JOURNAL OF ANIMAL SCIENCE
The Premier Journal and Leading Source of New Knowledge and Perspective in Animal Science

The use of electrolyte solutions for reducing transport stress.

A L Schaefer, S D Jones and R W Stanley

J ANIM SCI 1997, 75:258-265.

The Use of Electrolyte Solutions for Reducing Transport Stress

A. L. Schaefer*, S.D.M. Jones*, and R. W. Stanley†

*Agriculture and Agri-Food Canada, Lacombe Research Centre, Lacombe, Alberta and
†STS Agriventures, Red Deer, Alberta

ABSTRACT: The transport and handling procedures imposed on beef cattle during the normal course of marketing can be a significant stressor. Factors including time off feed, water deprivation, mixing and the resulting behavioral problems, transport movement, unfamiliar noise, inclement weather, and so forth are often present and collectively result in live weight and carcass losses as well as degraded meat quality. In addition, a growing public concern regarding animal welfare in such situations is evident. Understanding how cattle adapt to and are influenced by these factors is a necessary first step in being able to reduce these stresses and a major research effort globally has been directed toward this end. Studies at the Lacombe Research Center have focused on understanding the role of electrolytes in attenuating transport and handling stress. Apparent in this research has been the consistent observation that transport and handling reduce blood pH, glucose concentration, and interstitial water space ($P < .05$), and increases in serum chloride, hemoglobin, urine sodium, and urine osmolality ($P < .05$) are evident. These changes are also accompanied by significant increases in the neutrophile/lymphocyte ratio. The application of oral electrolyte therapy, especially if similar in constituents to interstitial fluid, seems to attenuate these physiological changes. Resulting improvements in both live and carcass weights (less shrink) of up to several percent in treated animals as well as a reduction in meat quality degradation (reduced dark cutting) is evident in such trials. These studies suggest that the use of electrolyte therapy may be an effective means of reducing stress in transported cattle.

Key Words: Transport, Stress, Electrolytes, Dehydration, Hypoglycemia

J. Anim. Sci. 1997. 75:258–265

Introduction

Most athletes recognize that a vigorous workout or competition can result in the loss of several percent of body weight. These athletes will also be aware of the abundant body of scientific and popular press literature advising them of the physiological requirements during such activity and the numerous training regimens teaching the importance of nutritional support of their bodies during such times. Nutritional strategies to combat factors including dehydration, electrolyte loss, hypoglycemia, muscle catabolism, and fatigue abound. These strategies are recognized and accepted by most coaches, trainers, and athletes to be logical approaches to assist with athletic performance and these nutritional strategies are viewed as simply another tool for training, no less important than game tactics or fitness regimens.

By comparison, most domestic animals also experience physiological insults when they are transported and handled. Of course, as discussed by Hails (1978), Fraser (1979), Grandin (1993), Friend et al. (1994), and Stull and McDonough (1994), our various codes of practice and humane treatment of animals legislation are intended to prevent flagrant abuse of our animals. However, our “pregame meal” strategies have clearly not evolved to the same level as with humans. The purpose of the present article is to review the need for a more sophisticated approach to nutritional modulation during times of physiological non-steady state such as when animals are transported and handled. The current article is intended to focus on transport and handling stress in domestic ruminants and primarily refers to issues arising in the antemortem environment.

Transport and Handling Effects

There are three primary reasons why we would wish to reduce the stress of transport and handling in domestic animals. First, transport and handling stress

[1]Presented at a symposium titled “Effects of Stress in Farm Animals” at the ASAS 87th Annu. Mtg., Orlando, FL, July 26, 1995.

Received August 25, 1995.
Accepted April 21, 1996.

reduces live weight and carcass yield. Second, transport and handling stress degrades meat quality, and third, it could be argued that transport and handling stress degrades animal well-being. Therefore, there are both economic and benevolent reasons to attenuate transport and handling stress.

Live and Carcass Weight

When cattle are transported they are usually held off feed. Feed deprivation alone will clearly cause the animals to lose weight (Ozutsumi et al., 1984). When the effects of fasting are combined with the effects of transport and handling the cattle typically lose more weight than is observed with fasting alone (Phillips et al., 1985; Warriss, 1990). In fact, transit shrink in beef steers is shown to represent as much as 68% of the shrink resulting from the combined effects of fasting and transport within 46 h (Phillips et al., 1985). For example, more weight is generally lost from cattle moved off pasture (Schaefer et al., 1993; Church et al., 1994) or transported long distances (Jacobesen et al., 1993) than from cattle directly shipped and slaughtered. Clearly, weight loss varies in an animal depending on the circumstances surrounding its treatment. However, in general, it is estimated that about .75% of farm weight will be lost per day, although not necessarily in a linear fashion, with feed and water deprivation (Shorthose and Wythes, 1988), but this value can increase severalfold when transport is added (Jones et al., 1988). Noteworthy also, and contrary to many commonly held beliefs that transport weight loss is simply gastrointestinal tract fill, is the observation that much of this loss is actually from carcass components and not simply gastrointestinal tract fill (Jones et al., 1988; Warriss, 1990).

Meat Quality

The impact of transport and handling stress on meat quality has been well documented (Warriss, 1990). Quality attributes primarily affected by transport and handling in cattle include pH, color, texture, and moisture, and a degradation of these variables is collectively referred to as dark cutting or dark-firm-dry, high pH, low glycogen meat (Price and Tennesson, 1981; Lacourt and Tarrant, 1985; Lister, 1988; Tarrant, 1988, 1989; Warner, 1988).

Transport and handling conditions including exposure of animals to such factors as mixing, time off feed and water, and temperature and weather aberrations are well known to contribute to dark cutting (Christopherson et al., 1980; Price and Tennessen, 1981; Lacourt and Tarrant, 1985). The need to minimize preslaughter stress in particular, including transport and handling stress, are suggested as key factors in reducing the incidence of dark cutting (Haurez and Chupin, 1986; Baker, 1988; Tarrant, 1988; Grandin, 1988; Shorthose, 1988; Warner, 1988).

Additional meat quality factors are also affected by transport and handling stress, particularly in the antemortem environment. These effects include an increase in toughness (Schaefer et al., 1990) and a negative impact on palatability attributes (Jeremiah et al., 1992; Schaefer and Jeremiah, 1992).

Animal Physiology

Animal welfare and well-being are often difficult concepts to define. As discussed by Lefcourt (1986), we are often left with simply defining the clinical conditions surrounding events. However, the classical, albeit perhaps dated (Axelrod and Reisine, 1984), Selyenian view that increased stress is accompanied by an increase in circulating cortisol is still widely preferred (Selye, 1956). Transport and handling are reported to evoke an increase in circulating cortisol and in this context transport and handling are thus viewed as stressors (Crookshank et al., 1979; Stephens, 1980; Locatelli et al., 1987; Mitchell et al., 1988; Morisse et al., 1988; Murphy and Fordham, 1988; Fordham et al., 1989; Locatelli et al., 1989; Cockram and Corley, 1991; Scott et al., 1993). These observations are consistent with the reported findings of other coinciding cortisol-driven events in transported cattle such as neutrophile/lymphocyte responses (Murata et al., 1987; Murata, 1989; Church et al., 1994) and evoked responses of other stress hormones such as beta endorphin (Murphy and Fordham, 1988; Fordham et al., 1989) and thyroxin (Scott et al., 1993). In fact, based on a comparative response in circulating corticoid levels, transport and handling is considered to be one of the most potent stressors for cattle (Johnson and Buchland, 1976).

An alternative definition of stress is suggested to be a comparative departure of physiological factors from “normal” (Lefcourt, 1986). In this context an important question arising from the foregoing observations is, what are the physiological insults accompanying the loss in weight and degradation in meat quality in transported and handled animals? Understanding the nature, magnitude, and etiology of these physiological changes would clearly enable the animal industries to make more informed decisions regarding treatment. In this respect, in addition to the aforementioned endocrine factors, a plethora of physiological insults are documented when animals are transported and handled. Some of the more significant changes are as follows.

Muscle Glycogen. Transport and handling usually oblige cattle to a reduced energy intake as well as to some degree of physical exercise and, occasionally, to mixing, which in turn can precipitate such events as fighting and mounting. Such activities deplete muscle glycogen, especially of the fast twitch fibers (Lacourt and Tarrant, 1985). In addition, cattle typically display lower blood glucose levels compared to nonruminant animals. This situation usually contributes to a lower muscle glycogen content and rate of muscle glycogen repletion (McVeigh and Tarrant, 1982), which in part is one of the causative factors in dark cutting and may also have implications for immune function (Cole et al., 1993).

Hematology. Transport and handling stress have been observed to alter numerous blood cell components. In general, an increase in packed cell volume is commonly seen (Fenwick and Green, 1986; Schaefer et al., 1988, 1990, 1992; Jacobsen et al., 1993) and likely reflects both a splenic response to stress and a degree of dehydration. Notable differences in white blood cell differential counts are also observed. Leukocyte responses in cattle to transport and handling are frequently reported (Murata et al., 1987; Cole et al., 1988; Morisse et al., 1988; Murata, 1989; Jacobsen et al., 1993; Church et al., 1994). Most commonly, a leucocytosis and neutrophilia accompanied by a reduction in T lymphocyte numbers and blastogenesis are observed (Wegner et al., 1974; Blecha et al., 1984). Although changes in immunoglobulin G or immunoglobulin M concentrations are not commonly seen in transported cattle (Kelley et al., 1981), these responses in general may be cortisol-driven and are immunosuppressive, resulting in an immunocompromized condition, as has been observed in mice (Landi et al., 1985; Aguila et al., 1988).

Electrolyte Balance. As discussed by Novotna et al. (1986), cattle have a substantial buffering capacity. However, transport and handling can be seen to cause significant changes in electrolyte balance (Baker, 1988; Fosha-Dolezal and Fedde, 1988; Schaefer et al., 1988, 1990). Particularly notable in this respect are changes in major ions including chloride, potassium, calcium, and magnesium. The anion gap measurement, a mathematical approximation of differences in major anions and cations ($[Na + K] - [Cl + HCO_3]$), has been shown to have some utility in diagnosing aberrant acid-base conditions in transported cattle (Schaefer et al., 1990). Depending on when in the course of transport and handling these measurements are taken, a decrease in this measure has been observed in transported cattle and likely reflects to some extent the increase in plasma chloride concentration in these animals (Schaefer et al., 1990).

Hydration. The importance of hydration in transported and handled cattle is highlighted by Lofgreen (1983). On the basis of in vivo dye dilution studies (Gortel et al., 1992) or even simple measures of plasma and urine osmolality (Schaefer et al., 1990, 1992) transport and handling are observed to cause dehydration. This is clearly a logical result of factors such as time off water, increased respiration rates, urinary and ruminal water loss, and excessive sweating in transported and handled animals. Collectively, this water loss seems to affect the pool size in the interstitial water space (Gortel et al., 1992). Dehydration effects may be very insidious in terms of economic costs to live and carcass weight loss as well as organ weight loss and hide hydration. Also, hydration can affect additional intracellular acidification events (Waddell and Bates, 1969), likely resulting in changes in meat quality attributes.

Thermal Regulation. Transport and handling are reported to cause a rise in deep body temperature (Warriss, 1990). However, these values likely vary according to when and how the measurements are taken. Monitoring surface infrared temperatures after transport, for example, has indicated that cattle actually display a cooler temperature with increasing stress levels (Schaefer et al., 1988). This observation would be consistent with the observed depletion of glycogen stores and thus a reduced energy supply to support heat production.

Additional Metabolic Changes. In addition to the foregoing, a host of significant metabolic changes have also been observed in transported and handled cattle. These include an increase in blood enzymes such as creatine phosphokinase (Sinclair et al., 1992; Scott et al., 1993; Unanua and Buitrago, 1985; Kenny and Tarrant, 1988; Cockram and Corley, 1991), lactate dehydrogenase, and aspartate aminotransferase (Doornenbal, 1987; Cole et al., 1988; Scott et al., 1993). Blood metabolite changes including increased concentrations of blood lactate (Mitchell et al., 1988; Schaefer et al., 1992), ketones (Lambooy and Hulsegge, 1988), and β-hydroxybutyric acid (Frohli and Blum, 1988; Warriss et al., 1989) and altered blood urea nitrogen concentration (Cole and Hutcheson, 1985) have also been reported. Notable changes in cardiovascular events, particularly an increased heart rate, are likewise seen to occur in transported and handled cattle (Stermer et al., 1982; Kenny and Tarrant, 1987; Eldridge, 1988). Collectively, the aforementioned physiological events documented to occur during transport and handling of cattle should suffice to demonstrate that the animals are not in a steady-state condition while being transported and handled. Understanding these events, however, has been a necessary first step in being able to intelligently suggest treatment regimens to attenuate transport and handling stress.

The Treatment of Transport and Handling Stress

The foregoing discussion serves to illustrate some of the metabolic insults affecting animals when they are subjected to transport and handling stress. Clearly, the nature and etiology of these metabolic events is a complex matter and designing treatments to resolve these insults is equally complex.

Numerous strategies have been employed in an attempt to attenuate some of the physiological responses associated with transport and handling stress. These include the use of preconditioning regimens (Woods et al., 1973; Cole, 1988), vitamin treatments (Cole et al., 1982), vaccines (Johnson et al., 1988), and the feeding of fats (Cole and Hutche-

Table 1. The effect of antemortem electrolyte therapy on live and carcass weight loss in transported and handled cattle

Item	Control[a]	Treated[b]	*P*
Hot carcass yield[c], kg overnight held, long haul (4 h) Post-transport treatment (Schaefer, unpublished data)	288.1 (n = 53; steers)	298.4 (n = 117)	<.01
Hot carcass yield[c], kg overnight held, long haul (4 h) Pretransport treatment (from Scott et al., 1993)	281.9 (n = 38; bulls)	288.4 (n = 38)	<.05
Hot carcass yield[c], kg overnight held, long haul (8 h) Pretransport treatment (from Jacobsen et al., 1993)	264.4 (n = 20; steers + heifers)	280.4 (n = 41)	.01
Hot carcass yield[c], kg overnight held, long haul (4 h) Pretransport treatment (from Gortel et al., 1992)	288.4 (n = 20; bulls)	298.2 (n = 25)	<.05
Live weight loss (%) in pasture-raised, overnight held, moderate haul (1 h) Pretransport treatment (from Schaefer et al., 1993)	6.7% (n = 31; steers + heifers)	4.9% (n = 31)	<.0001

[a]Control animals offered water only.
[b]Treatment was with the electrolyte therapy product NUTRI-CHARGE®, a trademark of Agriculture and Agri-Food Canada. U.S. Patent 5505968, Lacombe, Alberta.
[c]Data normalized to 500 kg (1,100 lb.) liveweight.

son, 1987), to mention a few. All of these treatments have met with varying degrees of success. Two strategies in particular, however, have been notably successful: the use of electrolyte-mineral treatments and the use of high-energy treatments.

Electrolyte-Mineral Treatments

Discussion in the foregoing section demonstrated the negative impact of transport and handling on electrolyte metabolism in cattle. The utility of balancing ion charges and electrolytes in the diet in order to optimize performance has been recognized in dairy cattle for some years (Wang et al., 1987; Beighle et al., 1988; Tucker et al., 1988; Safarpour and Daniels, 1988). This approach has also been used to good effect in treating calves displaying metabolic acidosis and viral diarrhea (Booth and Naylor, 1987) as well as cattle showing symptoms of heat stroke (Wagner, 1987) and perspiration loss (Armantano and Solorzano, 1987). The importance of using selective electrolytes in treating transported and handled cattle, particularly the use of high dietary potassium levels, was also recognized over 10 yr ago by the Texas USDA group (Hutcheson et al., 1984; Hutcheson, 1988) and was shown to improve performance in treated cattle. In addition, the use of dietary chromium supplement to improve immune response in transported cattle has been demonstrated by Chang and Mowat (1992) and, in general, the use of the dietary electrolyte balance approach to effect changes in performance in beef cattle has also been discussed more recently by Ross et al. (1994). However, such treatments are also known to have their limitations, and electrolyte treatment must be administered prudently (Kaneko, 1980). In fact, improperly applied, electrolyte treatments can be counter-productive causing among other things potassium depletion (Sranmek and Pozdesek, 1987) and diarrhea (Chester-Jones et al., 1986).

High-Energy Feeding

Energy depletion or hypoglycemia is one of the predictable outcomes of transport and handling in cattle (Phillips et al., 1982; Cole and Hutcheson, 1985,

Table 2. The effect of antemortem electrolyte therapy on the frequency of dark cutting in transported bulls and steers

	Control[a,b] (n = 713)	Treated[a,c] (n = 750)	*P*[d]
Dark cutters[e]	27	14	.026
Normal	686	736	—

[a]448 steers, 1,015 bulls.
[b]Control animals offered water only.
[c]Treatment was with the electrolyte therapy product NUTRI-CHARGE®, a trademark of Agriculture and Agri-Food Canada. U.S Patent 5505968, Lacombe Research Centre, Lacombe, Alberta.
[d]Chi-square test.
[e]Dark cutters = Canadian B4 grade.

1987; Lofgreen and Kiesling, 1985). Consequently, attempts to remedy this condition through electrolyte nutritional treatment and high-energy diets either before or after transport have been made (Hutcheson and Cole, 1986; Matter et al., 1986). This approach has been shown to be efficacious both for treating animal performance in the feedlot (Phillips et al., 1982; Cole and Hutcheson, 1985; Lofgreen and Kiesling, 1985; Cole et al., 1986) and for controlling meat quality and carcass yield aberrations (Wajda and Wichlacz, 1987; Eldridge, 1988; Lister, 1988; Tarrant, 1988). However, as discussed by McVeigh and Tarrant (1982) and Lister (1988), recovering animals using these methods has been shown to be a slow process that often requires several days. Clearly, this time scheme would not be compatible with some market realities such as those at abattoirs and sales yards.

Combined Strategies

All of the aforementioned treatment strategies have shown important insights and have been welcomed additions to treating stress in cattle. As presented, most of the treatment regimens have been designed for specific and often clinical purposes such as treating diarrhea and dehydration in calves or for receiving diets after transport. Of notable importance, however, is the knowledge that transport and handling stress, especially in the antemortem period, is a unique non-steady-state situation and it is not likely that any single regimen will be totally effective in this environment as a treatment. As discussed in the previous sections, there seems to be common agreement regarding the fundamental nature of physiological insults experienced by transported and handled cattle. These insults include primarily electrolyte imbalance, an energy deficit, and the related catabolism and dehydration accompanying the stress. Logically, a successful treatment regimen would consider the attenuation of each of these insults. Research at the Lacombe Research Centre has attempted to use electrolyte therapies to that end.

Initial studies in this respect demonstrated that electrolyte therapy was an efficacious (albeit unpractical at the time) way to treat antemortem stress in market cattle (Schaefer et al., 1990, 1992). More recent studies have demonstrated substantial utility and cost-effectiveness in treating transport and handling stress in cattle in a number of market niches (Table 1), including pasture cattle (Schaefer et al., 1993; Church et al., 1994) and feedlot animals (Jacobsen et al., 1993; Scott et al., 1993; Dubeski et al., 1995). Collectively, these studies demonstrate at least partial attenuation of live weight and carcass loss as well as meat quality attributes (Table 2). Also, by virtue of normalizing physiological stress parameters the improvement of animal welfare might be attained.

Implications

Our animal industries are currently undergoing substantial rationalization with fewer but larger production units and processing plants and longer distances between them. Such conditions often oblige longer transport and handling exposure of our animals, which in turn can cause loss of weight, degradation of meat quality, and alterations in some physiological stress parameters. Alleviating these stresses in a humane manner is a prime concern for animal scientists. Clearly, efforts must continue with respect to improving handling and management facilities and the teaching of handling and management protocol. However, the use of nutritional modulation to treat transport and handling stress also merits consideration. Electrolyte therapy regimens in this respect have been shown to be efficacious for treating transport and handling stress in domestic animals and offer one additional tool for use in our animal industries.

Literature Cited

Aguile, H. N., S. P. Pakes, W. C. Lai and Y. S. Lu. 1988. The effect of transportation stress on splenic natural killer cell activity. In: C57BL/6J Mice. Lab. Anim. Sci. 38:148.

Armentano, L. E., and L. C. Solorzano. 1987. Buffers for dairy cattle: mechanisms of action as a basis for formulating optimal buffer mixtures. 10th Annu. Int. Mineral Conf. Pitman Moore. pp 53–64.

Axelrod, J., and T. D. Reisine. 1984. Stress hormones: Their interaction and regulation. Science (Wash., DC) 224:452.

Baker, S. K. 1988. Dark cutting in relation to objective criteria for assessing stress. In: S. U. Fabiansson, W. R. Shorthose, and R. D. Warner (Ed.) Dark Cutting in Cattle and Sheep. pp 75–76. Proceedings of an Australian Workshop. Organized by Aust. Meat Livestock R and D Corp., Anim. Res. Inst. Victorian Dept. Agric. and Rural Affairs and CSIRO. Div. of Food Proc. Meat Res. Lab.

Beighle, D. E., W. B. Tucker, and R. W. Hemken. 1988. Interactions of dietary cation-anion balance and phosphorus: Effects on growth and serum inorganic phosphorus in dairy calves. J. Dairy Sci. 71:3362.

Blecha, F., S. L. Boyles, and J. G. Riley. 1984. Shipping suppresses lymphocyte blastogenic responses in Angus and Brahman × Angus feeder calves. J. Dairy Sci. 59:576.

Booth, A. J., and J. M. Naylor. 1987. Correction of metabolic acidosis in diarrhead calves by oral administration of electrolyte solutions with or without bicarbonate. JAVMA 191:62.

Chang, X., and D. N. Mowat. 1992. Supplemental chromium for stressed and growing feeder calves. J. Anim. Sci. 70:559.

Chester-Jones, H., J. P. Fontenot, and H. P. Veit. 1986. Physiological effects of feeding high magnesium levels to steers. Virginia Polytechnic Institute and State University Animal Science Res. Rep. 5:50.

Christopherson, R. J., M. A. Price, and J. R. Thompson. 1980. Seasoned and environmental effects on the color of meat from pulls. In: 59th Annual Feeders Day Report. Dept. Ani. Sci. Univ. of Alta., Edmonton. pp 36–38.

Church, J. S., J. M. Jones, R. J. Hudson, R. W. Stanley, and A. L. Schaefer. 1994. The effect of transport and handling stress and electrolyte therapy on neutrophile/lymphocyte ratios in cattle raised on pasture. In: P. A. Thacker (Ed.) Livestock Production for the 21st Century: Priorities and Research Needs. p 318 (92P-28). Dept. of Anim. and Poult. Sci., University of Saskatchewan, Saskatoon.

Cockram, M. S., and K.T.T. Corley. 1991. Effect of pre-slaughter handling on the behaviour and blood composition of beef cattle. Br. Vet. J. 147:444.

Cole, N. A. 1988. Preconditioning of beef calves. In: Proc. of the Annu. Mtg. of Livestock Conservation Institute.

Cole, N. A., T. H. Camp, L. D. Rowe, Jr., D. G. Stevens and D. P. Hutcheson. 1988. Effect of transport on feeder calves. Am. J. Vet. Res. 49:178.

Cole, N. A., D. M. Hallford, and R. Gallavan. 1993. Influence of a glucose load in fed or unfed lambs on blood metabolites and hormone patterns. J. Anim. Sci. 71:765.

Cole, N. A., and D. P. Hutcheson. 1985. Influence of prefast feed intake on recovery from feed and water deprivation by beef steers. J. Anim. Sci. 60:772.

Cole, N. A., and D. P. Hutcheson. 1987. Influence of receiving diet fat level on the health and performance of feeder calves. Nutr. Rep. Int. 36:965.

Cole, N. A., J. B. McLaren, and D. P. Hutcheson. 1982. Influence of preweaning and B-vitamin supplementation of the feedlot receiving diet on calves subjected to marketing and transit stress. J. Anim. Sci. 54:911.

Cole, N. A., W. A. Phillips, and D. P. Hutcheson. 1986. The effect of pre-fast diet and transport on nitrogen metabolism of calves. J. Anim. Sci. 62:1719.

Crookshank, W. R., M. N. Glissade, R. G. White, D. C. Clanton, and H. E. Smelley. 1979. Effect of transportation and handling of calves upon blood serum composition. Can. J. Anim. Sci. 48:430.

Doornenbal, H., A.K.W. Tong, J. A. Newman, N. L. Murray, and G. J. Mears. 1987. Blood and serum components and organ weights in steers, bulls and zeranol-implanted bulls. J. Anim. Sci. 64:489.

Dubeski, P. L., A. L. Schaefer, R. W. Stanley, and A.K.W. Tong. 1995. Effect of preslaughter electrolyte treatment on meat quality in cattle. In: M. Ivan, Minister of Supply and Services Canada (Ed.) Animal Science Research and Development. p 607 (Abstr. 95 p 13).

Eldridge, G. A. 1988. Road transport factors that may influence stress in cattle. In: 34th Int. Cong. Meat Sci. Tech. Congress Proceedings Part A. pp 148–149. Brisbane, Australia.

Fenwick, D. C., and D. J. Green. 1986. The effects of handling procedures, breed differences and treatment with Lithium and dexamethasone on some blood parameters in sheep. Appl. Anim. Behav. Sci. 16:39.

Fordham, D. P., G. A. Lincoln, E. Ssewannyona, and R. G. Rodway. 1989. Plasma β-endorphin and cortisol concentrations in lambs after handling, transport and slaughter. Anim. Prod. 49:103.

Fosha-Dolezal, S. R., and M. R. Fedde. 1988. Serum potassium during exercise in Hereford calves: influence of physical conditioning. J. Appl. Physiol. 65:1360.

Fraser, A. F. 1979. The nature of cruelty to animals. Appl. Anim. Ethol. 5:1.

Friend, T. H., D. C. Lay, Jr., D. M. Bushong, and D. W. Pierce. 1994. Wisconsin's "Stale Calf" issue and a study designed to resolve some of the animal welfare concerns. J. Anim. Sci. 72:2260.

Frohli, D., and J. W. Blum. 1988. Effects of fasting on blood plasma levels, metabolism and metabolic effects of epinephrine and norepinephrine in steers. Acta Endocrinol. 118:254.

Gortel, K., A. L. Schaefer, B. A. Young, and S. C. Kawamoto. 1992. Effects of transport stress and electrolyte supplementation on body fluids and weights of bulls. Can. J. Anim. Sci. 72:547.

Grandin, T. 1988. Practical experience of solving the problem of dark cutting beef carcasses in North America. In: S. U. Fabiansson, W. R. Shorthose, and R. D. Warner (Ed.) Dark Cutting in Cattle and Sheep. Proceedings of an Australian Workshop. pp 38–41. Organized by Aust. Meat Livestock R and D Corp., Anim. Res. Inst. Victorian Dept. Agric. and Rural Affairs and CSIRO. Div. of Food Proc. Meat Res. Lab.

Grandin, T. 1993. Teaching principles of behavior and equipment design for handling livestock. J. Anim. Sci. 71:1065.

Hails, M. R. 1978. Transport stress in animals: A review. Anim. Regul. Stud. 1:289.

Haurez, P., and J. M. Chupin. 1986. Prevention of high pH meat: Some recommendations. Viandes et produits carnes 7:231.

Hutcheson, D. P. 1988. Nutrient requirements of diseased, stressed cattle. Vet. Clin. North Am. Food Anim. Pract. 4(3):523.

Hutcheson, D. P., and N. A. Cole. 1986. Management of transit-stress syndrome in cattle. Nutritional and environmental effects. J. Anim. Sci. 62:555.

Hutcheson, D. P., N. A. Cole, and J. B. McLaren. 1984. Effects of pretransit diets and post-transit potassium levels for feeder calves. J. Anim. Sci. 58:700.

Jacobsen, T., A. L. Schaefer, A.K.W. Tong, R. K. Stanley, S.D.M. Jones, W. M. Robertson, and R. Dyck. 1993. The effects of transportation on carcass yield, meat quality and hematology values in electrolyte treated cattle. In: Cong. Meat Sci. Technol. Calgary, Alberta, Aug. 1–6. Paper 52, p 11.WP.

Jeremiah, L. E., A. L. Schaefer, and L. L. Gibson. 1992. The effects of antemortem feed and water withdrawal, antemortem electrolyte supplementation, and postmortem electrical stimulation on the palatability and consumer acceptance of bull beef after aging (6 days at 1°C). Meat Sci. 32:149.

Johnson, B. D., V. S. Hays, D. R. Gill, R. A. Smith, F. N. Owens, and R. L. Ball. 1988. Respiratory syncytial virus vaccine for stressed stocker cattle. Anim. Sci. Res. Rep. Okla. State Univ. p 105.

Johnson, J. D., and R. B. Buckland. 1976. Response of male Holstein calves from seven sires to four management stresses as measured by plasma corticoid levels. Can. J. Anim. Sci. 56:727.

Jones, S.D.M., A. L. Schaefer, A.K.W. Tong, and B. C. Vincent. 1988. The effects of fasting and transportation on beef cattle. 2. Body component changes, carcass composition and meat quality. Livest. Prod. Sci. 20:25.

Kaneko, J. J. 1980. Clinical Biochemistry of Domestic Animals (3rd Ed.). Academic Press, Orlando, FL.

Kelley, K. W., C. A. Osborne, J. F. Evermann, S. Parish, and D. J. Hinrichs. 1981. Whole blood leukocyte vs. separated mononuclear cell blastogenesis in calves: Time-dependent changes after shipping. Can. J. Comp. Med. 45:249.

Kenny, F. J., and P. V. Tarrant. 1987. The physiological and behavioral responses of crossbred Friesian steers to short-haul transport by road. Livest. Prod. Sci. 17:63.

Kenny, F. J., and P. V. Tarrant. 1988. The effect of estrous behaviour on muscle glycogen concentration and dark cutting in beef heifers. Meat Sci. 309:21.

Lacourt, A., and P. V. Tarrant. 1985. Glycogen depletion patterns in myofibres of cattle during stress. Meat Sci. 15:85.

Lambooy, E., and B. Hulsegge. 1988. Long distance transport of pregnant heifers by truck. Appl. Anim. Behav. Sci. 20:249.

Landi, M., J. W. Krieder, C. M. Lang, and L. P. Bullock. 1985. Effect of shipping on the immune functions of mice. 8th ICLAS/CALAS Symp., Vancouver, 1983. pp 11–18. Publ. Gustav Fischer Verlag Stuttgart, New York.

Lefcourt, A. M. 1986. Usage of the term stress as it applies to cattle. Diergenccskundig Tijdschrift. 55:258.

Lister, D. 1988. Muscle metabolism and animal physiology in the dark cutting condition. In: S. U. Fabiansson, W. R. Shorthose, and R. D. Warner (Ed.) Dark Cutting in Cattle and Sheep. Proceedings of an Australian Workshop. pp 19–25. Organized by Aust. Meat Livestock R and D Corp., Anim. Res. Inst. Victorian Dept. Agric. and Rural Affairs and CSIRO. Div. of Food Proc. Meat Res. Lab.

Locatelli, A., F. Agnes, and P. Sartorelli. 1987. Effects of road and simulated transportation for 30 min. on blood values in calves. Arch. Vet. Ital. 38:81.

Locatelli, A., P. Sartorelli, F. Agnes, G. P. Bondiolotti, and G. B. Picotti. 1989. Adrenal response in the calf to repeated simulated transport. Br. Vet. J. 145:517.

Lofgreen, G. P. 1983. Nutrition and management of stressed beef calves. Vet. Clin. North Am. Large Anim. Prac. 5(1):87.

Lofgreen, G. P., and H. E. Kiesling. 1985. Effects of receiving and growing diets on compensatory gains of stressed calves. J. Anim. Sci. 61:320.

Matter, S. K., L. W. Greene, D. K. Lunt, G. T. Schelling, and F. M. Byers. 1986. Serum mineral concentrations in three breeds of cattle supplemented with different levels of magnesium oxide. In: Beef Cattle Research in Texas. pp 25–56. Tex. Agric. Exp. Sta., Coll. Station.

McVeigh, J. M., and P. V. Tarrant. 1982. Glycogen content and repletion in beef muscle, effect of feeding and fasting. J. Nutr. 112:1306.

Mitchell, G., J. Hattingh, and M. Ganhao. 1988. Stress in cattle assessed after handling, after transport and after slaughter. Vet. Rec. 123:201.

Morrise, J. P., J. P. Cotte, and D. Huonnic. 1988. Stress in Calves: Physiological, zootechnical and sanitary consequences. Recl. Med. Vet. 164:849.

Murata, H. 1989. Suppression of lymphocyte blastogenesis by sera from calves transported by road. Br. Vet. J. 145:257.

Murata, H., H. Takahashi, and H. Matsumoto. 1987. The effects of road transportation on peripheral blood lymphocyte subpopulations, lymphocyte blastogenesis and neutrophil function in calves. Br. Vet. J. 143:166.

Murphy, A., and D. P. Fordham. 1988. Plasma cortisol and β-endorphin concentrations in lambs after handling, transport and slaughter: UFAW Report 1987/88.

Nash, D., and J. P. Pollreisz. 1988. Evaluating beef cattle operations for stress-management procedures. Compend. Continuing Education Pract. Vet. 10:971.

Novotna, B., D. Zemanova, A. Bus, and Z. Dvorak. 1986. Acid base balance in the blood of cattle in relation to the occurrence of DFD meat. Veterinary Medicine, Czechoslovak Academy of Agriculture, Institute of Scientific and Technical Information in Agriculture. 31(12):713.

Ozutsumi, K., K. G. Ito, T. Kawanishi, T. Yamazalli and Y. Karia. 1984. Physiological changes in body weight and blood characteristics of fattened cattle during fasting from finishing to slaughter. Jpn. J. Zootech. Sci. 55:735.

Phillips, W. A., N. A. Cole and D. P. Hutcheson. 1985. The effect of diet on the amount and source of weight loss by beef steers during transit or fasting. Nutr. Rep. Int. 32:765.

Phillips, W. A., R. P. Wettemann, and F. P. Horn. 1982. Influence of preshipment management on the adrenal response of beef calves to ACTH before and after transit. J. Anim. Sci. 54:697.

Price, M. A., and T. Tennessen. 1981. Preslaughter management and dark cutting in the carcasses of young bulls. Can. J. Anim. Sci. 61:205.

Ross, J. G., J. W. Spears, and J. D. Garlich. 1994. Dietary electrolyte balance effects on performance and metabolic characteristics in growing steers. J. Anim. Sci. 72:1842.

Safarpour, M., and L. B. Daniels. 1988. The effects of dietary mineral buffers on plasma pH and mineral levels of Holstein steers. Nutr. Rep. Int. 37:1289.

Schaefer, A. L., V. S. Baron, R. W. Stanley, S.D.M. Jones, and A.K.W. Tong. 1993. The effect of pre and post transport electrolyte therapy on live weight loss in heifers and steers raised on pasture. Proc. World Conf. Anim. Prod., Edmonton, Canada. p 275 (Abstr. 366).

Schaefer, A. L., and L. E. Jeremiah. 1992. Effect of diet on beef quality. pp 123–128. In: Proc. 13th Western Nutrition Conference Saskatoon, Univ. of Saskatchewan.

Schaefer, A. L., S.D.M. Jones, A.K.W. Tong, and B. C. Vincent. 1988. The effects of fasting and transportation on beef cattle. 1. Acid-Base-electrolyte balance and infrared heat loss of beef cattle. Livest. Prod. Sci. 20:15.

Schaefer, A. L., S.D.M. Jones, A.K.W. Tong, and B. A. Young. 1990. Effects of transport and electrolyte supplementation on ion concentrations, carcass yield and quality in bulls. Can. J. Anim. Sci. 70:107.

Schaefer, A. L., S.D.M. Jones, A.K.W. Tong, B. A. Young, N. L. Murray, and P. LePage. 1992. Effects of post-transport electrolyte supplementation on tissue electrolytes, hematology, urine osmildity and weight loss in beef bulls. Livest. Prod. Sci. 30: 333.

Scott, S. L., A. L. Schaefer, S.D.M. Jones, G. J. Mears and R. W. Stanley. 1993. Stress indicators and lean tissue yield in transported cattle treated with electrolyte. In: 39th Int. Cong. Meat Sci. Technol, Calgary, Alberta, Aug. 1–6. Paper 52. p 22.

Selye, H. 1956. The Stress of Life (Rev. Ed.). McGraw Hill, New York.

Shorthose, W. R. 1988. Dark cutting meat in beef and sheep carcasses under the different environments of Australia. In: S. U. Fabiansson, W. R. Shorthose, and R. D. Warner (Ed.) Dark Cutting in Cattle and Sheep. Proceedings of an Australian Workshop. pp 68–74. Organized by Aust. Meat Livestock R and D Corp., Anim. Res. Inst. Victorian Dept. Agric. and Rural Affairs and CSIRO. Div. of Food Proc. Meat Res. Lab.

Shorthose, W. R., and J. R. Wythes. 1988. Transport of sheep and cattle. In: 34th Int. Congr. Meat Sci. and Technol. p 122.

Sinclair, K. D., C. Jessiman, and A. M. Clark. 1992. The effect of haulage distance on the performance and welfare of beef bulls and the eating quality of the beef. Anim. Prod. 54(3):496.

Sranmek, J., and J. Pozdeseu. 1987. The effect of sodium chloride supplement on the content of sodium and potassium in blood plasma and on sodium and potassium retention in heifers. Zivocisna Vyroba 32:515.

Stephens, D. B. 1980. Stress and its measurement in domestic animals: a review of behavioral and physiological studies under field and laboratory situations. Adv. Vet. Sci. Comp. Med. 24: 179.

Stermer, R. A., T. H. Camp, and D. G. Stevens. 1982. Feeder cattle stress during handling and transportation. Trans. ASAE 25: 246.

Stull, C. L., and S. P. McDonough. 1994. Multidisciplinary approach to evaluating welfare of veal calves in commercial facilities. J. Anim. Sci. 72:2518.

Tarrant, P. V. 1988. Animal behaviour and environment in the dark-cutting condition. In: S. U. Fabiansson, W. R. Shorthose, and R. D. Warner (Ed.) Dark Cutting in Cattle and Sheep. Proceedings of an Australian Workshop. pp 8–18. Organized by Aust. Meat Livestock R and D Corp., Anim. Res. Inst. Victorian Dept. Agric. and Rural Affairs and CSIRO. Div. of Food Proc. Meat Res. Lab.

Tarrant, P. V. 1989. Animal behaviour and environment in the dark-cutting condition in beef: A review. Ir. J. Food Sci. Technol. 13: 1.

Tucker, W. B., G. A. Harrison, and R. W. Hemken. 1988. Influence of dietary cation-anion balance on milk, blood, urine and Rumen fluid in lactating dairy cattle. J. Dairy Sci. 71:346.

Unanua, A. P., and J.M.G. Buitrago. 1985. A study of plasma enzymes in fighting bulls killed in Spanish bullfights. Reprod. Nutr. Dev. 25:599.

Waddell, W. J., and R. G. Bates. 1969. Intracellular pH. Physiol. Rev. 49:285.

Wagner, D. 1987. Maintaining or improving performance of heat stressed cattle. Agric. Pract. 8:21.

Wajda, S., and H. Wichlacz. 1987. Effect of giving molasses on pH and colour of bull meat. Fleischwirtschaft 67:962.

Wang, C., D. A. Christensen, and B. Laarveld. 1987. Effect of dietary supplementation of sodium and potassium on the performance of dairy cows. Dairy cattle management feeding and research results. pp 89–93. In: Dept. of Anim. and Poult. Sci. U of S Research. Univ. of Saskatchewan.

Warner, R. 1988. The problem of dark cutting meat. Summary of workshop findings. In: S. U. Fabiansson, W. R. Shorthose, and R. D. Warner (Ed.) Dark Cutting in Cattle and Sheep. Proceedings of an Australian Workshop. pp 100–103. Organized by Aust. Meat Livestock R and D Corp., Anim. Res. Inst.

Victorian Dept. Agric. and Rural Affairs and CSIRO. Div. of Food Proc. Meat Res. Lab.

Warris, P. D. 1990. The handling of cattle pre-slaughter and its effects on carcass and meat quality. Appl. Anim. Behav. Sci. 28: 171.

Warris, P. D., E. A. Beris, S. N. Brown, and J. G. Ashby. 1989. An examination of potential indices of fasting time in commercially slaughtered sheep. Br. Vet. J. 145:242.

Wegner, T. N., J. D. Schuh, F. E. Nelson, and G. H. Stott. 1974. Effect of stress on blood leukocyte and milk somatic cell counts in dairy cows. J. Dairy Sci. 59:949.

Woods, G. T., M. E. Mansfield, and R. J. Webb. 1973. A three year comparison of acute respiratory disease, shrink and weight gain in preconditioned and non-preconditioned Illinois beef calves sold at the same auction and mixed in a feedlot. Can. J. Comp. Med. 37:249.