MINERAL CONCENTRATIONS IN HAIR AS INDICATORS OF MINERAL STATUS: A REVIEW

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Summary

Mineral content of hair is affected by season, breed, hair color within and between breeds, sire, age and body location. Seasonal effects may be due to stage of growth of hair and to changes caused by perspiration, surface contamination and diet. Breed and sire effects on mineral content of hair complicate prediction of nutritional status based on hair analyses because, in many commercial cattle, neither breed nor sire is known. Hair from young animals may be lower in Zn, Mn and Fe, but is higher in Na, Ca, Cu and K than that from older animals. Pigmented hair apparently is higher in Ca, Mg, K and Na than white hair, but trace mineral concentrations are similar in hair of different colors. The effect of body location on mineral content of hair may be due to differences in surface contamination, differences in hair growth cycles and differences in texture of the hair. Concentrations of Ca, P and Cu in hair are not affected by dietary intake of these minerals. Zn and Se contents of hair may reflect dietary intake. Information on other required minerals is lacking. Pb, As and, possibly, Cd levels in hair may be related to dietary or environmental exposure. Because of the many factors that cause variation in mineral content of hair, hair analyses are not likely to be precise indicators of the mineral status of animals. Hair analyses may help to detect severe deficiencies of some required minerals or exposure to some heavy metals. However, if hair analyses are to be conducted, care must be taken to compare values from test animals with those from animals of similar breed, sex, season, sire and color. In addition, new hair growth should be analyzed, environmental contamination should be minimized and the hair samples should be cleaned before analyses.

(Key Words: Hair, Mineral Concentrations, Mineral Status, Trace Minerals.)

Introduction

It has been proposed that body stores of minerals may be estimated from hair analyses, because growing hair is metabolically active and is a sequestering tissue. Thus, hair may reflect concentrations of minerals that were in the hair follicle at the time the hair was formed. Analyses of hair for mineral content may also reflect surface contamination by minerals in urine, feces, sweat, feed and airborne matter. Because of an interest by researchers and commercial nutritionists in using hair as an indicator of mineral status, we prepared this literature review in an attempt to determine which factors influence hair analyses and, hence, to identify instances when mineral analyses of hair may be useful in predicting mineral status.

Review

Hair Growth

The hair shaft is a keratinized filament that develops from matrix cells of a hair follicle in the epidermal epithelium. Each follicle is a miniature organ that includes smooth muscle and glandular components. The glands associated with hair follicles are either sebaceous or apocrine. Wysocki and Klett (1971) and Hopps (1977) proposed that sweat secreted by the sebaceous glands may be an important source of minerals in hair and that fatty secretions of apocrine glands may provide physical or chemical means by which exogenous mineral may bind to hair.

Hair is formed at a rate of .2 to 5 mm/d in humans (Hopps, 1977) and, during its formation, is exposed to circulating blood, lymph and extracellular fluid. As the hair shaft approaches
the skin surface, it is removed from sites of metabolic activity and undergoes keratinization. Keratins contain disulfide bonds that may be major binding sites of minerals in hair (Hinners et al., 1974; Hopps, 1977).

Hair growth in most animals is cyclic, with a period of active growth followed by a resting phase. In cattle, hair growth cycles are regulated by length of day (Hopps, 1977) and a follicle normally produces two or three hairs/year with a resting phase between each growth. When the winter coat is being maintained, most follicles are in a resting state. In Germany, Anke (1965) found that the most suitable periods for sampling hair were from December to mid-February and from July to August. Mid-February to mid-May and September to November were not suitable periods because hair was in the process of being shed and new growth was being produced during these periods.

Growth of hair occurs in four stages. The anagen phase is the period when hair is actively growing. The follicle matrix is fully differentiated and is exposed to circulating blood, lymph and extracellular fluid. As the anagen phase ends, the catagen phase begins. Cells of the follicle matrix rapidly degenerate, causing the follicle to shrink. This leaves only a small group of undifferentiated cells, which form a new follicle when the next growth phase begins. The telogen phase is the resting stage of the growth cycle. The hair shaft may be easily dislodged during the telogen phase and often will fall out.

Near the end of the telogen phase, an intermediate phase begins and a new follicle forms from the remainder of the follicle of the previous hair cycle. After this formation, a new hair forms and the anagen phase starts again. The new hair shaft normally will push out old hair remaining from the previous cycle, but occasionally two hairs (one from the previous cycle and one from the current cycle) will protrude from a single canal.

Growth of hair may be altered slightly to induce more hair growth. Plucking of hairs is one of the most effective ways to increase hair growth (Hopps, 1977). Cutting hairs, without damaging the follicle, has little effect on growth of hair. To stimulate hair growth, the follicle must be damaged (Hopps, 1977). This causes an increase in amount of hair growth because the resting cycle is shortened. The actual rate of hair synthesis is not altered. Several chemicals, including barium sulfate, increase hair growth.

The binding of metals in hair is believed to involve S (Hinners et al., 1974; Hopps, 1977). Hair is composed principally of protein and, in humans, between 11 and 18% of hair protein is cysteine and cystine (Hinners et al., 1974). Methionine-S is also present in small amounts. Controversy exists over the stability of metal-S bonds. Some investigators consider these bonds highly stable and resistant to breakdown and subsequent loss of the metal (Kopito et al., 1967; Weiss et al., 1972). Others (Senning, 1972; Hinners et al., 1974) note that the metal-S bonds are not particularly stable and may be broken by dilute acids.

Carboxyl groups have also been proposed (Hinners et al., 1974) as possible metal binding sites in hair. It has been reported (Bate, 1966; Hambidge et al., 1972) that hair will absorb more metals at pH 6 than at pH 4. Unbound carboxyl groups of proteins would be protonated to a high degree at a low pH and would present fewer anions for binding with metal cations.

Factors Affecting Mineral Content of Hair

Hair has many properties that make it a likely biopsy tissue. It may be collected easily with little trauma and it can be stored until analysis is convenient because it does not deteriorate readily. Trace elements are accumulated in hair at concentrations that are at least 10 times higher than those present in blood serum and urine (Maugh, 1978). Hair acts as a recording filament because elements are deposited in the hair matrix within a short time and are removed from active metabolism as the hair shaft grows from the follicle. The major disadvantage of using hair as a biopsy material is that many factors other than diet are known to affect mineral content of hair. Factors that have significant effects on mineral concentrations in hair include season, breed, age, hair color and body location.

Season. O'Mary et al. (1969) collected hair from Hereford cattle in March and August and found higher concentrations of Na, Ca, Cu, Mg, Mn and K in the August samples. They reported that Zn and P contents did not change between seasons and that Fe concentration was lowest in the samples obtained in August. Wysocki and Klett (1971) found higher concentrations of Ca and P in pony hair in the summer than in winter. They speculated that this may have been
due in part to increased perspiration during summer months. Strain et al. (1966) also reported that Zn content was higher in samples of human hair collected during the summer than in samples collected at any other time of the year. Miller et al. (1965) reported a seasonal pattern for Zn accumulations in hair of Holstein cattle. Hair collected in November was lower in Zn than hair collected at any other time of year. Seasonal effects on mineral content of hair may also reflect dietary changes unless care is taken to ensure a uniform feed supply.

**Breed.** Few trials have been conducted comparing mineral content of hair from different breeds of cattle. O'Mary et al. (1970) compared white hair from Holstein and Hereford cattle and found Holstein white hair to have more Na, Ca and K than that from Hereford cattle. Holstein black hair contained more Na, P, K, Mg and Ca than red hair from Herefords. Combs et al. (1979) also showed that hair of Angus calves produced by different sires differed significantly in K, Ca, Mg, Fe and Mn content.

**Age.** Hambidge et al. (1972) reported that Zn concentrations in human hair decline sharply after birth, remain low for 2 or 3 yr and then increase toward original values. Miller et al. (1965) reported that Zn content of cattle hair may be affected in a similar manner. They found that Zn content of hair increased substantially as calves increased in age from 8 to 15 wk. Zn content of hair from 5-mo-old heifer calves was also higher than that of mature cows; however, diets of the two groups were different. O'Mary et al. (1969) evaluated the effect of age on mineral composition of hair from Hereford cattle and reported that hair from calves had higher concentrations of Na, Ca, Cu and K, but lower concentrations of Mn and Fe than hair from mature cows. O'Mary and co-workers did not find significant differences in Zn, P or Mg content of hair from cattle of various ages. As is also true for effects of season on hair analyses, changes in mineral content of hair may reflect change in age and diet.

**Color.** Davis (1958) observed that Cu deficiency in cattle caused depigmentation of hair and Stirn et al. (1935) found that Zn deficiency caused depigmentation of black hair in rats. These findings, along with the observation that ash content of white hair is lower than that of pigmented hair (Anke, 1965; O'Mary et al., 1970; Hall et al., 1971), have led to the assumption that mineral content of cattle hair varies because of color. Mineral contents that appear to be influenced most by color are Ca, Mg, K and Na, all of which are higher in pigmented hair (Anke, 1965; O'Mary et al., 1970; Hall et al., 1971). Data to date indicate that trace elements are not greatly influenced by hair color. Anke (1965) and Hall et al. (1971) reported that Zn content of pigmented and white hair from Holstein and Hereford cattle did not differ significantly. However, Miller et al. (1965) found a significant difference in Zn content (124.1 vs 112.2 ppm) of black and white hair from Holstein cattle.

Cu concentrations in hair apparently are not affected by hair color. Cu contents of red and white hair from Herefords (O'Mary et al., 1970; Hall et al., 1971) and black and white hair from Holsteins (Anke, 1965) were similar.

**Body Location.** Body location also influences mineral content of hair. Anke (1965) found that black hair from the forehead of cattle contained higher concentrations of Fe, Zn, Mn and Cu than black body hair. Miller et al. (1965) reported that Zn concentrations in hair from various parts of the body were similar, except that hair from legs contained less Zn. Miller et al. (1965) emphasized that body location may not influence mineral content of hair as much as the fact that hair on different parts of the body may be in different cycles of growth at the time of sampling.

Miller et al. (1965) found higher concentrations of Zn in white tail switch hair than in black or white body hair. Miller et al. (1965) cited literature indicating that Zn contributes to stiffness of hair in rats and humans. Tail switch hairs of cattle are stiff and coarse in comparison to body hair.

**Hair as an Indicator of Mineral Status**

The effect of diet on mineral concentrations in hair is of considerable interest. Several laboratories conduct hair analyses and make dietary recommendations for livestock based on these analyses. Utilization of hair as a biopsy material for this purpose is controversial. Research to date indicates that concentrations of certain trace elements in hair may be related to dietary intake.

**Ca and P.** Ca and P are important elements that are frequently deficient in livestock diets. The use of hair analyses to monitor intake of these elements has generally been unsuccessful.
Cohen (1973a) found no correlation between P concentrations in pasture and concentrations of P in hair from grazing steers. Later, Cohen (1973b) found that drenching growing steers with P did not change hair P or Ca concentrations. Wysoki and Klett (1971) reported low correlations between intakes of Ca and P by ponies and Ca and P contents of their hair. Anke (1966) reported that dietary supplementation with Ca and P significantly increased concentrations of Ca and P in pigmented hair of dairy cattle. He also reported that dietary Ca had an antagonistic effect on P content of hair. Because the major site of mineral deposition in hair is thought to be the follicle, it appears that changes in Ca content of the diet should not be discernible by hair analysis. Ca concentration in blood is homeostatically controlled and concentration of this element in blood is elevated or depressed for only short periods of time by changes in diet.

**Mg.** Mg deficiency in ruminants is associated with grass tetany. Cattle suffering from grass tetany are commonly observed to have blood serum Mg levels below 1.0 mg/100 ml, compared with a normal level of 2.1 mg/100 ml. Because blood Mg levels are low, hair may have low Mg levels following a Mg deficiency. Anke (1966) reported that Mg levels were higher in hair from cattle when the diet was supplemented with Mg. Hall et al. (1971) compared Mg content in hair from cows that had grass tetany in previous years with that in hair from cows that had no history of grass tetany. Samples were taken five times during the year and no significant differences were found between the two groups. No cows in either group suffered from grass tetany during the trial, and, to date, little information is available to indicate how hair responds to a Mg deficiency.

**Cu.** Cu deficiency in ruminants is often associated with depigmentation and impaired keratinization of hair. Cu content of hair from mammals has been studied as a potential index of Cu status. O'Mary et al. (1970) reported that level of dietary Cu affected concentration of Cu in hair of Holstein and Hereford cattle. White hair from both breeds was affected more than pigmented hair, and Cu content of black Holstein hair was not consistent with increasing levels of dietary Cu. Anke (1966) reported that pigmented hair of dairy cattle was not influenced by dietary supplementation with Cu. Van Koestveld (1958) observed that hair Cu concentrations below 8 ppm were associated with Cu deficiency, but Cunningham and Hogan (1958) found little relationship between Cu content of hair and that in the diet or liver. Anke (1966) concluded that Cu status was best indicated by Cu levels in the liver. Also, Cu content of hair may be affected by dietary S and Mo concentrations. This interrelationship may complicate the use of hair analyses to indicate Cu intake.

**Zn.** Zn contents of feeds may vary considerably due to production factors, but, in general, concentrations are higher in protein-rich feeds than in cereal grains. Cattle fed diets composed largely of cereal grains and supplemented with urea may be marginally deficient in Zn (Miller, 1970). The reduced use of galvanized water pipes and pens has also decreased the amount of Zn in the environment of cattle. Many trace mineralized salt mixtures contribute insignificant amounts of Zn in relation to the animals' requirements (Miller, 1970). Severe Zn deficiencies in cattle have been reported to Finland, Guyana and other areas. Borderline Zn deficiencies are difficult to diagnose (Miller, 1970).

Several researchers have attempted to determine the relationship between hair and tissue levels of Zn and nutritional status. Strain et al. (1966) found that levels of Zn in hair from men with severe Zn deficiencies were significantly lower than those in hair from normal men (54.1 vs 103.1 ppm). Zn content of hair also increased (54.1 vs 121.1 ppm) when the deficient men were treated with oral ZnSO₄. Hambidge et al. (1972) found that preschool children suffering from Zn deficiency, diagnosed by lower growth percentiles, had lower hair and blood serum Zn levels. Controlled experiments conducted with animals indicate that hair Zn may reflect dietary Zn intake, but it does not adequately assess the status of Zn nutrition as measured by growth and feed consumption. Reinhold et al. (1968) and Deeming and Weber (1977) reported that rats fed diets severely deficient in Zn (2 or 3 ppm) had substantially lower concentrations of Zn in hair than rats fed Zn-adequate diets (12 to 20 ppm). Deeming and Weber (1977) reported that Zn additions to an adequate diet resulted in increased amounts of Zn in hair from rats. Reinhold et al. (1968) and Deeming and Weber (1977) concluded that Zn levels in hair are related to dietary Zn levels but do not necessarily reflect the severity of Zn deficiencies.
deficiency, as manifested by impaired growth rates.

In research with ruminants, Miller et al. (1966) and Miller (1970) reported that Zn concentrations in hair reflected dietary Zn levels of cattle and goats more consistently than concentrations in any other tissue. Miller et al. (1966) noted, however, that because of variation among animals, Zn deficiency could not be adequately diagnosed by hair analyses. Similar results were reported by Beeson et al. (1977) who conducted a series of trials in which basal diets that contained approximately 20 ppm Zn were supplemented with 0 to 620 ppm of Zn. Zn content of hair of beef cattle increased significantly in only a few trials and was generally an inconsistent indicator of increased dietary Zn.

Se. Se deficiencies in domestic livestock have been reported in many areas of the world (Gardiner, 1966). Hidiroglou et al. (1968) reported that cows with hair Se concentrations between .06 and .23 ppm produced calves with white muscle disease, while no white muscle disease was found in calves from cows with hair Se greater than .25 ppm. In a study with feedlot cattle, Perry et al. (1976) found that concentrations of Se increased from .3 ppm in hair from cattle fed no supplemental Se to .49, .58 and .60 ppm in hair from steers fed diets supplemented with .1, .2 and .4 ppm Se. Olson (1969) reported that continuous intake of 5 ppm Se by cattle may result in selenosis and that concentrations of 5 to 10 ppm Se in the hair of cattle may indicate Se toxicity.

Hair as an Indicator of Heavy Metal Status

Hair analyses have been proposed as a method of assessing exposure of humans and animals to Cd, Pb and As. Hammer et al. (1972), Petering et al. (1973), Klevay (1973), Orheim et al. (1974) and Dorn et al. (1974) reported significant correlations between Cd, Pb and As contents of human and animal hair and exposure of humans and animals to these elements. Hammer et al. (1972), Klevay (1973) and Petering et al. (1973) emphasized, however, that the extent to which hair predicts environmental exposure to heavy metals depends on factors such as age, sex, length of hair and chemical treatment of hair. These factors influence heavy metal concentrations of hair to such an extent that only individuals or groups that are similar in age, sex and place of residence may be compared.

It is well documented that Pb and As contents of hair are useful as indicators of dietary Pb and As intake and as a diagnostic aid in Pb and As toxicity (Kopito et al., 1967; Underwood, 1977). Cd content of hair appears to be poorly related to dietary intake of Cd.

Cd. Cd is widely distributed because of its use in industry and as a contaminant in phosphate fertilizers and sewage sludges (Friberg et al., 1971). It is toxic to nearly every system in the body and is considered a serious health hazard to humans and animals. Cd interacts with divalent cations, most notably Zn, Se, Cu and Fe (Neathery and Miller, 1976a), and it appears that this is a major cause of Cd toxicity. Symptoms of Cd toxicity include anemia, retarded testicular development or degeneration, enlarged joints, scaly skin, liver and kidney damage, reduced growth and increased mortality (Neathery and Miller, 1976a).

The deposition of Cd in hair may occur via dietary, pulmonary or surface routes. Underwood (1977) reported that pulmonary absorption is a relatively unimportant route of Cd intake in animals and nonsmoking humans. Friberg et al. (1971) indicated that the intake of Cd in nonsmoking humans is less than 5 ug/d from pulmonary routes. Underwood (1977) reported that the average dietary intake of Cd by humans is between 26 and 96 ug/d.

Several researchers have proposed that hair may be a useful tissue with which to monitor environmental exposure of humans and cattle to Cd. Hammer et al. (1972) and Petering et al. (1973) reported that significant correlations existed between Cd content of human hair and exposure to Cd. Dorn et al. (1974) examined Cd content of hair from cattle grazing on a farm located within 800 m of a Pb smelter and compared them with Cd content in hair from cattle grazing on a farm that was free of industrial Cd exposure. The authors found significantly higher Cd levels in hair of cattle on the farm located near the smelter than in hair of cattle on the control farm. Cd content of hair was affected by season. Hair collected from cattle near the smelter had the highest levels of Cd in the spring, while hair collected from control cattle had the highest Cd concentrations in the winter. In both groups of cattle, hair collected during the summer had the lowest levels of Cd. The higher Cd in hair of cattle located near the lead smelter may have been due in part to exogenous airborne contamina-
Nishiyama and Nordberg (1972) found that they could not differentiate exogenous from endogenous Cd once the exogenous Cd had been adsorbed onto hair. They reported that various treatments could remove Cd from hair, but found no treatment that would separate exogenously from endogenously deposited Cd.

Hair has generally been found to be a less accurate indicator of dietary Cd intake than of exogenous Cd. Several experiments showed that kidney, liver and small intestine are good indicators of dietary Cd intake in ruminants (Miller et al., 1968, 1969; Neathery et al., 1974; Doyle et al., 1974). Miller et al. (1969) reported that only .0165% of a single oral dose of radioactive Cd was deposited in hair. Doyle et al. (1974) reported that Cd levels in kidney and livers from lambs increased as levels of dietary Cd increased from 0 to 60 ppm. Cd concentrations in wool from lambs fed various amounts of dietary Cd were similar. Cd levels in wool from lambs were similar to Cd levels found in human hair (Friberg et al., 1971) and were slightly higher than concentrations in hair from calves fed normal diets (Powell et al., 1964).

**Pb.** Pb toxicity is one of the most frequently reported causes of acute poisoning in farm animals, especially cattle (Neathery and Miller, 1976b). Major sources of Pb are Pb-based paints, waste motor oils and Pb-arsenate pesticides. It is also possible for domestic livestock to become chronically poisoned from environmental Pb exposure. Cattle grazing on land treated with sewage sludge or located near Pb mines or smelters may inhale significant amounts of airborne Pb or ingest high levels of Pb deposited on grasses (Neathery and Miller, 1976b).

Human and animal data indicate that environmental Pb exposure is positively correlated with concentrations of Pb in hair. Hammer et al. (1971, 1972), Petering et al. (1973) and Klevay (1973) reported that humans have hair Pb levels that corresponded to environmental Pb exposure. Dorn et al. (1974) reported that cows grazing within 800 m of a Pb smelter had higher concentrations of Pb in their hair than cows grazing on a farm that was free of Pb exposure. It appears that the major source of Pb in the hair of cows grazing near the smelter was exogenous contamination. Blood Pb levels were low and not correlated with hair Pb levels of cattle grazing near the Pb smelter. Rüssel and Schoberl (1970), however, found a significant correlation between hair and liver concentrations of Pb in cattle with chronic Pb poisoning. Suzuki et al. (1958) reported a positive correlation between Pb in hair and Pb in blood and urine of workers with acute Pb poisoning. Jaworowski et al. (1966) also reported that radioactive Pb injected subcutaneously was taken up by hair of rabbits.

**As.** Exposure of livestock and humans to As can occur via arsenical sprays that are used for insect control and by the burning of coal that releases large amounts of As into the air. Arsenic is also widely distributed naturally in the environment. It is found in soils at levels between 1 and 40 ppm and certain plants are known to accumulate As (Porter and Peterson, 1975). Arsenic has also been used as a growth stimulant for swine and poultry. It does not appear to accumulate in internal organs (Underwood, 1977) and the best tissue and fluid with which to assess As status may be hair and urine, respectively.

Arsenic is distributed throughout the body in low, but variable, concentrations. Peoples (1964) reported that cattle fed .05 to 1.25 mg of As/kg body weight for 8 wk had no detectable quantities of the element in blood or bone. Wagner and Weswig (1974) also reported that blood As levels were not good indicators of As exposure in humans. Hair and urine As contents are currently used for assessing the exposure of individuals to As. Browning (1961) and Peoples (1964) reported that urinary As levels increased with increasing As intake and that total As excretion is a good indicator of As exposure. Hammer et al. (1971), Chattopadhyay and Jervis (1974) and Orheim et al. (1974) reported that As levels in hair from humans and cattle are positively correlated with As exposure. However, Hammer et al. (1971) noted that levels of As in hair are affected by many factors, including sex, age and hair length of the individual.

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