009). As feeding concentrates decrease chewing, secretion of saliva will decrease resulting in less buffering of the gastric content and a lower pH. Hereby, deprivation of feed between meals has the same implications. In contradiction to the free ranging horse ingesting small meals throughout the day, sport horses are typically fed fewer larger meals. The survey conducted by Hoffman et al. (2009) showed that sport horses in New England were typically meal fed at specific times during the day, with a mean number of 2.1 ± 0.7 meals per day. This is similar to the findings in a study of feeding practices of French Standardbred trotters conducted by Fortier et al. (2013), where all trainers fed 3 meals a day of concentrate. Videla and Andrews (2009) indicate that meal feeding and feeding concentrates increase the risk of gastric ulceration. Further they emphasize that deprivation of feed between meals makes the horse consume its feed more rapidly. The imbalance between protective factors (mucus, bicarbonate) of the gastric mucosa and ulcerogenic factors (hydrochloric acid, bile acids and pepsin) may be responsible for gastric ulcers (Ethell et al., 2000; Lester, 2004).

When large amounts of readily fermentable carbohydrates are fed, resident bacteria form short chain VFA by fermentation decreasing the stomach pH additionally. Further, the high prevalence in stabled and intensively trained horses might also be associated with stress. A study conducted by Vatistas et al. (1999) showed that the stressful environment might contribute to ulceration of the gastric mucosa as all horses in their study developed gastric ulcers within 2 weeks of intensive training. Nevertheless, similar cortisol levels were found in horses not trained intensively. The etiology of gastric ulceration is complex, but the influence of diet composition, meal size and feeding frequency on saliva production and further intragastric fermentation seem to play an important role in the risk of developing gastric ulcers. The management of horses should approach the natural feeding of the horse by increasing the number of meals, limiting concentrates and providing sufficient amounts of fibre.

The low feeding frequency indicates that large amounts are fed per meal. The fast consumption of palatable feed further indicates that fast ingestion of large amounts occur. In contradiction, the equine stomach is relatively small (Auer and Stick, 2012).

Horses have a limited capacity to digest hydrolysable carbohydrates (e.g. simple sugars and starches) to hexoses pre-caecally (Hinchcliff et al., 2008). A low concentration of α-amylases in equine saliva (Julliand et al., 2006; Hoffmann, 2009) and pancreatic juice (Frape,2004) and the rapid transit trough the small intestine (up to 30 cm/min; Gerring and Hunt, 1986) with limited enzymatic digestion is responsible for this limitation of starch digestion. This is reflected in the natural diet of the horse. As seen in table 3, the forage-only diet in the study conducted by Jansson and Lindberg (2012) did not contain starch, but a high amount (6-7 kg) of fibre. This was in contrast to the diet consisting of forage and concentrates, where mixed feeds containing grain contributed to a high intake of starch (2.5 kg per day), and a significantly decreased content of fibre (3.5-4 kg).

When the amounts of starch in the diet exceeds the digestive capacity **o**f the small intestine, the amount reaching the hindgut is higher causing an increase in amylolytic bacteria and decrease the cellulolytic and related bacteria (Drogoul et al., 2001; Julliand et al., 2001), contributing to colic and laminitis as discussed in chapter 4.2 and 4.3.

As the prevalence of colic and laminitis cases is significantly increased during spring, and consumption of fast growing pasture is highly associated with intestinal problems (Steenhaut et al., 2000). Sudden access to carbohydrate rich young grass in the spring should be avoided. Gradual introduction to pasture in spring should be taken into consideration, allowing the intestinal flora to adapt, decreasing the risk of colic and laminitis (NRC, 2007).

Slowing the rate of ingestion of concentrates is likely to reduce problems associated with gastro-intestinal dysfunction (Davidson and Harris, 2002). Increasing the meal frequency may slow the rate of ingestion as well as increase the total time spent eating, also reducing the overall risk of stereotypic behaviour (McGreevy et al. 1995; Davidson and Harris, 2002). These findings were similar in almost all literature reviewed for this paper. However, a study conducted by Cooper et al. (2005) investigated the effect on stereotypic activities by increasing the number of meals of *concentrate,* and found an increase in pre-feeding stereotypic behaviour. This contradict a study performed by McGreevy et al. (1995), where more frequent *forage* meals reduced the overall risk of stereotypic behaviour. The response to concentrate or forage seems to be different. Cooper et al. (2005) indicated that reducing the amount of concentrate fed at each meal has the potential to reduce oral stereotypy, but that this may be negated by unwanted behaviour before feeding if cues were not removed. As the increase in unwanted behaviour was also seen in horses not included in the study elsewhere in the yard, the unwanted behaviour such as weaving and nodding could be actions in the anticipation of meals rather than a direct result of the number of meals and the feeding of concentrates. By the fact that they did not remove pre-feeding cues, some questions remain unanswered. Whether this increase in unwanted behaviour (despite an increased meal frequency) is solely learned behaviour in the anticipation of food, or associated with other factors in this meal feeding management, remain to be proved.

Current feeding practices find their basis in the fact that the energy required for maintenance and performance needs to be covered by the diet. Zeyner et al. (2004) indicate that intensively managed horses often may require a moderate level of concentrate in order to meet its energetic demands, if the forage consists of the traditional late-cut forage. Practical considerations regarding management, such as availability and ability to store large amounts of forage, seem to be a limiting factor in feeding a high-quality forage-only diet. According to Muhonen et al. (2009) and Ringmark et al. (2012) forage only could be sufficient to cover the energetic needs of the horse, without negative effects on body condition or health, if good quality energy-dense forage is provided. Figure 5 illustrates that providing forage high in energy can reduce the amount of concentrate in the diet.

Why horses are fed like this, when problems are common, is an interesting question. Knowledge can be a limiting factor in the development of rations for horses, as seen in a survey conducted by Hoffman et al., (2009). Fifty percent estimated the amount of hay that should be fed to less than 2 percent of the horses' body weight. In contrast, Kiley-Worthington (1987) reported that a horse will eat around 27% of fibrous material over 24 hours, provided free access, with variation depending on physiological demands. The National Research council (2007) estimated that a horse on pasture will have a dry matter intake of between 1,5 and 3,1% of their body weight per day. Owners in this study seemed to overestimate the BW of their horses and fail to give the amount they intended to give.

The study conducted by Hallebeek et al. (2000) illustrated the difficulties of ration calculations. Calculations of energy requirements were compared to intake, resulting in an apparent energy intake 30% higher than the estimated requirements. As the horses had a constant body weight, this study showed that values calculated may be difficult to interpret, and the body weight may be a good tool to evaluate whether requirements and intake correlate. Hereby, the knowledge and the rations put together by the trainers seemed to be adequate.

A study conducted by Honoré and Uhlinger (1994) found that quality and nutrient composition of grain and hay fed to pleasure and sport horses in the UK were extremely variable. As Hoffman et al. (2009) found that only 20% of the horse owners in the surveyed group had analysed the content of the forage given, unawareness might be an explanation.

Further, an increased body weight (BW) as a result of feeding forage only, is an important factor of concern by trainers worldwide. The increased BW may influence performance negatively. Nevertheless, Connysson et al. (2012) indicate that water content rather than biological mass is responsible for the increased weight of the digesta and total BW. Hereby, a lower BW is seen during forage deprivation during a forage-only diet, than on a concentrated diet. This indicates that a small weight gain by a forage-only diet might not be a factor if feed intake is reduced prior to competition. Forage in the diet may rather be beneficial to prerace fluid balance (Connysson et al., 2012).The positive effects of high forage rations seem to outweigh the increase in BW.

Although several studies indicate an increase in bodyweight (3 kg: Connysson et al., 2012; 10.6 kg: Ellis et al., 2002), comparison of the findings should be interpreted carefully. The different responses between these studies may be multifactorial and the lack of standardization complicates comparison. Although parallels are often obvious, quantification may greatly differ. “Forage only” -diets seem to vary greatly in chemical and total energy intake, besides differences in training intensity of the horses in these studies.

Processing of grain can be a factor contributing to a better digestibility and limiting of disorders. Grinding, micronizing and popping improve the extent of enzymatic hydrolysis in the small intestine and hereby precaecal digestibility, reducing the amount of starch reaching the large intestine (Julliand et al., 2006). Further, oats have higher fibre and lower energy content and is a safer source of energy than other grains, especially in case of excess (Hussein et al., 2004).

The use of fat as an energy source has been proposed, as the equine pancreas seems to have a high lipase activity, and horses seem to digest fat efficiently (Lorenzo-Figueras et al., 2007). Nevertheless, the horses have not evolved as fat eaters, and long term negative effects on metabolism could be a problem. Zeyner et al. (2002) performed a study to investigate these potential long term negative effects. They found no apparent adverse effect of the high fat ration compared to a high starch ration. Though, this was under a precondition that substantial bodyweight changes were prevented. Further, fat in the diet might lead to fat-induced depression of fibre digestion. Horses do not have a gall bladder, and adding an emulsifying substance like lecithin may improve fat digestion. Zeyner et al. (2002) indicated that the depression of fibre digestion in horses consuming 1.33 g of soy bean oil per kg BW per day, could be prevented by adding lecithin as 10% of the total amount of fat. However, limiting the fat content of the diet seemed to be more important.

In the attempt to limit grain associated disorders, “limiting” concentrates and “increasing” forage are important factors. As these are vague terms, quantification may be necessary. According to NRC (2007), horses should be fed at least 10g/kg body weight (BW) /day of forage DM, based on long stem forage. Intake of starch should certainly not exceed 200g starch/100kg BW/meal, or approximately 2 kg of concentrate feed for a 500-

kg horse (Julliand et al., 2006). According to Cuddeford (2001) 2g /kg BW per meal or 1 kg for a 500-kg horse is a safer upper limit.

Possible limitations in comparison of studies within this field often seem to be characterized by the difficulties in isolating and identifying one underlying factor. Changing one factor is often associated with several other factors. Studying the influence of meal frequency is often associated with other changes of management such as stabling the horse and even deprivation on social interaction. Different levels of exercise are also highly associated with different diets. Further, several problems associated with grain feeding have different and multifactorial etiologies, indicating that all these factors have to be studied. In order to investigate the role of each and every factor they all have to be isolated and studied separately, which in some cases might be impossible.

Further, difficulties in standardizing might influence the quality of comparison. Within a study, standardizing the environment in different trials might be impossible. As an example Dulphy et al. (1997) report that in two trials, the grass hays had somewhat different content. For the same reason comparison between studies might be influenced by these dissimilarities.

The chosen subpopulation of horses in the trials might also not be representative for the whole population. In the study by Hoffman et al. (2009) where a study was performed during two months in a veterinary clinic the results might be affected by seasonality. Further, a high number of orthopaedic problems, and other characteristics may prevent data from being applied to the general horse population.

This paper has treated sport horses as one homogenous group, failing to consider the variations between different types of sport horses. Avoiding this extrapolation from one type of sport horse to another might yield different and more accurate conclusions.

Suggestions for further research may comprise researching the effects of feeding less concentrates, feeding concentrates lower in starch and higher in oil and fibre, as well as testing the implementation into practice.

In summary, this paper suggests that the equine gastrointestinal tract is not evolutionary adapted to digest diets fed in current feeding practices. Limitations in forage besides over-feeding of starch seem to have potential adverse effects on the health and welfare of the horse (Durham, 2009). Cereal feeding, restricted forage, bad forage quality as well as abrupt dietary changes, fasting periods, and irregular feeding times are factors that compromise the welfare and health of the horse. Although practical aspects have to be taken into consideration, the objective should include limiting the intake of concentrate and providing a large amount of forage. As energy dense forage-only diets seem to provide sufficient energy to maintain BW of horses in training (Jansson and Lindberg, 2008; 2012), this could be a nearby solution to the problems experienced in association with current feeding practices.

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