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Bioavailability of Minerals in the Horse

Ellen Kienzle and Natalie Zorn

Introduction

The term bioavailability is used in pharmacology and toxicology as well as in nutrition. Its pharmacologic definition is as follows: "Bioavailability is a measurement of the rate and extent of therapeutically active drug that reaches the systemic circulation and is available at the site of action (Shargel and Yu 1999). Extended to nutrients the definition can be formulated: Bioavailability is a measurement of the rate and extent of a nutrient that reaches the systemic circulation and is available at target tissue level.

For minerals bioavailability depends strongly on absorption from the gastrointestinal tract into the systemic circulation. For most minerals this is the limiting step. Consequently true digestibility is often used to quantify mineral bioavailability. There are, however, situations where other factors than absorption from the gastrointestinal tract may be limiting bioavailability of minerals. For instance, in copper deficient animals iron cannot be used to build hemoglobin (Mertz 1986).

The bioavailability of a mineral in an animal is a rather elusive entity which may be changing relatively quickly. Factors which affect bioavailability of minerals relating to the animal are species, life stage, health and nutritional status. Factors relating to the diet are level of intake (in relation to requirements), intake of other minerals, intake of substances which may enhance or impair the absorption of the mineral in question. And finally there are factors related to the mineral compound used, such as water solubility and chelating qualities of the mineral (Mertz 1986, Kirchgessner 2004).

The gastrointestinal tract of different species shows enormous differences in anatomy and function. Peculiarities in ruminants such as interactions between magnesium and potassium or between copper and sulfate which do not play a role in monogastric species demonstrate the importance of such differences for mineral absorption very clearly (Mertz 1986, Kirchgessner 2004). Setting aside ruminants there are still big differences between monogastric species. A major species specific difference is the typical feed and its interaction with the mineral in question. For instance, hem-iron is not an ingredient of a typical equine diet. The acidification of the stomach content and the pH of other parts of the gastrointestinal tract differ between monogastric species and may have a strong impact on the solubility of the mineral in question. Passage time through the small intestine or the large bowel may affect absorption. Transport systems through the intestinal wall may be similar in quality but may differ hugely in quantitative capacity. In some cases the systems are not the same, for instance for calcium in horses there is a vitamin D independent absorption which is not much affected by nutritional status (Meyer and Coenen 2002). Excess calcium is excreted by urine in the horse. By contrast in carnivores, pigs and ruminants urine is not a major route of calcium excretion, but the absorption from the gut is highly regulated. In trace elements there may be barriers to prevent trace element overload. For instance, the toxicity of copper differs between species (Mertz 1986). Iron has a low toxicity in domestic animals and men, however, for some exotic species whose natural diet is low in iron, a diet with an iron content as recommended for domestic animals or men may be detrimental (Wood and Clauss 2004). This is not necessarily linked to the anatomy and function of the gastrointestinal tract: Adult horses tolerate high iron

diets very well, but some concentrate selecting hindgut fermenters such as the black rhinoceros (Dierenfeld et al. 2005) do not. Analogies from other species must be interpreted with extreme caution in the horse.
The age of an animal may affect its gastrointestinal tract, its nutritional status and its diet. A foal does not have a fully developed hindgut, and it is likely to have a high demand for minerals like calcium, and it has only small stores of some trace elements such as copper. Its diet does not yet contain large percentages of roughage (Meyer and Coenen 2002). In horses old age often affects the health of the teeth. This may alter the size of the feed particles in the gastrointestinal tract which in turn may affect many features of digestive physiology from saliva production and passage time to microbial fermentation. Bad teeth may also decrease the percentage of roughage in the diet eaten which in turn affects the abs orption of certain minerals (see below). Apart from the health of the teeth there may be other effects of old age on the function of the gastrointestinal tract and mineral absorption. Female reproduction creates high demands for some minerals and is therefore likely to affect their bioavailability. In the horse physical activity leads to high mineral losses by sweat production which may have an impact on mineral bioavailability (Meyer and Coenen 2002).. In addition during life stages with increased energy demands the composition of the ration and the amount of food changes and this in turn may also affect mineral bioavailability.
Health may affect mineral bioavailability directly or indirectly. For instance, diarrhea may reduce the absorptive capacity of the gut, bad teeth may affect digestion, the demand for minerals may increase or a special diet which affects mineral absorption may be indicated.
Nutritional status may affect bioavailability of a mineral. The ability of the animal to absorb a mineral may increase during deficiency of this mineral and it may decrease during excessive intake of this mineral (Kirchgessner 2004, Mertz 1986). Deficiency or excess of other nutrients may also affect bioavailability of a mineral.
There are several interactions between minerals such as between calcium and phosphorus, between zinc and copper or between calcium and zinc which are generally supposed to occur in men and domestic and experimental animals (Mertz 1986. Kirchgessner 2004, Meyer and Coenen 2002). The same is true for interactions between minerals and compounds of the diet such as fat and calcium or phytate and phosphorus or zinc. In the target species horse, however, few of these interactions have been verified, and they may not exist or may be somewhat different. On the other hand it makes sense to take into account the possibility of interactions between dietary compounds and mineral availability when formulating rations for horses, even if some of these interactions have never been demonstrated in horses.

The mineral compound used as a source for the mineral or trace element in question may play an important role (Kirchgessner 2004). For cation major minerals hydroxides and oxides are very uncommon because of their corrosive effects. Sulfates are unusual as well, in part because of their bitter taste and/or because of laxative effects. Carbonates, chlorides, phosphates are in general use. Organic salts of cation major minerals such as gluconates contain usually much less of the minerals than carbonates, chlorides or phosphates. For trace elements as a general rule it is supposed that oxides and carbonates are less available than sulfates (Mertz 1986). Chelates and other organic trace element compounds are often supposed to have a better bioavailability than inorganic salts of trace elements. Again this is questionable in the target species horse.

There are several experimental approaches to measure bioavailability of minerals. A simple method is the addition of a mineral salt to a deficient diet. If the addition of the mineral compound in question can prevent symptoms of deficiency which do occur on the unsupplemented diet, then it is reasonable to assume that the mineral in question is bioavailable. If the mineral is added in amounts supposed to meet the requirements and it cannot prevent or cure symptoms of deficiency then its bioavailability is very low. For instance, cupric oxide has been demonstrated to be unable to prevent symptoms of copper deficiency in cats (Fascetti et al. 1998). A less extreme approach from the view point of animal welfare are dose response curves using an indicator which reacts highly sensitive to a low supply of the mineral investigated.

Measuring true digestibility of minerals is a more sophisticated approach to estimate bioavailability. Unfortunately it requires the use of isotopes which is more or less prohibitive in large species including horses.

Apparent digestibility may be an alternative if it is sufficiently high and if the intake of the mineral is considerably higher than endogenous fecal losses. For instance, chloride usually has an apparent digestibility of 90 % and more (Coenen 1991, Stürmer 2005), which can be accepted as proof of it being highly available. By contrast, a negative apparent digestibility does not prove that a mineral is not available, it may be absorbed in quantities which are smaller than the faecal losses either because the intake does not meet the requirements or in some elements because the organism of the animal is saturated with this mineral.

Plasma or serum response after the intake of a dose of the mineral salt in question is a rather crude method to demonstrate mineral availability. If the plasma content of the element investigated increases this certainly demonstrates that it was bioava ilable under the respective experimental conditions. If the plasma content does not increase this does not prove that the mineral salt is not bioavailable. Regulatory mechanisms may come into play and keep the plasma level steady even though large amounts of the mineral are absorbed. For instance, it would not be possible to demonstrate bioavailability of sodium chloride by measuring the plasma sodium content. Single high doses of a mineral are more likely to result in a plasma response than lower doses applied for a longer time frame. Long-term application may even result in a decrease of the plasma mineral content as demonstrated in horses after long-term intake of zinc supplements (Kreyenberg 2003). On the other hand single high doses (especially of trace elements) may overset protective homeostatic mechanisms against overload with this trace element. Thus it may rather demonstrate a higher potential toxicity than a higher bioavailaibility.

Bioavailability of major minerals in the horse

Calcium absorption in the horse seems to differ somewhat from absorption in most other domestic animals and in men. A large percentage of dietary calcium is absorbed from the gastrointestinal tract. The calcium which is absorbed in excess of net requirements is then excreted by urine (Meyer and Coenen 2002). The process appears to be independent of vitamin D. Calcium absorption and excretion in the horse resembles sodium absorption and excretion to some extent. Calcium seems to be bioavailable for horses from most feed stuffs (Schryver 1975). Judging from apparent digestibility and renal excretion of calcium in various experiments of balance, calcium carbonate and calcium chloride appear to be readily absorbed from the gastrointestinal tract (Schryver et al. 1970, Lensing 1998, Stürmer 2005). The most important factor affecting calcium bioavailability is the ratio of concentrates to roughage (Meyer et al. 1982). This effect may in part depend on a lower calcium/phosphorus ratio in diets with a high percentage of cereals. It was, however, also demonstrated independently of the calcium/phosphorus ratio. Pectin from sugar beet pulp does not have a similar effect as roughage (Olsman et al. 2004). Phytate appears to decrease calcium absorption in the horse (van Doorn et al. 2004). Cereals are high in phytate. Therefore it is extremely difficult to sort out the effects of the roughage to concentrate ratio, of the calcium/phosphorus ratio and of the phytate content. For practical feeding the conclusions are obvious: To ensure high bioavailability of calcium (fed according to requirements) feed large amounts of roughage, avoid feeds extremely high in phytate such as wheat bran, and keep the calcium/phosphorus ratio within the recommended range. Oxalate in amounts of more than 2 % dry matter decreases bioavailability of calcium (Meyer and Coenen 2002). Hintz et al. (1984) found calcium from alfalfa highly available for horses regardless of its oxalate content. According to Zeyner (2002) a high fat diet did not affect apparent calcium digestibility.

Availability of magnesium in horses is high. Magnesium absorption and excretion follows the pattern of calcium absorption and excretion (Meyer and Coenen 2002). Feeding high percentages of roughage enhances magnesium absorption from the gastrointestinal tract. Zeyner (2002) observed a decrease of apparent magnesium digestibility in horses fed high fat diets. Magnesium appears to be available as sulphate. After application by tube in horses with colic hypermagnesemia and associated hypocalcemia has been observed Henniger and Horst 1997). By contrast the availability of magnesium oxide is questionable (Harrington 1975).

Phosphorus deficiency is an extremely rare occurrence in horses. Hintz and Schryver (1972) reported a high availability of phosphorus from steamed bone meal, di-calcium-phosphate and sodium mono-phosphate. Phosphorus from wheat bran appears to be about half as available as from inorganic sources (Hintz et al. 1973). Apparent digestibility of phosphorus is lower in rations with a high percentage of roughage (Meyer et al. 1982). Meyer et al. (1982) hypothesized that in horses eating large amounts of roughage more phosphorus is secreted into the gastrointestinal tract with digestive juices, and consequently more phosphorus is excreted by the faeces. Calcium/phoshorus ratio and phytate do not appear to play a major role for phosphorus absorption (Meyer and Coenen 2002, van Doorn et al. 2004).Zeyner (2002) observed a decrease of apparent phosphorus digestibility in horses fed high fat diets.

Provided the intake is not in a similar range as the endogenous losses apparent digestibility of sodium, potassium and chloride is high (Lindner 1983, Gürer 1985, Coenen 1991).

Bioavailability of trace elements in the horse

Iodine as iodide has an extremely high bioavailability in horses, which is known from cases of iodine toxicity as well as experiments of balance (Silva et al. 1987, Engelschalk 2001). Some plants such as rapeseed contain thioglycosides and/or cyanogenic glycosides. They have been demonstrated to induce disorders of iodine metabolism in the thyroid gland in other many species (Wiesner 1967, Rudert and Oliver 1976, Kursa et al. 1998).

Selenium in the chemical form of sodium selenate and sodium selenite is highly biovailable in the horse (Podoll et al. 1992). Organic selenium compounds such as selenium yeast are highly available in other species (Payne et al. 2005). Compared to inorganic selenium they may be more efficient in increasing tissue selenium levels in other species.

For copper it is likely that bioavailability plays a highly important role in the horse. Requirement figures for copper are not unequivocally agreed upon (NRC 1989, Meyer et al. 1994, Hintz 1996). Variation of bioavailability of copper is an obvious reason for differing evidence on copper requirements. Zinc is supposed to be a potent antagonist of copper. In the horse, however, 500 mg of zinc/kg of diet did not have obvious effects on copper metabolism (Coger et al. 1987, Hoyt et al.1995). By contrast 1000 or 2000 mg of zinc/kg diet had adverse effects on copper metabolism in foals (Cymbaluk and Smart 1993). High molybdenium intake had little impact on copper metabolism of horses (Cymbaluk et al. 1981, Strickland et al. 1987). Other potential copper antagonists are iron, calcium, cadmium or ascorbic acid (Meyer et al. 1994).The availability of the copper source may also differ. Copper oxide is available in ruminants but it has a low availability in many other species (Baker and Ammerman 1995). It was completely unavailable in cats (Fascetti et al. 1998). So far the effect of the chemical form of copper on its availability has not been extensively investigated in horses.

Bioavailability of zinc may be affected by diet. Numerous substances such as calcium, iron or phytate have been reported to interfere with zinc absorption in other species (Mertz 1986). There is, however, only one study on experimental zinc deficiency in the horse and naturally occurring clinical zinc deficiency has not been unequivocally described so far in the horse. Excess intake of iron decreased plasma and liver zinc content in ponies (Lawrence et al. 1987). Wichert et al. (2002) investigated the plasma response after oral administration of high single doses of either zinc oxide, zinc lactate, zinc sulfate or an organic zinc chelate. Under the given conditions zinc oxide and zinc lactate were not highly available, whereas zinc sulfate and the organic zinc chelate induced a clear-cut plasma response.

Since iron deficiency is not a practicalproblem in horses it can be assumed that feed iron in typical horse rations is sufficiently available. Soil contamination of fodder appears to be an important source of iron for growing foals (Brommer et al. 2001). Iron toxicity has been induced in suckling foals by administration of iron fumarate (Mullaney and Brown 1988)

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