Epidemiology, ethics and managing risks for physiological and behavioural stability of animals during long distance transportation

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Summary

Mechanisms to maintain the physiological and behavioural stability of animals during long distance transport are explored according to the epidemiological concept of the risk factor. The purpose is to consider quality assurance and risk management as two practical means of protecting animal health and welfare during long distance transport. The hierarchy of welfare, health and disease is treated as an indivisible whole to ensure that surveillance for welfare will encompass surveillance for infectious disease and that ethical consideration applies to the totality. Disease can have devastating effects on the well-being of both animals and people. Risk factors and epidemiological methods are explained and promoted for use in managing the health and welfare of animals transported over long distances. A 'one medicine' approach is emphasised and the depiction of stress as the cost of adaptation to stressors or the allostatic load is introduced to illuminate the challenges confronting transported animals. Aspects of heat stress in cattle are explored to illustrate how various sources of information, including inference from general biological knowledge, can assist in characterising risk factors that derive from the constitution of animals themselves.

Keywords

Animal, Behaviour, Epidemiology, Ethics, Long distance, Physiology, Risk, Transport, Welfare.

Epidemiologia, rischi etici e di gestione del rischio per la stabilità fisiologica e comportamentale degli animali durante il trasporto a lunga distanza

Riassunto

I meccanismi per il mantenimento della stabilità comportamentale e fisiologica degli animali durante trasporti a lunga distanza vengono esaminati sulla base della teoria epidemiologica dei fattore del rischio. Lo scopo è quello di prendere in considerazione l'assicurazione di qualità e la gestione del rischio come due approcci pratici grazie ai quali tutelare sanità e benessere animale durante i trasporti a lunga distanza. Il benessere, la sanità e le patologie vanno gestite congiuntamente per assicurare che la sorveglianza sul benessere includa anche la sorveglianza sulle malattie infettive e le considerazioni etiche. Le patologie possono avere un effetto devastante sul benessere di uomini ed animali. Vengono illustrati e proposti i fattori di rischio ed i metodi epidemiologici utilizzati nella gestione della sanità e del benessere degli animali nei trasporti a lunga distanza. Per chiarire le molteplici difficoltà nella gestione del trasporto di animali viene evidenziato un approccio di medicina unica e viene introdotta la rappresentazione dello stress come un costo di adattamento ai fattori di stress o al carico allostatico. Vengono studiati gli

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effetti dello stress da calore nei bovini per spiegare come varie fonti di dati, incluse quelle della conoscenza della biologia di base, possano supportare nell'individuazione dei fattori di rischio legati alla natura dell'animale stesso.

Parole chiave
Animale, Benessere, Comportamento, Epidemiologia, Etica, Fisiologia, Lunga distanza, Rischio, Trasporto.

Introduction

This chapter is intended to complement and extend other accounts of how long distance transport may challenge the physiological and behavioural stability and resilience of animals and affect their health, well-being and welfare (13, 21, 31, 45). It organises discussion of the effects of long distance transport on animals, the predisposing and inciting causes of these effects and the mediating mechanisms involved around the epidemiological notion of 'risk factor' (32). The idea is to facilitate the application of risk management and quality assurance to the long distance transportation of animals. Risk factors provide a coherent link between the body of scientific knowledge and its use in practical animal husbandry and veterinary medicine where it can be applied to the 'hands-on' and anticipatory management of animal welfare. Risk factors linked to heat stress in cattle, a major challenge for long distance transport, are used to exemplify general principles and to illustrate the importance of species-specific knowledge.

The chapter seeks to invoke the power of the one medicine concept (30), which can bring the full breadth and depth of basic biomedical knowledge to bear on animal problems. Accordingly, contemporary concepts of 'allostasis' and 'allostatic load' are introduced to the discussion of transport effects on animals. They have value for illuminating the problematical idea of stress.

Another problematical idea, animal welfare, is discussed first. The purpose is to make plain that the present chapter treats welfare as a part of a chain that includes health and disease. Experience with emerging and re-emerging infectious diseases emphasises that it is unsafe, and therefore unethical, for both animals and people, if the surveillance and monitoring of animals for welfare and well-being are separated from that for health and disease.

Relationship between disease, health and welfare

Guidance here comes from the World Organisation for Animal Health (*Office International des Épizooties*: OIE) with statements that welfare is a broad term, which includes the many elements that contribute to the quality of life of an animal (55) and that there is a critical relationship between animal health and animal welfare (54). At the same time, it is recognised that linguistic and conceptual problems with the English term 'welfare' can lead to misunderstandings and cross-purposes on the international scene. These problems have been explored previously (33) but seem set to continue.

Dictionary definitions of the English term 'welfare' include the health, happiness and fortunes of individuals and the efforts to deliver the basic physical and material well-being of individuals in need. In other words, 'welfare' as it applies to animals covers the same two meanings as the French terms *bien-être* and *bien-traitance*. The distinction between welfare as an end or objective (*bien-être*) and welfare as a means to that end (*bien-traitance*) is used in Figure 1. This figure shows the continuum starting from animal welfare as *bien-être* to disease and then to death. It also shows how risk factors may impair *bien-être* (well-being) and may be counteracted by *bien-traitance* (good husbandry).

The logical connections between disease, health and welfare as a hierarchy are explained by the biomedical meaning of these terms. Disease occurs when the adaptive mechanisms of an organism fail to adequately counteract the stimuli or stresses to which it is subject, resulting in a disturbance in function or structure of any part, organ or system of the body (29). The concept of adaptation to stimuli or stresses is taken up again when welfare (*bien-être*) is referred to as the 'the state of an individual [animal] as regards its attempts to cope with its environment' (12).

Health lies at the interface between *bien-être* and disease. It is described by the World Health Organization (WHO) as a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity. According to the hierarchy shown in Figure 1, *bien-être* is ruled out when disease is present and is compromised *pari passu* when health is poor. On the other hand, the absence of disease does not necessarily add up to wholly satisfactory welfare (*bien-être)* for animals. Paradoxically, sick, injured or moribund animals may have good welfare if they are receiving competent veterinary care and *bien-traitance* operates.

A clear picture of animal welfare and its connections with health and disease is required for the practical expression of ethics through good husbandry or *bien-traitance* of animals. Margaret Somerville, the University of Toronto's recipient of UNESCO's Avicenna Prize for Ethics in Science, provides a view of applied ethics that can be acted upon at a practical level by those involved with animals, and which can be used in the public policy arena (46).

'It also merits noting that people often confuse ethics as a sub-discipline of moral philosophy (what we call classical ethics, which is long established in our universities) with "applied ethics" as a discipline that has developed in the last thirty years. Although they are related, it is useful to distinguish between them. Perhaps the best analogy is to the difference between legal theory (classical jurisprudence) and law in everyday practice. We don't have to understand legal theory to use law, but some experts do need to study and develop legal theory if we are to have good law. And "doing ethics" is similar to "doing law" – but the body of knowledge used in each differs. Applied ethics requires the systematic application of informed, structured and disciplined discernment to analysis of situations in relation to the ethical issues they raise and to decision-making in these situations. And it is not correct, as some people claim, that no established body of knowledge and technique to inform that process exists. In fact, there is a large, intellectually sophisticated and rapidly increasing body of such knowledge.'

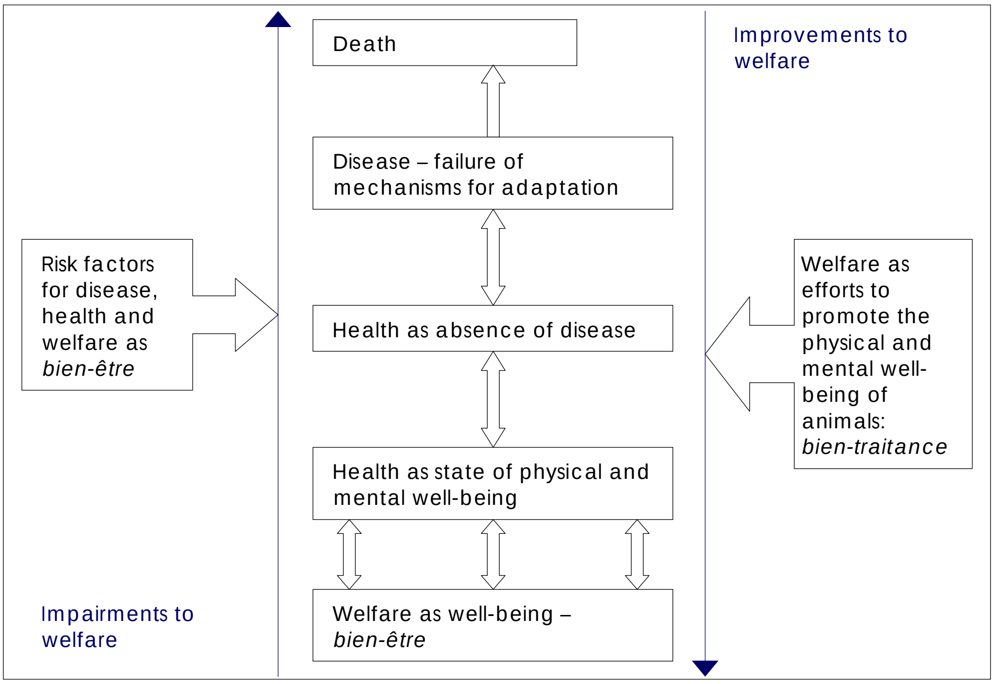

Figure 1
The hierarchy of welfare (*bien-être*), health and disease showing the impairing impact of risk factors and protection and restoration by good husbandry (*bien-traitance*)

A point that emerges from Figure 1 is that ethical concerns are not restricted to animal welfare and attach to both animal health and animal disease. Infectious disease can have catastrophic and escalating impacts on animals and the containment of infection can be proposed as a major and persistent ethical concern for the long distance transport of animals. The conclusion is that welfare, health and disease should be regarded as indivisible for both practical and ethical reasons.

Risk factors and epidemiology

Controlled experiments have been highly valuable in advancing the science applying to the long distance transport of animals. Their value will persist as they continue to test hypotheses suggested by the practice of animal transport. A limitation is that results from controlled experiments can be situation-specific and cannot necessarily be generalised to all circumstances.

There are, however, routes to reliable knowledge other than direct experiment. One important route is consolidated experience with the transport of animals itself, particularly when this experience is framed against the process of learning by doing and is informed by the discipline of epidemiology, which has been invaluable for the sea transport of sheep (37, 38, 39).

Epidemiology is described as the study of the distribution and determinants of health-related states or events in specified populations and the application of this study to the control of health problems (32). Epidemiology is particularly useful for health problems that have multi-factorial causes. Animals that undergo long distance transport are a defined population. Furthermore, the welfare, health and disease problems that occur in transported animals is multi-factorial and may result from a web of causes involving interactions between their genetic make-up, their developmental environment and resulting phenotype, their preparation and conditioning for transport and the prevailing environment in the transport chain. These interactions are set out in Figure 2, which illustrates their connections to the concept of the risk factor.

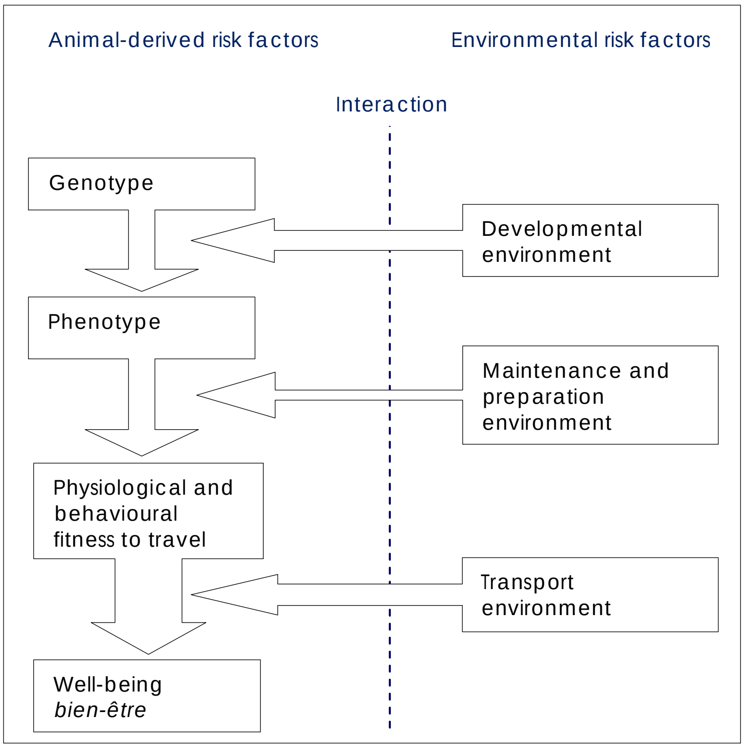

Figure 2
Interactions among the genetic make-up of animals, their developmental environment and resulting phenotype, their maintenance environment and the environment in the transport chain that give rise to risk factors for welfare

Risk factors are variables or attributes of animals or environmental exposures associated with an increased risk of disease, ill-health or poor welfare. Risk factors are not necessarily causal. Risk factors include stressors and other disease determinants that can be modified by intervention to reduce the probable occurrence of poor health or welfare. Mitigation or elimination of risk factors is the purpose of risk management and quality assurance and the reason for their application to the long distance transport of animals.

Quality control concepts are applicable to the management for good animal welfare during long distance transport. Quality control, in its technical sense, seeks to distinguish whether particular problems in a process are due either to randomly occurring variations, so-called 'common causes' that are not connected to that process, or to extraordinary or 'assignable' causes that can be attributed to the process itself. The distinction between common causes and assignable causes applies to animal welfare during transport. For example, heat or cold stress or physical injuries would classify as assignable causes of poor welfare, disease or mortality during long distance transport. By contrast, the rupture of a pre-existing aortic aneurysm in an animal during long distance transport may be beyond prediction and prevention and would classify as a common cause. The task of risk management and quality management is to anticipate and prevent assignable causes of poor welfare.

Epidemiological surveillance can be used to initiate action when the incidence of poor welfare (health problems, mortalities etc.) points to assignable causes that can be attributed to the process of transportation and to lapses in general husbandry. Thorough investigation is a first step towards action and may require the application of competent forensic veterinary investigation (18) if legal processes are to be successful.

Stress, allostasis and allostatic load

Stress is an important systemic state for animal health and welfare. It appears when the mechanisms in animals for coping with their environment become overextended and start to break down (47). The environmental factors that produce stress when they act excessively are termed stressors. The stressors on animals during long distance transport can be classified as physical, nutritional, behavioural and those related to infection (disease stressors). Adaptive responses to them involve the action of every single body system and not just the nervous, endocrine and immune systems.

The notion of stress is linked to the ideas of homeostasis, comfort zones, physiological reserve, the fight/flight or alarm reaction, acclimation (where a specific physiological function changes in response to environmental stimuli) and acclimatisation (where a spectrum of physiological functions change in response to environmental stimuli). Stressors can act differentially on different organ systems and sub-systems and distinctly different responses occur to different stressors; for example heat and cold. Some general responses occur to all stressors as described in the general adaptation syndrome with its three stages of alarm, maintenance of adjustment and then exhaustion (44). Stress is neither identical to emotional arousal nor nervous tension, nor does it always cause damage to an animal. In addition, blood concentrations of corticosteroids or other hormones may elevate during stress responses but raised concentrations of these hormones alone do not reliably measure stress. Stress is best monitored by changes in both behaviour and physiology.

A recent depiction of stress as the cost of adaptation to stressors, or the so-called allostatic or homeostatic load (35), provides a useful way of looking at the problems of stress confronted by animals during long distance transport and for facilitating the epidemiological approach. Allostasis is a more recent elaboration of the concept of homeostasis or the maintenance of a constant internal state in an animal. It refers to 'stability through change' and is an essential means for adjusting the internal environment of animals to the challenges that confront them.

Stress responses are initially protective but can then become damaging. This sequence of protection then damage is exemplified by the immune response. Exposure to stressors can actually improve immune function. However, if stress responses are repeated, excessive and prolonged and the allostatic load exceeds adaptive capacity, immune function can be damaged and an increased incidence of infectious disease can result. When allostatic systems are overtaxed, the systemic state referred to as 'stress' occurs.

The view of stress as the cost of adaptation or the allostatic load provides helpful guidance for the management of transported animals. The cost of adaptation can be repaid, or the allostatic load can be shed, if animals are allowed to adapt or recover at particular points in the transport chain. Without proper recovery, allostatic loads will rise and the cost of adaptation will become an increasing debt.

The identification and characterisation of risk factors for animal welfare

The notion of the risk factor is valuable for driving a structured approach to animal welfare that employs risk management and quality assurance with support from standards and legislation. Risk factors have the potential to impair animal welfare as *bien-être.* They can be mitigated by counter-measures that are implemented through good husbandry or *bien-traitance* (Fig. 1). The design of these counter-measures requires the identification and characterisation of risk factors in a systematic manner and an appreciation of the underlying evidence for them and the uncertainties involved with them.

Risk factors may derive from the constitution of animals or the past and present environments of animals (Fig. 2). They have implications for the preparation, assessment and selection of animals before transport, the provision of suitable environments, feed, water, comfort and rest during transport and for arrangements for recovery and restoration after transport. For convenience, risk factors can be categorised under headings of the physical stressors, nutritional stressors, behavioural stressors and disease stressors encountered during the process of transport.

Disease risk factors where there are obvious clinical signs are outlined in documents such as the Australian Standards for the Export of Livestock (5). These standards prohibit the transport of animals with conditions with obvious physical signs that prohibit the transport of animals, as follows:

- lethargy, weakness, ill-thrift, dehydration
- anorexia (inappetence)
- lameness or abnormal gait
- abnormal soft tissue or bony swellings
- scouring, dysentery, profuse diarrhoea
- bloat
- nervous signs (e.g. head tilt, circling, incoordination)
- abnormal or aggressive behaviour/ intractable or violent
- external parasites (unless treatment is to be performed prior to loading for embarkation)
- cutaneous myiasis (flystrike)
- significant lacerations
- discharging wounds or abscesses
- generalised papillomatosis, ringworm or dermatophilosis
- generalised and extensive buffalo fly lesions
- pink eye/keratoconjunctivitis (active inflammation of one or both eyes)
- cancer eye
- blindness in one or both eyes
- abnormal nasal discharge
- coughing or respiratory distress
- scabby mouth
- excessive salivation
- bleeding horn stumps
- balanitis (pizzle rot in sheep

The Australian Standards for the Export of Livestock contain two requirements related to heat stress (Table I) that will be explored as a case study of the type and weight of evidence that can be used to characterise risk factors. Heat stress increases in importance as animals move across latitudes and climate zones. Reliable knowledge of these risk factors came from both direct experimentation and the application of established biological concepts. Cattle are the species in question and the risk factors selected for examination are: type, breed and strain of cattle, acclimatisation, geographic derivation, pre-transport history, very large or very fat animals, thin animals, animals with undesirable temperaments and pregnancy.

Table I
Animal requirements for thermal stress from the Australian Standards for the Export of Livestock

Animal	Requirement
Pregnant *Bos taurus* cattle	Must be bred in an area of Australia south of latitude26°S and must not be sourced for export to the Middle East from May to October
Sheep and fat *Bos taurus* breeds of cattle	Must not be sourced for export from the ports of Darwin, Weipa or Wyndham from 1 November in any year to 31 May the following year (inclusive)

Risk factors for heat stress

Type, breed and strain of cattle

Primary evidence for *Bos indicus* cattle being better able to cope with heat stress than *Bos taurus* cattle comes from the observation that cattle indigenous to tropical and sub-tropical regions have evolved in the prevailing conditions of heat and that cattle indigenous to temperate and cool regions have evolved in a different set of climatic conditions. Epstein and Mason (20) state this view in their treatment of the evolution of domestic cattle: 'the hereditary physiological adaptation of zebu cattle in tropical and sub-tropical environments must be attributed to their evolution in a warm climate'. The word 'adaptation' is used here to refer to the 'characteristics of a living organism evolved as a consequence of natural selection in its evolutionary past and which result in a close match with features of the environment and/or constrain the organism to life in a narrow range of environments' (8). To avoid confusion, use of the term 'genetic adaptation' has been suggested for this situation (53).

Epstein and Mason (20) divide *Bos indicus* into zebu-type cattle, which have thoracic humps and zeboid cattle, such as Sanga cattle, which have cervico-thoracic humps. Both derive from tropical regions. They also divide *Bos taurus* cattle (European cattle) into longhorn and shorthorn (brachyceros) types. Longhorn types are linked to hotter climates than shorthorn types and there is evidence that longhorn cattle are adapted to hot conditions. Accordingly, the general zoo-geographical argument that animals indigenous to tropical and sub-tropical regions are better adapted to heat applies to *Bos taurus* as well as to *Bos indicus*. Temperate *Bos taurus* (for example, the Hereford and Angus breeds) and tropical *Bos taurus* cattle have inferior and superior heat tolerance, respectively (28).

A body of secondary evidence points to differences in the physiological mechanisms for heat tolerance among types, breeds and strains of cattle (24). The general idea is sustained that *Bos indicus* cattle and their crosses with *Bos taurus* cattle have superior heat tolerance compared to *Bos taurus* cattle derived from temperate regions. In addition, tropical *Bos taurus* cattle are also better adapted to heat than temperate *Bos taurus* cattle. Differences are recorded in autonomic heat control mechanisms, such as fasting metabolic rate, non-evaporative or sensible heat exchange (convection, conduction and radiation) and evaporative or insensible heat loss. There are differences of hair coat between *Bos taurus* and *Bos indicus* which influence both non-evaporative and evaporative cooling. Characteristics of the skin and hair coat are vital for protection against solar radiation. These were discussed in a report on heat stress in feedlot beef cattle (11).

Fasting metabolic rate, which reflects resting heat production, is lower in Brahmans than in Hereford × Shorthorn crosses and Africander cattle (50). A figure of 80%-85% lower when adjusted for metabolic weight (liveweight$^{0.75}$) has been suggested (11). This translates to daily heat production of 30 MJ for a *Bos indicus* individual of 300 kg and contrasts with the 39 MJ computed for a *Bos taurus* individual of the same weight. The difference could be significant for the design of transport environments.

Differences in non-evaporative heat exchange occur between *Bos indicus* and *Bos taurus* cattle.

Finch (23) exposed Brahman, Shorthorn and Brahman half-bred cattle to air temperatures ranging from 25°C to 45°C and examined the transfer of metabolic heat from the core to the shell of the animal body and the sensible or non-evaporative component of heat loss from the skin to the environment. Non-evaporative heat transfer during heat stress in this study was 20% and 34% poorer in Shorthorns compared with that for Brahman half-breds and pure Brahmans. The thicker hair coat of *Bos taurus* cattle impedes non-evaporative forms of heat loss (26). In this connection, the common-sense observation that clipping of the coat helps animals cope with heat stress has been demonstrated formally in cattle (52).

Several studies point to the superiority of evaporative heat loss mechanisms in *Bos indicus* compared with *Bos taurus* cattle and in tropical *Bos taurus* breeds compared with temperate *Bos taurus* breeds. In hot room studies, Jersey cattle started to sweat earlier than zebus and had a higher respiratory rate (1). The sweating response, which integrated sweating rates and rectal temperatures, was a good indicator of the differences in thermoregulatory ability of Brahman, Brahman × Hereford-Shorthorn cross and Shorthorn steers exposed to a radiant heat environment (25). Sweating responses reached their limit during the study in the Shorthorns but not in the Brahmans or Brahman crosses. Heat resistance was evaluated in the F1 progeny of Boran, Tuli and Brahman bulls and Hereford dams in an environmentally controlled chamber (27). Sweating rates were highest in the Brahman × Hereford and Boran × Hereford crossbreds. Sweating rates in the 'tropical' *Bos taurus* breeds of cattle, White Fulani and N'Dama, were similar, but were significantly higher than for N'Dama-German Brown crosses, the 'temperate' *Bos taurus* breeds, German Browns and Friesians (4).

Other studies emphasise the generally superior heat tolerance of *Bos indicus* cattle and their crosses. *Bos indicus* and *Bos taurus* crossbred dairy cattle were compared for heat tolerance with a test integrating sweating rate, respiratory rate, rectal temperature and feed and water consumption (3). Half-bred *Bos indicus* were superior to quarter-bred *Bos indicus* and the test selected animals from dams derived from hot compared to temperate environments. Rectal temperatures, respiration rates, cutaneous evaporation rates and skin temperatures were measured in Brahman cross, water buffalo (*Bubalus bubalis*), Banteng (*Bos javanicus)*, and Shorthorn steers exposed to heat and exercise stress in the sun (36). The buffalo were least heat tolerant followed by the Shorthorns with Brahman crossbreds, with the Bantengs being most heat tolerant.

Heat tolerance in heifers of 'temperate' *Bos taurus* breeds (Angus and Hereford), 'tropical' *Bos taurus* breeds (Senepol and Romosinuano), *Bos indicus* (Brahman) and reciprocal crosses of the Hereford and Senepol, have been investigated (28). Senepol and Romosinuano heifers were substantially heat tolerant, as were the crosses between the Senepol and the two 'temperate' breeds. The heat tolerance of the Senepol and Brahman heifers was similar. A set of physiological responses to heat and exercise stress in imported *Bos taurus* and native *Bos taurus* of the Simmental breed and in native *Bos indicus* cattle were examined in Brazil (16). The imported Simmentals could not complete the exercise test. The native Simmentals could, but with severe respiratory stress. The native *Bos indicus* were well adapted and completed the test without obvious signs of stress.

In regard to the properties of skin and hair coat important in thermoregulation, short, glossy and sleek hair coats are superior to rough, thick coats for survival against heat stress in cattle; coat scores have been developed to test the difference (52). The importance of sleek coats for heat tolerance has been corroborated (43, 48). Short, sleek hair coats are characteristic of *Bos indicus* cattle (20). Sweat glands are larger and more abundant in the skin of *Bos indicus* cattle and are located closer to the skin surface (2, 22).

Acclimatisation, geographic derivation and pre-transport history

It is important to select cattle that have been acclimatised to warm weather conditions if they are to be transported to or through climatic zones of high temperature and humidity. Scientific support for this practice is associated with the concepts of acclimation and acclimatisation which refer either to the persisting change in a specific function (acclimation) or the persisting spectrum of changes (acclimatisation) brought about by prolonged exposure to environmental conditions, such as hot temperatures. The two concepts are combined for the present considerations. Acclimatisation involves adaptations that can occur within an animal's pre-existing genetic capacity for change. In other words, *Bos taurus* cattle can acclimatise to some hot conditions but the ceiling in this capacity will be lower than that for *Bos indicus.*

Acclimatisation to heat in cattle is stated to begin within two weeks of exposure to hot conditions and to complete within four to seven weeks (11). Accordingly, satisfactory acclimatisation will not occur during the process of transport and acclimatisation should be in place before transport commences.

The time estimate of four to seven weeks for heat acclimatisation is built from several sources. Exposure to either a hot-dry or hot-humid environment for various daily periods over three weeks is shown to result in acclimatisation, accompanied by increased rates of sweating and lower metabolic heat production (9, 10). Further support for this time estimate comes from comparisons of compared heat production during heat stress in cattle acclimatised to cold, thermoneutral and hot conditions (34, 40).

It is likely that different processes associated with acclimatisation adjust at different rates and are affected by season. For example, the long and dense winter hair coat of *Bos taurus* is an impediment to heat loss (23, 52) and acclimatisation depends upon the rate at which it can change. Sweat glands may have an enhanced capacity to respond to heat stress during the hotter periods of the year (43).

Very large or very fat animals, thin animals and animals with undesirable temperaments

Scientific support for large size, obesity, thinness and undesirable temperament as risk factors for heat-related disorders comes from general knowledge about the response of mammals to hot conditions rather than from the results of specific investigations.

The argument for large size being a risk factor for heat stress comes from the idea that heat loss occurs through evaporative and non-evaporative mechanisms. Non-evaporative pathways operate completely through the skin and thus depend upon an animal's surface area. In cattle, approximately 70% of evaporative cooling occurs through the skin and effectiveness depends upon an animal's surface area. The problem is that surface area decreases in relative terms as animals become heavier. Consequently, larger animals have a reduced capacity and smaller animals have an increased capacity for heat flow from the body (19). The mathematics on this point is that the surface area of a body of given density and isometric shape increases with the square of its linear dimensions, whereas the volume and hence mass, increases with the cube of its linear dimensions. Large animals have an inherent problem for heat loss.

Scientific support for obesity as a risk factor for heat-related disorders comes from the ideas about size described above, plus a particular phenomenon associated with obesity. Obesity increases the insulating capacity of the shell of an animal because fat has a lower thermal conductivity than water, which is the main component of non-fatty tissue (19). In addition, fatty tissue has a lower blood supply than non-fatty tissue and a large layer of subcutaneous fat will impede the action of arteriovenous anastomoses which divert blood flow to or away from the skin (41).

Scientific support for thinness as a risk factor for heat-related disorders differs from that applying to large size or obesity. Two factors compromise thin cattle exposed to hot conditions. Firstly, the high core temperatures that can accompany heat stress lead to increased metabolic rates which are difficult for thin cattle to cope with from their diminished energy reserves. Secondly, feed intakes are reduced by heat stress (17, 51) which means that thin cattle may only have the option of fuelling their higher metabolic rate from body reserves of energy. An additional problem is that heat stress can lead to the catabolism of body protein (49, 51), which thin animals are also unlikely to be able to sustain.

Undesirable temperament, particularly when expressed as flightiness, is a risk factor for heat-related disorders in transported cattle. Flightiness refers to the tendency of cattle to display the alarm reaction more prominently and with lower stimulation than expected of the species (7). The alarm reaction, the fight-or-flight response, is associated with an increased metabolism and heat production (42). The added heat from this source will be damaging if the heat load is already high. Heart rate increases in animals during the alarm reaction and persistent displays of alarm raise the resting heart rate. In this regard, heart rate can be used to gauge energy expenditure and thus heat production of cattle (14). Finally, flighty behaviour in one animal can influence the general behaviour of in-contact animals and escalate heat production in groups of animals.

Pregnancy

Pregnancy is a risk factor for heat stress because pregnant animals have a reduced heat tolerance and a greater susceptibility to heat-related disorders. Reduced heat tolerance in pregnancy is supported from basic physiology and from general experience with pregnant cows. The developing foetus adds further tissue mass for heat production without adding sufficient surface area to dissipate the extra heat. An underlying factor is that pregnancy and the demands of the developing foetus make inroads into an animal's physiological reserve. This is the extra capacity in body systems that allows an animal to cope with demanding circumstances. For example, the capacity for exercise and physical exertion is lower in pregnant animals.

Specific information from controlled experiments into the loss of physiological reserve and the function of various body systems during pregnancy was sought for cattle but not found. Heat stress can lead to loss of embryos and early foetal mortality in the initial stages of pregnancy (6). Heat stress in the last third of pregnancy can precipitate ketosis ('pregnancy toxaemia') if it perturbs water balance or decreases feed intake (15).

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