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Desk Top Study of Electrolyte Products

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EXECUTIVE SUMMARY

1. A number of electrolyte solutions are recommended for cattle and sheep during transport. Unfortunately, there is little information to justify the use of such electrolyte mixtures/solutions. This desktop study was commissioned by Meat and Livestock Australia, to evaluate the current electrolyte mixtures to determine their likely usefulness, when related to theoretical losses calculated during transport/shipping.

2. Determination of the molar concentrations of the major electrolytes, when electrolyte mixtures were constituted as indicated by the manufacturers, showed that all commercial electrolyte mixtures were very hypotonic. Sodium values range from 0.2 to 13 mmol/l, potassium from 0.8 to 4 mmol/l, chloride from 0 to 6.6 mmol/l and bicarbonate from 0.3 to 7.4 mmol/l. This can be contrasted with the normal composition of extracellular fluid where the sodium is around 140 mmol/l, potassium around 4 mmol/l, chloride around 100 mmol/l and bicarbonate around 30 mmol/l.

3. Estimated losses were calculated, based on 300 kg steers with 5 and10% dehydration, which is the more severe end of the dehydration spectrum. These calculations demonstrated that for 10% dehydration, sodium losses were likely to be in the range 800 to 4500 mmol and potassium losses in the range 2000 to 4000 mmol.

4. If steers drank 30 litres of any of the electrolyte solutions investigated in this desktop study, the amounts of electrolytes replaced (90 to 390 mmol of Na^+; 0 to 180 mmol of Cl^-; 30-120 mmol of K^+; 6-200 mmol of HCO_3^-) are in all cases, represent less than 5% of the body's exchangeable electrolytes. Similarly, the use of electrolytes in the feed in the amounts recommended will have little effect on electrolyte balance.

5. Currently available commercial electrolyte solutions are likely to be of little value for the maintenance of normal body fluid electrolytes or glucose during shipping. It seems more important to focus on the ensuring adequate water is provided, prior to further studies on measured losses and determining whether cattle will drink more concentrated electrolyte solutions.

BACKGROUND

There are several solutions recommended for use to prevent dehydration in cattle and sheep during shipping. Unfortunately there is no physiological basis for use of these solutions because the effect of shipping on body fluid and electrolyte status has not been described, nor the impact on fluid consumption of different concentrations of electrolytes in fluid or feed offered to dehydrated cattle. The lack of information on which to base rational treatments has been clearly described in the report to MLA and Livecorp by Alliance Consulting and Management (2001). This latter report is a comprehensive review of the relevant literature on the subject.

Dehydration and hyperthermia during shipping is clearly a threat to animal welfare. There is no clear consensus among industry participants concerning the need for therapy or the clinical applicability of the electrolyte products purported to be useful for on-board supplementation in water or food. However, it is evident that rational and effective use of electrolyte solutions could decrease death rates and promote the welfare of sheep and cattle during shipping.

In this report, the aim is to describe the solutions that are prepared by mixing the electrolytes in water according to the manufacturers recommendations and to provide some theoretical analysis based on information in the scientific literature. The list of commercial electrolytes analysed was supplied by Meat and Livestock Australia. Our report is based on the likely losses and requirements for fluid and electrolytes in 300 kg steers.

RESULTS

Table 1. Commercial electrolyte supplements studied. The concentrations (g/kg) of each of the salts are described, according to the manufacturers information. There are very large differences between the products.

Product	**Composition g/Kg**					
	$NaHCO_3$	NaCl	Na_2SO_4	K_2SO_4	KCl	Glucose
Selectrolyte	500	266	0	0	50	179.69
Solulyte Concentrate	500	266	0	0	50	179.69
Glucotrans	40	140	50	0	50	710
Topstock	300	25	0	0	270	400

Table 2. Molar concentrations of the salts when the products are mixed in water according to the manufacturers recommendations.

	Concentration as directed by Manufacturer (mmol/l)					
	$NaHCO_3$	NaCl	Na_2SO_4	K_2SO_4	KCl	Glucose
Selectrolyte	7.44	5.724	0	0	0.832	0.224
Solulyte Concentrate	7.44	5.724	0	0	0.832	0.224
Glucotrans	0.793	4.02	0.479	0	1.11	1.183
Topstock	3.178	0.383	0	0	3.2	0.3556
Selectolyte	0.264	0	0	1.931	0	0

Data calculated obtained from information provided by MLA

Table 3. Osmolality of each of the ions in the solutions when mixed according to manufacturers

recommendations. The total osmolality also is listed, and the relative tonicities are calculated. *Relative tonicity has been calculated as osmolarity/300 (where 300 is the approximate osmolality of the extracellular fluid of sheep and cattle).*

	Concentrations of ions (mmol/l) in prepared solution as per manufacturers instructions							
	Na^+	Cl^-	K^+	$SO4^-$	$HCO3^-$	Glucose	Osmolality mOsm/l	Relative Tonicity
Selectrolyte	13.164	6.556	0.832	0	7.44	0.224	28.2	.094
Solulyte Concentrate	13.164	6.556	0.832	0	7.44	0.224	28.2	.094
Glucotrans	5.771	5.13	1.11	0.479	0.793	1.183	14.5	.0482
Topstock	3.561	3.583	3.2	0	3.178	0.3556	13.9	.0463
Selectolyte	0.264	0	3.862	1.931	0.264	0	6.3	.0211

Water turnover rate in a cow is described in Table 4. Water turnover rate could be much higher during shipping transport in hot conditions. It could be expected that 300 kg cattle in such conditions could need up to 40 litres or more of fluid per day.

Table 4. Water balance in a non lactating Friesian cow (Swenson and Reece, 1993).

WATER INTAKE	**LITRES**
Drinking	26
Metabolic	2
Food	1
WATER OUTPUT	
Faeces	12
Urine	7
Vapour	10
TOTAL	**29 litres**

Table 5. Typical composition of the extracellular (ECF) fluid of sheep and cattle. A small species and individual differences could be expected around these values (Swenson and Reece, 1993).

Ion or compound	**Concentration (mmol/L)**
Na^+	145
K^+	4
Mg^{2+}	1
Cl^-	105
HCO^{3-}	27
Glucose	6
TOTAL	**288**

SOME ESTIMATIONS OF FLUID AND ELECTROLYTE LOSS DURING TRANSPORT

Given the information cited in this report and data reported by Schaefer et al (1990) and Philips et al (1985), it is possible to do some modeling of the likely losses of fluid and electrolytes during transport, making assumptions about the fluid losses, which have been shown to be principally from faeces and urine.

An equation that has been shown to be valid for all species is that of Edelman et al (1958). Essentially this shows that:
(Exchangeable Na + Exchangeable K) = (Total Body Water x Serum Na)

For a 300 kg steer, the total body water is about 200 litres and one can assume that the normal serum Na is around 145 mmol/l.
Thus the total exchangeable Na+K = 29,000 mmol
Most of the sodium is in the extracellular fluid and most of the potassium is in the intracellular fluid. The extracellular fluid is about one third of the body water and the intracellular fluid about two thirds.

Therefore:
Extracellular fluid = 67 litres
Intracellular fluid = 133 litres
Because most of the exchangeable Na is in the extracellular fluid, the total exchangeable Na is therefore approximately 9,715 mmol (67x145). Therefore the total exchangeable K is 19,285 mmol (29,000-9,715).

The extent of the electrolyte losses therefore will differ depending on where these losses come from. From data in horses (Tasker, 1958), we know that in diarrhoea, the electrolyte losses are principally (70%) sodium, whereas in food and water deprivation, the losses are principally (85%) potassium. Using these two extremes of fluid and electrolyte loss, we can make the following calculations for 300 kg steers, to examine the effect of 5% dehydration (moderate dehydration) and 10% dehydration (severe dehydration), which could be expected to produce life-threatening physiological effects. In all these calculations, it is assumed that 90% of the weight losses are due to water loss.

Effects of 5 and 10% dehydration due to diarrhoea

With 5% dehydration, the water loss is 13.5 litres in a 300 kg steer.
Assuming a decrease in serum Na to 130 mmol/l, (this is the normal situation in diarrhoea because the animals drink to partially correct the dehydration but have no access to electrolytes to replace the Na losses). We can make the following calculations in the dehydrated animal:
(Exchangeable Na+Exchangeable K) = 130 mmol/l x (200-13.5L)
= 24,245 mmol
In the normal steer, exchangeable Na+K= 29,000 mmol

Therefore the total losses of exchangeable Na+K = 4,755 mmol

Assuming 70% of the losses are Na, then:
Na losses = 3,328 mmol
K losses = 1,427 mmol
Water loss = 13.5 litres

Using similar calculations to those above, for 10% dehydration:
Na losses = 4,557 mmol
K losses = 1,953 mmol
Water loss = 27 litres
Losses can then be summarized as follows:

Table 6. Summary of Estimated Body water, Exchangeable Na and Exchangeable K in 300 kg steers with 10% dehydration due to diarrhoea

	Total body water	Fluid loss	Exchangeable Na	Exchangeable K
Normal steer	200 litres	0 litres	9,715 mmol	19,285 mmol
5% dehydration	186.5 litres	13.5 litres	6,387 mmol	17,858 mmol
10% dehydration	173 litres	27 litres	5,158 mmol	17,332 mmol

Thus, the electrolyte losses are principally Na, with about one third to one half of the total body Na being lost, depending on the extent of the fluid loss. This will have a major effect on physiological functions, as Na is the principal regulator of extra-cellular fluid volume. The potassium losses are likely to be less severe and the potassium reserves greater so that the impact of the K depletion will be more limited.

Effects of 5 and 10% dehydration due to food and water deprivation

With 5% dehydration, the water loss is 13.5 litres in a 300 kg steer.
Assuming that the serum Na decreases slightly to 140 mmol/l, (this is often found in food and water deprivation, because of contraction of the extracellular fluid volume). We can make the following calculations in the dehydrated animal:
(Exchangeable Na+Exchangeable K) = 140 mmol/l x (200-13.5L)
= 26,110 mmol

In the normal steer, exchangeable Na+K= 29,000 mmol

Therefore the total losses of exchangeable Na+K = 2,890 mmol
Assuming 15% of the losses are Na and the remainder K, then:
Na losses = 434 mmol
K losses = 2,457 mmol
Water loss = 13.5 litres

Using similar calculations, for 10% dehydration:
Na losses = 717 mmol
K losses = 4,063 mmol
Water loss = 27 litres

Fluid and electrolyte balance can then be summarized as follows:

Table 7. Summary of Estimated Body water, Exchangeable Na and Exchangeable K in 300 kg steers with 10% dehydration due to food and water deprivation

	Total body water	Fluid loss	Exchangeable Na	Exchangeable K
Normal steer	200 litres	0 litres	9,715 mmol	19,285 mmol
5% dehydration	186.5 litres	13.5 litres	9,281 mmol	16,828 mmol
10% dehydration	173 litres	27 litres	8,998 mmol	15,222 mmol

Thus, the electrolyte losses are principally K, with about 14 to 21 per cent of the total body K being lost, depending on the extent of the fluid loss. In contrast, there are likely to be minimal losses of Na, in the order of 4 to 7 per cent. These sodium losses will have minimal adverse effects. However, potassium losses may be more significant to intracellular function.

Effects on Acid Base Balance

There is little data on the effects of transport and/or food and water deprivation on acid base balance but data in horses with food and water deprivation from Tasker (1958) and from dehydrated cattle (Roussel et al., 1998) and cattle transported and dehydrated (Schaefer et al., 1990), indicates that there is unlikely to be major acid base disturbance. Blood bicarbonate appears likely to remain within ±5 mmol/l of the normal values, unless there is severe dehydration or other metabolic abnormalities.

Respiratory alkalosis

Respiratory alkalosis is thought to be a problem in cattle during transportation, particularly in the heat. Respiratory alkalosis is characterised by low tensions of carbon dioxide in arterial blood, usually secondary to hyperthermia. It is not caused by disturbances to body fluid electrolyte concentrations.

If hyperventilation secondary to hyperthermia did occur in cattle on ships, a respiratory alkalosis could develop. In that case it would be important not to exacerbate the alkalosis by administering electrolyte solutions or providing electrolytes in the feed that contain high concentrations of bicarbonate ions.

Selectrolyte and Solulyte Concentrate contain the highest concentrations of bicarbonate ions (approximately 7 mmol/l) when mixed according to manufacturers recommendations. Use of these solutions for drinking may contribute to increased blood bicarbonate concentrations and alkalosis, although the concentrations of bicarbonate in the solutions, as recommended, are very low.

If respiratory alkalosis secondary to hyperventilation did occur in cattle during prolonged exposure to heat, treatment with specific electrolytes would not be appropriate. Rather, affected cattle should be aggressively cooled and treated with a balanced electrolyte solution that restored body fluid volumes. Further research is needed to determine the body fluid, electrolyte and pH disturbances in heat stressed cattle on ships.

Glucose in Oral Fluid and/or Feed

Glucose should be used specifically to treat ketosis. We do not know if ketosis is a problem in cattle on the ships. Use of large amounts of oral glucose in ruminants that do not have ketosis and are not accustomed to its use is not recommended. Its use could disturb rumen function and contribute to metabolic acidosis and inappetance. The amounts of glucose in each kilogram of electrolyte mixture ranges from 180 to 710 g. The manufacturer’s recommendation for Selectrolyte is for 500 g of the mixture per 160 kg feed. This would give only 0.56 g of glucose per kg of feed, which would make little contribution to maintenance of blood glucose, in contrast to that provided by normal feedstuffs.

Interpretation of Calculations and Evaluation of Likely Effects of Consumption of A Typical Electrolyte Solution

In modeling two very different causes of dehydration in cattle (food and water deprivation, and diarrhoea), it is clear that the impacts on the major electrolyte losses are also very different.

Table 8. Summary of estimated fluid and electrolyte losses in 300kg steers, due to either diarrhoea or food and water deprivation

Losses	10% dehydration due to food and water deprivation	10% dehydration due to diarrhoea
Sodium (mmol)	717	4,557
Potassium (mmol)	4,063	1,953
Water (litres)	27	27

These calculations show that there can be very different effects of the same fluid loss, depending on the loss of the major electrolytes. Balance studies are needed to determine the electrolyte losses that occur during transportation. From the data reported, it is unlikely that disturbances of acid-base balance *per se* will be of major physiological significance.

Given the estimates made in the preceding part of this report, we can evaluate the likely electrolyte and fluid losses compared with the replacement of these losses from the consumption of 30 litres of one of the commercial electrolyte solutions.

Table 9. **Predicted ion deficits after consumption of 30 litres of a commercial electrolyte solution.** *The data in the table assumes that the commercial electrolyte solution used for drinking has 13, 6, 3, 7 mmol/l of sodium, chloride, potassium, and bicarbonate respectively. These concentrations are typical of some commercial products (see Table 3).*

Ion	Requirement (mmol)	Intake (mmol)	Deficit (mmol)
Sodium	800-4,500	390	400-4,000
Potassium	2,000-4,000	90	2,000-4,000
Chloride	300-1000	180	100-800
Bicarbonate	400	210	200

If there is an increased turnover of electrolytes during transport, addition of electrolytes to the feed may be of value. If electrolyte mixtures are used in the feed, consumption of 50 g (about 2 oz) of a typical electrolyte and glucose mixture indicated above would provide:

Sodium	174-526 mmol
Potassium	34-182 mmol
Chloride	204-328 mmol
Bicarbonate	24-298 mmol
Glucose	50-197 mmol

It would appear that the recommended quantities of the electrolyte mixtures being administered in the feed are much less than 50 g per feed.

Electrolytes in the feed also may be contraindicated to treat dehydration. Appropriate solutions should be used, with electrolyte compositions that match specific requirements. Use of electrolytes in the feed assumes that the animals will drink appropriate volumes of water each day, which may be one of the problems encountered during transport.

The important points concerning the commercially available electrolytes are as follows.

1. When mixed according to instructions, the solutions or mixtures are very low in sodium, chloride and bicarbonate.
2. All the mixed solutions are hypotonic.
3. While there are large differences in the molar composition of the electrolyte mixtures, when constituted as recommended, there is likely to be little physiological difference between the solutions, in their capacity to replace electrolyte losses. All provide little sodium, negligible potassium and little of the major anions.
4. Little is known about the impact on drinking behaviour of steers when different concentrations of electrolytes are added. This is important as while the potential electrolyte losses are important, in the acute situation, water is of critical importance. While it appears that much higher concentrations of electrolytes are necessary to have any effect, the addition of electrolytes to drinking water may worsen dehydration, if the steers are reluctant to drink because of the taste.

CONCLUSIONS

1. Use of the solutions investigated would be unlikely to provide the daily requirements of electrolytes in steers during shipping. It seems unlikely that with the quantity of electrolytes provided that there is any value in providing these electrolyte solutions compared with the provision of water alone. Normal feed has significant quantities of electrolytes, and more information is needed on feed intake during shipping as it will have a much more significant effect on the exchangeable electrolytes in the body than provision of current electrolyte mixes.

2. The daily requirements may exceed those used in Table 5 when cattle are exposed to heat and consequent dehydration. Daily requirements may also be affected by extra losses in individual animals due to clinical conditions such as diarrhoea.

3. The nature of the fluid losses in sheep and cattle during shipping is unknown. The composition of the lost fluid will depend on the composition of sweat, the loss of respiratory water vapour, and losses due to diarrhoea. The disturbances to body fluid and electrolyte status during shipping may vary greatly between individuals.

4. Currently available commercial electrolyte solutions are likely to be of little value for the maintenance of normal body fluid electrolytes during shipping. It seems more important to focus on the ensuring adequate water is provided, prior to further studies on measured losses and determining whether cattle will drink more concentrated electrolyte solutions.

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APPENDIX 1
Suggestions to Collect Further Information in Cattle During Shipping

1. Select 30 animals at random before the trip.
2. Collect blood and weight the animals before transport.
3. Measure:
    a. Haematocrit (PCV), plasma total protein (TPP)
    b. Serum Na, K, Cl, lactate (gives SID), HCO_3^-
    c. Blood glucose, (so take blood in EDTA, LiHep and FluOx tubes). To do this there would need to be a freezer and centrifuge etc on board.
    d. Arterial (or jugular venous) blood gases
    e. Serum ketoacids could be measured too to see how much tendency to ketosis
4. Collect samples of the drinking fluid for later analysis.
5. Repeat measurements during the trip as is possible, and at the end of the trip.
6. If possible, collect blood samples from other animals during the trip that develop clinical signs such as heat stress or weakness.
7. If possible, measure water consumption, even if this is done per pen with flow meters on the pipes

The priorities for measurement are bodyweight, the serum or plasma electrolytes and PCV/TPP