CHAPTER 1

INTRODUCTION

Assessment of the physical condition of individual herds or sub-populations of African ungulates is useful as a measure to compare the effects of current and past management practices, stocking rates, weather, disease and other ecological conditions (Smith, 1970). The physical condition of an animal is a fairly accurate indicator of its nutritional status, but it does not always give an accurate indication of the mineral nutritional status of the animal. To quantify this aspect, tissue samples need to be analysed for mineral content. Certain tissues are better indicators of specific minerals than others (Van Ryssen, 2000). In this study samples of the liver were analysed.

The methodologies available for body condition estimation differ in terms of accuracy with which they predict body condition, composition or nutritional status. To accurately quantify the effects of environmental conditions on wildlife, it is necessary to evaluate the accuracy and feasibility of the available methodologies. Recently the effects of BTB on the African buffalo (*Syncerus caffer*) in the Kruger National Park has come under investigation in an extensive BTB monitoring programme involving a variety of researchers.

Bovine tuberculosis (BTB) is a chronic wasting disease caused by a complex of mycobacteria, *Mycobacterium tuberculosis* that include *M. tuberculosis*, *M. microti*, *M. africanum* and *M. bovis* (Kubica & Wayne, 1984). These mycobacteria can affect clinical disease symptoms in a wide range of mammalian hosts, including humans (Morris *et al.*, 1994). *Mycobacterium bovis*, known most commonly as a pathogen of livestock, was almost entirely eliminated from cattle and humans in the 1980's (Cosivi, Meslin, Daborn, & Grange, 1995). Recently it has become widespread in wildlife populations (Tessaro, 1986; Barlow, 1994; O'Reilly & Daborn, 1995; Schmitt, Fitzgerald, Cooley, Bruning-Fann, Sullivan, Berry, Carlson, Minnis, Payeur & Sikarskie, 1997; Bengis, 1999), and its prevalence has been increasing worldwide. Wildlife populations appear to

act as reservoir for the disease and it is accepted that they play a key role in its epidemiology.

Mycobacteriosis has been known to be present in the Kruger National Park (KNP) since 1967 (De Vos, McCully, & Van Niekerk, 1977), when it was described in an impala (*Aepyceros melampus*). No isolation of the causative organism was, however, attempted. Although BTB has been known to occur in free-ranging African buffalo (*Syncerus caffer*) since the middle 1960's (Woodford, 1982), it was not considered to be of practical importance to buffalo in the KNP and other areas in which buffalo occurred as late as the 1980's (Bengis & Erasmus, 1988). In 1990 it was however diagnosed in an African buffalo bull, which was found recumbent near the South-Western boundary fence of the KNP (Bengis, Kriek, Keet, Raath, De Vos & Huchzermeyer, 1996). Further investigation into the BTB status of the buffalo population in the KNP ensued. In 1992 the BTB prevalence was estimated to be 0%, 4.4% and 27.1% in the north, central, and southern regions of KNP respectively. By 1998 the BTB prevalence had increased to 1.5%, 16% and 38.2% for the three regions respectively (Rodwell, Kriek, Bengis, Whyte, Viljoen, De Vos & Boyce, 2001).

BTB was apparently first introduced into African buffalo in the southern region of the KNP during the 1960's or 1980's from domestic cattle (Bengis *et al.*, 1996). According to official reports, tuberculosis infected cattle had been identified on various farms south of the KNP in the period between 1955 and 1987 (Kloeck, 1998). Subsequent investigation has confirmed that BTB in the KNP had probably originated on a specific farm in the Barberton district of Mpumalanga Province where cattle and buffalo had reportedly mingled during the 1950's and 1960's (Vosloo, Bastos, Michel & Thomson, 2001).

The African buffalo, by reason of its high numbers, comparative high vulnerability to *M.bovis*, herd structure and characteristic behavioural patterns, serve as an effective maintenance host and reservoir of BTB. Once a buffalo herd becomes infected the prevalence can surpass 90% (Rodwell, 1999). Under these conditions, spillover of the infection to other species does occur and has been confirmed in a number of species (Bengis & Erasmus, 1998; Keet, Kriek,

Penrith, Michel & Huchzermeyer, 1996). When fences secluding wildlife and livestock areas are breached, infected buffalo accordingly pose a threat to cattle and also their owners.

Presently there are no practical methods for treating infected wildlife populations. Considering the risks these populations pose to livestock and humans, and as a result of growing concern for the health of infected wildlife populations, there is increased pressure to monitor and manage BTB in wildlife. The purpose of this study was to investigate a number of condition indices and to propose some in-vivo methods of condition / composition estimation not previously used in wild ungulates. The study also includes an investigation on the nutritional levels of micro minerals in the African buffalo (*Syncerus caffer*) and their influence on immune function as this may explain some of the variation in body composition. Although there are many variables that affect body composition, the hope is to gain a better understanding of the interaction between the animal and the various environmental factors, and to provide a reference base for future studies.

CHAPTER 2

EVALUATING METHODS FOR CONDITION ESTIMATION IN THE AFRICAN BUFFALO (*Syncerus caffer*)

2.1 Introduction

The assessment of body condition in wild African ungulates is important in view of their management, as it reflects not only their ability to survive under varying environmental conditions (Hirst, 1969; Sinclair, 1970) but also their potential as producers of meat (Monro, 1979). Assessment of the physical condition of individual herds or sub-populations is useful in the study of big game as the condition of game in one area can be compared with that of game in other areas. This would allow for evaluation of the effects of current and past management practices, stocking rates, weather and other ecological conditions (Smith, 1970). Body condition also serves to link the nutritional level of individuals and populations, in different seasons and under a variety of environmental conditions, with their growth and reproductive rates (Brooks, Hanks & Ludbrook, 1977).

Several body condition indices have been proposed for use with African ungulates (Smith 1970; Sinclair & Duncan 1972; Brooks *et al.,* 1977; Monro & Skinner, 1979). Kidney fat index (KFI) and bone marrow index (BMI), are the most frequently reported (Hanks, Cumming, Orpen, Parry & Warren, 1976; Brooks, 1978; Anderson, 1979; Dunham & Murray, 1982; Stelfox & Hudson, 1986; Shackleton & Granger, 1989; Van Rooyen, 1993).

The purpose of this chapter is to investigate a number of condition indices and to propose some in-vivo methods of condition / composition estimation not previously used in wild ungulates. Factors affecting suitability of the available methods will be discussed.

2.2 Justification for the use of fat as an indication of condition

It has been shown that in the earliest stages of normal growth of farm animals bone is the tissue, which develops at the fastest rate; later, muscle grows faster than bone, and finally fat becomes the fastest growing tissue. Fat is a metabolic tissue and primarily an energy store (Casey & Maree, 1993). This makes it a particularly useful index of the metabolic level and potential energy reserves of the animal. Implicit in the growth-rate principles, and metabolic function of fat, fat reserves within the body can thus be taken as a direct measure of condition, reflecting the animal's physiologic adjustment to its environment. In this paper, condition and total fat reserves are used synonymously.

Most wild animals are not as consistently well nourished as are farm animals, and their fat deposits are consequently not as well developed. Nevertheless, in general it is still possible to distinguish centres of location of their fats. The three main centres of location for body fats are the subcutaneous connective tissue, the abdominal cavity, and the inter-muscular connective tissue. The depot fats serve as the principal fuel storage reserves of the body. For this reason and because of the ease with which they can be observed in the carcass they serve as the principal criterion for assessment of condition (Riney, 1955).

The most obvious and straightforward way to determine fat reserves in the body is to dissect or render out all fat and express it as a percentage of the live weight or carcass weight. This is a tedious, expensive and time-consuming task, which generally results in various piles of lean, fat and bones, which are not as desirable for human consumption as is the intact carcass. We will consider other methods.

2.2.1 Order of fat deposition

The order of fat deposition is fundamental to the use of the amount of fat in various depots as an index to total fat reserved, or to condition. At any given time of change, fat is being laid on or taken off most of the depots at the same time. In other words, adipose tissue is in a dynamic state of continuous

synthesis, deposition, and utilisation. The order of deposition refers only to the start and finish of the process.

Various authors (Harris, 1945; Riney, 1955; Ransom, 1965; Trout & Thiessen, 1968) have indicated that the first fat depot to respond to a favourable metabolic change in various species is bone marrow. This is followed by the fat around the kidney, intestines, and stomach in that order, and, finally, by the subcutaneous fat on the back. Mobilisation of the fat depots observed, was in reverse order to that of deposition. This is in accordance with one of the characteristics of differential growth whereby fat deposition starts at different times in different depots. Wright & Russel (1984a) suggested that different fat depots play different roles in different physiological processes. In other words, fat depots are mobilised at varying degrees and at varying rates, depending on the physiological process involved.

2.2.2 Subcutaneous fat deposition

In animals, which are not subjected to cold stress, subcutaneous deposition of fat would probably serve as a physiological stressor during the summer season, which would be characterised in most cases by extreme heat. This assumption is supported by the examination of many East African ungulates, which have very little, if any fat under the skin (Smith, 1970). If fat was present, it would obstruct the dissipation of heat.

Minimum amounts of total fat found on the thinnest cattle (a temperate zone animal) raised in East Africa approximate those found on the fattest African game animals (Ledger & Smith, 1964; Ledger, Sachs & Smith, 1967). This suggests that fat is probably not the only major store of reserve energy in tropical ungulates or, conversely, that the wild animals are in poorer condition. Observations of other components such as lean percentage, which is from 10 – 16% higher in game animals than in Boran steers (Ledger & Smith, 1964), and higher dressing out percentages in game, tend to rule out that the animals are in poorer condition. This would rather indicate that they use protein as a stored reserve.

The fat related definitions of condition used might therefore not reflect the true physiological state of wild animals. Future research in this field would benefit from a better understanding of the metabolic reactions of tropical ungulates to nutritional stress, allowing "condition" to be more realistically defined.

2.2.3 Kidney fat index (KFI)

The KFI offers a simple, rapid and relatively objective quantitative measure of body condition. To obtain the data it is necessary to have only a knife and a balance capable of weighing to the nearest gram. The KFI is based on the mass percentage of the fat (capsula adiposa) surrounding the kidney. The KFI is determined as follows: The kidney together with the surrounding capsula adiposa is removed and weighed. The capsula adiposa is then peeled away from the surface and the kidney weighed without the fat. Condition is determined by the amount of fat around the kidney expressed as a percentage of the kidney weight, in order to place animals of different size on a comparable basis.

In addition to being an accurate indication of the fat stored in the body, (Riney, 1955; Smith, 1970; Brooks *et al.,* 1977) the KFI has a wide range and can be duplicated by different workers. The KFI reveals differences between animals of different sexes and social status and seasonal changes in condition are clear as fat is mobilised from around the kidney before any other region. In terms of time, energy, and money expended for a comparable degree of accuracy, the KFI fulfils the needs of a workable technique, except in the case of hippopotamus and lesser kudu (Smith, 1970).

The KFI is influenced by various factors other than nutrition alone. Rainfall and habitat will influence the KFI as they influence body condition through their effect on nutrition. Sinclair & Duncan (1972) attributed fluctuations in KFI to physiological events related to reproduction. Hanks *et al.* (1976) indicated that changes in body weight and KFI of impala (*Aepyceros melampus*) above the age of three years are related to reproduction, and noted a reduction in KFI of males during the rut. Bear (1971) found significant seasonal changes in the KFI of male

and female pronghorns (*Antilocapra americana*) in Colorado. It was found that females generally maintained higher levels of kidney fat than did males. Mean fat indices for males exceeded those of females only in June and early July, at which time the mean fat index for females was at the lowest level. The differences between the trends of males and females may be attributed to stress on the females during pregnancy, parturition, and raising the young. Herding during late August and September likely placed an increased metabolic demand on males, at which time fat is utilised maximally.

The use of the kidney index as a measure of condition has limitations with younger animals, where very little body fat is deposited regardless of condition. Hanks *et al.* (1976) found a highly significant difference ($P<0.001$) in the mean KFI between impala under the age of three and impala above that age. Up to three years of age, the mean kidney index is considerably lower than the mean index for Impala above that age (Monro & Skinner, 1979).

Several authors have cautioned against the use of KFI for interpretation of seasonal trends in herbivore condition (Dauphine, 1975; Attwell, 1977). This stemmed from the detection of seasonal differences in the mass of the kidney itself, which in turn influenced values of the KFI. Suttie (1983) also reported seasonal weight changes in the kidneys of red deer (*Cervus elephas*). Scotcher (1982) and Shackleton & Granger (1989), however, produced conflicting results, where no significant seasonal change in kidney mass was detected. Brooks (1978) and Anderson (1979) also found no seasonal fluctuation in the mass of the kidney of impala and nyala respectively. This clearly requires thorough investigation before kidney fat indices can be employed in wildlife management with any degree of confidence.

2.2.4 Bone marrow index (BMI)

The BMI is a representation of the percentage fat in the bone marrow of animals. As bone marrow predominantly consists of fat, the BMI may conceivably be a fair appraisement of body condition.

It has been stated that the BMI is seasonally limiting in its range by not reflecting the full change in body condition of animals (Riney, 1955), thus being limiting in its prediction of fluctuations in body fat across its entire range. In the study of Bear (1971) the bone marrow showed no significant seasonal fluctuations, with very few specimens having values less than 70 percent. Monro, (1979) found that the bone marrow fat did not significantly correlate with body condition of impala. Both studies seem to indicate the inefficiency of the BMI in mirroring body condition.

A number of authors (Harris, 1945; Ransom, 1965; Bear, 1971; Sinclair & Duncan, 1972; Hanks *et al.*, 1976; Brooks *et al.*, 1977) have investigated the relationship between the KFI and the fat content of the bone marrow. They suggest that the perinephric fat, barring a small persistent quantity of residual fat (Brooks *et al,* 1977), is mobilised before that of the bone marrow fat. Thus indicating that the bone marrow fat is mobilised after the kidney fat and hence is a better measure of condition when the animal is suffering from more extreme environmental stresses. The finding that the BMI does not significantly deteriorate until the KFI declines below a certain level, and the poor relationship observed by Ransom (1965) between these two indices, suggesting that they reflect different responses of the animal to environmental and physiological stresses, support this.

Thus the KFI has little merit for condition estimation at the commencement of mobilisation of fat from the bone marrow, and the BMI has little merit when the KFI is above a certain level. This suggests the complementary use of the two measurements as a means of assessing physical condition over its entire range.

Although of value in older animals the study of Hanks *et al.* (1976) has demonstrated the limitations of the fat content of the bone marrow as measure of condition in young animals. In impala under two years of age the bone marrow was still very active in red blood cell formation and very little fat deposition had taken place.

It was found that bone marrow samples from a variety of bones in the body did not differ by more than 10% fat content, even in animals with very low

levels of marrow fat (Bear, 1971; Sinclair & Duncan, 1972). This is a useful finding for it allows an estimation of condition to be made from any of the bones, often predators and scavengers carry away the limb bones leaving only the vertebral column and pelvic girdle. Brooks *et al.* (1977), however found a very positive sequence of marrow fat mobilisation in the limb bones that is initiated in the femur and humerus, and suggested that for more sensitive comparative studies of condition, these two bones should be collected.

Estimates of condition of naturally dying wild animals must be obtained before primary and secondary causes of death can be identified (Sinclair & Duncan, 1972). In these cases bone marrow fat is a better measure of condition than the kidney fat, as often the carcass is only found after scavengers have eaten the soft parts of the carcass including the kidneys, the bone marrow however is often intact.

2.2.4.1 Chemical determination of percentage of marrow fat

Riney (1955) described a method whereby marrow is taken from the central section of the femur and weighed. The red blood-making ends of the marrow are not used in the analysis. The marrow is dropped into boiling 95 per cent alcohol in the field. The alcohol is removed *in vacuo* and the dried tissue continuously extracted with petroleum-ether (boiling point 40-60°C) in a Soxhlet apparatus. The weight of the petroleum-ether extract is used to give the percentage fat in the bone marrow.

The chemical determination of bone marrow fat is of little use as a field technique, however, because of the difficulty in collecting and in transporting specimens to the laboratory and the length of time involved before results can be obtained (Riney, 1955).

2.2.4.2 The visual description of bone marrow

Riney (1955) described a visual method of estimating the condition of bone marrow, from its texture and colour. Colour was determined and the rating (0-3) was judged on the following basis:

0 = Reddish or brownish in colour.

1 = Intermediate between 1 and 2.

2 = Light, but with faint wash of colour.

3 = White, or white streaked with small red vessels.

White, with or without red streaks, indicates marrow with high fat content. As the fat content decreases, the colour deepens, the lowest fat content marrow being reddish or brownish in colour.

The texture of the marrow was also rated:

0 = Gelatinous or watery.

1 = Slightly greasy.

2 = Soft and thickly greasy but not waxy.

3 = Firm and waxy.

As the fat content of the marrow increases, the texture, which in marrow of low fat content is watery or gelatinous, becomes firmer and increasingly waxy. Colour and texture judged separately in this way were combined to form the "visual estimate of fat content in femur marrow" with values ranging from 0 to 6.

Sinclair & Duncan (1972) describe another method of visually estimating the condition of bone marrow, from its texture and colour. The categories used were:

- Solid white fatty.
- White opaque gelatinous.
- Red-pink opaque gelatinous.
- Translucent yellow or pink gelatinous.

The mean percentage dry weight for each of the classes was calculated, and these means were then compared. With few exceptions the percentage dry weights in Class 1 were above 90 and the mean was significantly different from all other classes ($P< 0.05$). Class 4 was usually below 20% dry weight and the mean was also significantly different ($P< 0.05$) from all other classes. Classes 2 and 3 both showed a wide range of values between 90% and 10% dry weight and were not significantly different from each other; the colour difference did not reflect a difference in fat content. The samples from Class 3 were however

mostly from juvenile animals. In juvenile animals the marrow has a very opaque gelatinous appearance and is still very active in red blood cell formation (Hanks *et al.*, 1976), hence the colour difference. Thus Classes 2 and 3 were combined to make three categories.

Bear (1971) found the relationship between per cent bone marrow fat and colour to be very poor, there was however mention of a possible correlation between consistency ratings and percentage of fat content. The conclusion made was that visual estimates of fat content, using colour and consistency were reliable only for extreme fat values. Neiland (1970) was of the opinion that a four-step visual classification is not an especially sensitive method of comparison, particularly for individual specimens collected infrequently. Riney (1955) and Sinclair & Duncan (1972), however, found visual estimates of bone marrow to reflect true differences in bone marrow fat content. This classification is useful in circumstances where it is not possible to collect a sample of the marrow for further analysis; at least one can say with confidence at what end of the scale of condition the animal was when it died.

2.2.4.3 A compression method indicates fat content of bone marrow

Greer (1968) described a method using the extent of bone marrow compression to estimate the fat content in the marrow. Uniform samples of marrow were obtained with the aid of a jig or device. The jig was made from a plastic pipe with an inside diameter of 1½ cm with about one-third of the circumference removed. An open section in the tube allowed the marrow to be laid in a horizontal position and also provided access for holding marrow in a natural, not stretched or compacted position, when cutting measured sections. One end of the marrow was cut with a knife held against the end of the jig. The cut marrow and end of the jig were butted against a flat surface and the remaining marrow was cut off flush with the other end of the jig. If the marrow was not stretched or squeezed, it was the precise length of the jig (Greer, 1968).

When a known length of marrow sample is removed from the measuring jig and placed on end, its consistency is revealed by the immediate compression

under its own weight which can be measured with a scale. Jig lengths may be selected to coincide with existing graduated scales. Scales may be engraved or attached to the jig (Greer, 1968).

Extremely limp or flaccid marrow will not stand unaided for measurements but these can be easily handled inside the vertical jig. Although the tube may restrict complete basal expansion in some samples, an extensive compression of the marrow will be noted. Tubes should be at least twice as great in diameter as marrow to permit some area for limp marrow to expand at the base. If measured marrow sections will not stand unaided, a thin rod inserted through the centre of the marrow shaft can be used to hold a sample upright while compression is measured (Greer, 1968).

It appears that broad intervals of 10 or 20 percent fat content may be adequate to indicate an animal's condition. The compression method may not be as accurate, and is considerably more difficult to carry out than the visual estimate of bone marrow fat content. It nevertheless provides a general index to fat content in big game bone marrow that may be useful when chemical analyses are not feasible or not desired (Greer, 1968).

2.2.4.4 Weight of dried marrow as indicator of marrow fat

Neiland (1970) pursued an objective technique for estimating bone marrow fat content other than the visual procedure or the conventional extraction procedure. It was believed that extraction procedures were too tedious and more accurate than necessary for routine use on large numbers of marrow samples. As bone marrow is essentially a three component system comprised of water, fat, and residue, this component amounting to only a small fraction of the fresh weight, a convenient analytical method could be based on the inverse relationship, which exists in ruminants between body fat and water. The aqueous, the fat-soluble, and the non fat-soluble fractions were determined by weighing before and after drying and after extraction.

Several authors (Neiland, 1970; Sinclair & Duncan, 1972; Brooks *et al.*, 1977; Shackleton & Granger, 1989) came to the conclusion that bone marrow fat

content could be conveniently estimated with suitable accuracy and precision by simply drying the sample. In other words bone marrow dry weight expressed as a percentage of its fresh weight is a good indication of its fat content. The dry weight of a sample is the weight of fat and residue in the wet marrow sample. The error in the method can be reduced to a minimum by taking into account the average amount of residual material in marrow samples at various fat concentrations. Thus for maximum accuracy in estimating marrow fat with the dry-weight method, the residue value corresponding to a specific dry weight should be subtracted from that dry weight value to give the correct percentage of fat.

The relationship between the percentage marrow fat (y) and its comparative percentage dry weight (x) is given in Table 1 as linear regression equations from which it would be possible to calculate the percentage marrow fat if the percentage dry weight of the marrow were known.

The slopes of the regression lines are sufficiently close to unity to allow a more general formula of the form $y = x - a$ to be used, where 'a' is a constant for each species, representing the non – fat residue in the marrow. At the present time there is insufficient information to indicate how this changes with the different ruminant species. The purposes for which marrow fat estimates are needed, namely the estimation of condition in wild animals, allow the approximation using the mean of the residue constants, %marrow fat = %dry weight – mean of residue constants for at least the medium and large sized ruminants (Sinclair & Duncan, 1972).

Table 1.1. Regression formulae manifesting the highly significant correlation between the percentage fat content and the percentage dry mass of bone marrow in several species

Species	Formula for regression	r	Reference
Blesbok	Y = 1.13x – 19.15	0.975	Shackleton & Granger (1989)
Eland	Y = 1.05x – 13.30	0.983	
Gemsbok	Y = 1.08x – 19.30	0.993	
Impala	Y = 0.87x + 1.66	0.781	
Red hartebeest	Y = 1.03x – 13.30	0.987	
Blue wildebeest	Y = 1.02x – 12.73	0.957	
Blesbok	Y = 0.99x – 5.04	0.997	Brooks *et al.* (1977)
Buffalo	Y = 1.02x – 5.91	0.992	
Eland	Y = 1.02x – 5.41	0.999	
Impala	Y = 1.03x – 7.14	0.992	
Kudu	Y = 1.06x – 8.35	0.993	
Nyala	Y = 1.05x – 8.33	0.988	
Reedbuck	Y = 1.04x – 10.33	0.991	
Wildebeest	Y = 1.01x – 6.42	0.997	
Kongoni	Y = 1.0488x – 6.9483		Sinclair & Duncan (1972)
Wildebeest	Y = 1.0042x – 7.2829		
Buffalo	Y = 1.0045x – 3.4182		

Extraction procedures are theoretically as accurate as desired, but time consuming for large-scale use. The dry-weight method has the advantage of being as accurate, or nearly so, as the extraction method yet is substantially quicker and less expensive. The dry-weight method is slower than the visual or compression methods, but with experience it can be effectively speeded up (Neiland, 1970).

2.2.5 Back Fat Index (BFI)

The BFI is highly correlated with the kidney fat, the abdominal fat and marrow ratings (Riney, 1955). To measure the back fat a forward cut of approximately 12 in. is made starting at the base of the tail and at an angle of approximately 45 degrees from the spinal column. The greatest depth of fat observed along this cut is then measured to the nearest millimetre.

As back fat is the last to be deposited in prodigious times of the year, and is again the first to be mobilised in times of more severe stress, it points to seasonal limitations of back fat as an index to condition. This restricts its application to the upper part of the theoretical condition scale. Thus during times of under nourishment, back fat disappears and is consequently of little use on a year – round basis or in areas where the levels of nutrition are consistently low.

2.2.6 Abdominal Fat Rating

Riney (1955) described a method whereby stomach, intestines, and kidneys are exposed. A four-choice rating is assigned to each organ, based on the amount of fat obvious at first glance:

0 = No trace of fat obvious on the ventral side of the stomach, small intestine or around the kidney.

1 = Small amounts of fat on the membranes surrounding the above organs

2 = Moderate amounts of fat present and intermediate in quantity between 1 and 3

3 = Fat abundant on the organ in question, the extreme condition being represented by numerous broad, thick bands of fat on the stomach and lower intestine. In prime animals, the kidney is often totally hidden by surrounding fat.

The arbitrary numerical ratings thus obtained on stomach, small intestine, and kidney are combined to make a maximum rating of 9. Different sized animals can thus be rated on a comparable basis. However, the scale is narrow (0 – 9), causing it to be less agreeable as a scale in contrast to, for example, KFI.

2.2.7 Visceral fat

The visceral fat index is obtained by dividing the weight of the visceral fat (grams) by the eviscerated carcass weight (kilograms). Smith (1970) and Bear (1971) concluded that the correlation of visceral fat with total fat follows closely the pattern for KFI with total fat. This method, however, does not lend itself to usage in the field as much time and energy is spent in the separation of fat from the stomach and intestines.

2.2.8 Live weight ratio

The live weight ratio is calculated as live weight (minus uterus weight in females) divided by the hind foot length (*os calcis* to tip of hoof), to correct for skeletal size differences (Smith, 1970). The hind foot length is used as a correction factor as growth of the extremities are affected less by nutritional differences than are more proximal bones. Smith (1970) showed that of 10 species collected the only significant correlation between live weight ratio and total lean occurred in the waterbuck and wildebeest.

2.2.9 Girth measurement

Girth measurement is taken on a carcass, or live animal, within the first 2cm behind the posterior edge of the scapula. As the flesh is usually flabby, it is necessary for reproducible measurement always to hold the tape with the same degree of tautness (Riney, 1955).

In addition to the apparent operator inaccuracy and the necessity to restrain the animal, a further complication in the assessment of condition occurs when comparing the technique with known body fat reserves. As an example, two animals could have identical weight and girth measurements (and would look identical in the field) and yet at the same time they could differ substantially in their deposited fat reserves as demonstrated by KFI and the fat content of the bone marrow. It is only after a further mobilisation of fat reserves that the body weight falls significantly and the girth measurement is reduced (Hanks *et al.*, 1976).

2.2.10 Leg fat

Smith & Ledger (1965) found, in wild African ungulates, that the weight of the leg of a standard dressed carcass bears a constant relationship to the animal's live weight irrespective of the age or degree of fatness. Also the deposition of fat on the legs was in direct proportion to the total amount of fat on the body. Thus by knowing the weight of the leg fat and the relationship it bears with the live weight, the total amount of fat on the body could be calculated.

Smith (1970) found a significant correlation between the leg fat expressed as a percentage of the leg weight and the total body fat. Even though this method is an accurate index of total fat, its main drawback is that it is not as rapid or as easily obtained as, for example, the KFI.

2.2.11 Blood Constituents

Various researchers have examined the possibility of using blood constituents to describe or establish condition in ruminants. Their efforts have met with varying degrees of success. Rosen & Bischoff (1952) reported on the relationship between some blood constituents and condition in California deer. They found no correlation between bodyweight (their criterion of condition) and red blood cells, haemoglobin, or packed cell volume. Stewart, Norden, Wood & Cowan (1964) found that an increase in plasma cholesterol of black-tailed deer (*Odocoileus hemionus columbianus*) was associated with the point of maximum gain in body weight. In female deer there was an initial rise in cholesterol ensued by a decline as weight loss occurred. Males exhibited reduced levels throughout the time of weight loss. Bandy, Kitts, Wood & Cowan (1957) investigating white-tailed deer (*Odocoileus virginianus*) found that fibrinogen increased and blood sugar decreased on low plane nutrition. Taber, White & Smith (1959) suggested the use of serum protein in mg/100 ml serum as a measure of protein reserves in the body. Patterson (1965) associated the occurrence of xanthophyll in the plasma of sheep with the mobilisation of fat depots. He reported that the pigment xanthophyll is connected with the plasma non-esterified fatty acid concentration and appears in the blood after four days of starvation. The appearance of

xanthophyll gives a yellow to green colour to normally clear plasma. Franzmann & Leresche (1978), studying moose (*Alces americana*) in Alaska, found that a combination of packed red cell volume, total plasma proteins, haemoglobin, calcium, and phosphorus levels gave a reasonable indication of body condition. Monro, (1979), studying impala, found no significant correlation between blood constituents and body fat.

Smith (1970) commented on the unfortunate lack of information regarding the short-term effects on blood constituents, brought about by changes in the environment, in free-ranging African ungulates. Further research pertaining to blood constituents, and its correlation with body composition, may provide a rich source of information for describing the condition of these animals.

2.2.12 Adrenal Index

An index which would measure the sum of all factors: nutritional, physiological, behavioural, pathological and others, would be the ideal method of condition estimation. In search of this most descriptive method, Hughes & Mall (1958) and Taber *et al.* (1959) proposed the use of an adrenal index to measure the response of the adrenal cortex to environmental stresses. The adrenal index proposed by Taber *et al.* (1959) was corrected for individual body size by dividing the adrenal weight by the adrenal surface area, as organ weights increase in relation to surface area. Surface area was calculated from whole weight by a formula found in the work of Spector (1956). Hughes & Mall (1958) corrected for the effect of individual size difference by dividing adrenal weight by total length. Smith (1970) used the weight of the kidney as a correction factor, as it is not affected by stress in the same manner as the adrenal gland.

Hughes & Mall (1958), using estimated kidney fat as the measure of condition, found good correlation between adrenal weight and kidney fat, and adrenal weight/body length and kidney fat. They suggest adrenal weight as another index of condition, using it as the most convenient measure of adrenal cortex hypertrophy in response to body stresses. Taber *et al.* (1959) indicated that there was a time lag of several months between environmental stress and its

effects on the adrenal gland's weight. Smith (1970) however found that only in the warthog was there a significant correlation between adrenal weight and total fat. He also attempted to correlate adrenal weight/total body length, and found no evidence for this as an index to condition of the animals studied.

2.2.13 Body Condition Score (BCS)

Jefferies (1961) designed a system to outline body condition in sheep, based on a 6-point scale. Each point was described in terms of the amount of tissue cover over the lumbar region of the spine. Russel *et al.*, (1969) using an adaptation of the system of Jefferies (1961), quantified BCS in Scottish Blackface ewes and showed that it was related closely to the proportion of chemical fat in the body. The system used for sheep by Russel *et al.* (1969), was adapted for use with cattle by Lowmann, Scott & Somerville (1976). The System defines six grades (0 to 5), and describes each one in terms of the amount of tissue cover over the transverse processes of the lumbar vertebrae and around the tail head.

Several authors report on a five-point scale in which animals are ranked from 1 to 5. Emaciated cows are scored 1; thin cows, 2; average cows, 3; fat cows, 4; and obese cows, 5 (Wildman, Jones, Wagner, Boman, Troutt & Lesch, 1982; Otto, Ferguson, Fox & Sniffen, 1991). Often the scale is refined, by using plus or minus signs, in .25 to .5 units, or an augmented nine-point scale to evaluate more subtle changes in body fat than are permitted by unit increments. A BCS is allocated to a cow based on the appearance of tissue cover over the bony protrusions in the back and pelvic regions. Specific regions include the spinous and transverse processes of the lumbar vertebrae (loin), the ileal (hook bone) and ischeal (pin bone) tuberosities, the ileo-sacral and ischeal coccygeal ligaments, the tail head, and the thurl region (or rump). Tissue cover is assessed either by palpation, or by visual inspection, or by both. A single factor may be misleading, however, all factors considered together provide an accurate score.

Wildman *et al.* (1982), outlines the five point body condition scale as follows:

BCS = 1 Individual spinous processes have negligible flesh covering, are conspicuous, the ends are sharp to the touch and together the processes form a definite overhanging shelf effect to the loin region. Individual vertebrae of the chine, loin, and rump regions are prominent and distinct, hooks and pin bones are sharp with limited flesh covering, and exceedingly depressed causing the bone structure of the area to appear extremely sharp.

BCS = 2 Individual spinous processes are visible but are not conspicuous. Ends of processes are sharp to the touch although they have greater flesh covering. The processes do not have a particularly distinct overhanging shelf effect. Individual vertebrae of chine, loin, and rump regions are not visually prominent but are discernible by palpation. Hook and pin bones are prominent, but the depression between them is less severe. The area below the tailhead and between the pin bones is depressed, but the bone structure is not devoid of flesh covering.

BCS = 3 Spinous processes are perceivable by applying slight pressure. Together the processes appear smooth and the overhanging shelf effect is not distinguishable. Vertebrae of the chine, loin, and rump regions are seen as a rounded ridge. The hook and pin bones are rounded and smooth. The area between the pin bones and around the tailhead appears smooth without any sign of fat deposition.

BCS = 4 Individual spinous processes are distinguishable by firm palpation and together, the processes appear flat or rounded with no overhanging shelf effect. The ridge formed by the vertebral column of the chine region is rounded and smooth, but loin and rump regions appear flat. Hook bones are rounded, and the span between the hooks is flat. The area around tailhead and pin bones is rounded, with evidence of subcutaneous fat deposition.

BCS = 5 Bone structure of the vertebral column, the spinous processes, and the hook and pin bone regions are not visually apparent. Evidence of subcutaneous fat deposition is prominent. The tail head appears to be buried in fatty tissue.

BCS is a non-invasive means of estimating fat stores in animals independent of frame size and body weight. Despite the fact that it is a subjective measure of body condition, it offers a very inexpensive method of assessing body composition with an acceptable degree of precision.

Wright & Russel (1984a) found that each of the four components, water, fat, protein and ash, and body energy were related to BCS. They concluded, in another paper (Wright & Russel, 1984b), that the precision of prediction of body composition from condition score compares favourably with other *in vivo* techniques used for estimating body composition. Otto *et al.* (1991), found BCS to be highly correlated with composition of the 9^{th} to 11^{th} rib section in cattle for dry matter (DM)(r^2 = 0.69), crude protein (CP) (r^2 = 0.61), ether extract (EE) (r^2 = 0.57) and ash content.

One problem associated with BCS is that there has been no standard system communicated among cattle producers, researchers, extension personnel and industry consultants. Condition scores have been expressed on a 17-point system (Gresham, Holloway, Butts & McCurley, 1986), a 9-point system (Whitman, 1975; Wagner, 1984) and a 5-point system (Lemenager, Nelson & Hendrix, 1980). Data compiled and published by Herd & Sprott (1986) indicated that percentage empty body lipid for BCS 1 through 9 was 0, 4, 8, 12, 16, 20, 24, 28 and 32, respectively. Data presented by Houghton, Lemenager, Moss & Hendrix (1990), indicated that percentage of empty body lipid for BCS 1 through 5 was 3.1, 8.7, 14.9, 21.5 and 27.2 respectively. These data suggest that condition scores 1, 3 and 5 on a 5-point system would be similar to condition scores 2, 5 and 8, respectively, on a 9-point system. Standardisation between operators is, therefore, essential to reduce variation.

Condition score assesses only subcutaneous fat cover (Wright & Russel 1984a). Thus variation in partitioning of fat among the main adipose tissue depots (subcutaneous, intermuscular and intramuscular, and abdominal) might be expected to influence the relationship between condition score and body fat. The outcome being that breeds differing in the partitioning of fat among the various depots will differ in the proportion of total body fat at the same condition

score. Wright & Russel (1984a+b) found that the proportion of fat contained in the major depots, however, remained relatively constant regardless of BCS, thus it probably correlates well with total body fat content.

BCS at lower ends of the scale (BCS = 1 to 2) may reflect changes in tissue water in addition to changes in CP and EE (Otto *et al.,* 1991). This provides evidence not only of fat depletion, but also of depletion of muscle in cows, with low BCS.

2.2.14 Weight to Height Ratio (WHR)

Weight to height ratio (WHR) has also been used as a predictor of mature cow body composition and is less subjective than BCS. The WHR is computed by dividing the weight of the animal with its hip height. Klosterman, Sanford & Parker (1968) and Nelsen *et al.* (1985) point out, however, that WHR is only dependable within a breed or biological type and only if the animals have a common nutritional background. Similar results were reported by Dunn *et al.* (1983), who observed that WHR was less significant as a forecaster of body composition (r = .56) than visual and palpated BCS (r = .86) were when a wide range of biological types with different nutritional histories were considered.

Houghton *et al.* (1990), using regression equations, concluded that BCS plus weight was a better predictor (r = .70 to .74) of percentage carcass lipid and total empty body lipid than were weight, weight height ratio or a combination of these factors. However, weight, weight transformations, WHR and BCS also were practical in predicting fat in the carcass and empty body (r = .62 to .70).

BCSs, even though they are subjective, can identify relative differences in cow body composition when a single person assigns condition scores to animals within a herd. Also, BCS has advantages over other body composition prediction methods such as WHR in that 1) cows do not need to be restrained, 2) no special equipment is needed and 3) evaluations can be made frequently. Visual BCS has been shown to be a reasonably good predictor of carcass and empty body lipid content when used in combination with weight (Houghton *et al.,* 1990).

2.3 Alternative Measures of Body Condition Estimation

Apart from considering the methods discussed above, any measurement, which might increase or decrease with changing condition could also be used if it were divided by any measurement which remained reasonably constant. Thus in the live individual, body mass and heart girth are changing parameters (Nelsen, Short, Reynolds & Urick, 1985). These could be divided by head length, metacarpal length, hind foot length, body length or shoulder height. In the slaughtered animal, carcass weight, buttock weight or buttock circumference could be divided by carcass length, metacarpal length, hind foot length or buttock length to give an index of condition (Monro, 1979).

Another method suggested by Monro (1979), which was in fairly good agreement with the assessment of body condition, was body fat divided by ash multiplied by 100, where fat and ash were both expressed as percentages of dry weight. As most indices have been used without defining what condition is in terms of body composition, some influence was given to non-fat reserves, which may play an important role in wild ungulates. Fat was therefore still the most important element, but the total amount of organic matter also played a role in determining condition.

To gauge the nutritional status of wild ungulates, Bandy, Cowan, Kitts, & Wood (1956), suggested a technique, which is based on the relationship of actual body weight to heart girth and body weight to hindfoot length. Assuming that the hindfoot length is little affected by nutritional status they estimated an optimum or ideal weight by a regression formula. The formula was derived by measuring increases in the length of hindfoot and body weight of penned black-tailed deer raised on a high plane nutritional diet. An estimated body weight based on the heart girth/body weight relationship (which is affected by nutritional status of the animal) was calculated and the ratio of this estimated weight and the ideal weight was used as an index of condition.

2.3.1 Probes To Measure Tissue Thickness

In pigs nearly 80% of the total carcass fat is located in the subcutaneous depot. Therefore an accurate method of determining subcutaneous fat thickness should provide a good prediction of total carcass fatness (Jones & Haworth, 1982). With cattle there is the problem of hide thickness and with sheep there are animal variations of fat depth (Kempster, Chadwick, Cue, & Grantley-Smith, 1984). Nevertheless probes are actively used on lamb and beef carcasses and form the basis of objective classification schemes in many countries (Jones & Haworth, 1982). In wildlife these methods have not yet to our knowledge been used.

2.3.2 The Back Fat Probe

To measure the actual fat depth, a small incision is made in the skin with a scalpel and a narrow ruler is forced through the fat layers or a ruler containing a needle point is forced directly through the skin and fat layers. Since nerve and vascular supplies in the skin and subcutaneous fat layers are minimal, pain and bleeding are not much of a problem in the live animal. The measuring device must penetrate the false lean or aponeurosis (sheet of fascial connective tissue separating the outer and middle layers of subcutaneous fat) and continue until there is a second resistance due to the epimysial connective tissue covering the muscle. The depth is usually verified and recorded (Kempster *et al.*, 1984)

Once the fat depth is known, it can be used in a previously developed regression equation with other variables such as live weight and muscling score to estimate composition. Fat depth alone usually accounts for most of the variation in composition but live weight and degree of muscling should improve the accuracy of the measurement (Fahey, Schaefer, Kauffman, Epley, Gould, Romans, Smith, & Topel, 1977).

The major advantages of this method are that it affords a reasonably accurate prediction of composition, it is easy to standardise, it makes a rapid measurement and it is inexpensive. On the other hand it requires that the animal

be restrained and it is too slow if a large number of animals or carcasses are involved (Fahey *et al*, 1977)

2.3.3 Reflectance (Optical) Probe

The optical probe (OP) or intrascope has a light source near its tip. Light is emitted through a lens carrying a clearly marked line at right angles to the probe shaft. The operator, by means of an internal mirror system, can observe this line through the top of the probe, adjacent to the handle. A graduated sliding barrel indicates the probe depth when the operator judges the line to coincide with the fat/lean interface. This is effectively a manually operated optical ruler.

The first automated detection of the tissue boundaries was based on the differential electrical conductivity of fat and lean tissues. This was the Danish probe, the KS meter (K= kod/meat; S= speak/fat) Fisher (1990). The automated version of this probe the KSA, sometimes referred to as the MFA (meat-fat automatic) in English texts, was based on a system where the electronic signals from the probe were interfaced to a microcomputer. The microcomputer calculated the lean meat percentage from fat and "meat" thickness based on data involving carcass dissections.

Other probe systems for estimating lean percentage via tissue thickness are based on the optical properties of lean and fat tissues. These are known as light reflectance probes and they may utilise visible light or light in the near infrared part of the spectrum. The mode of actions relies upon the fact that light emitted from an LED near the top of the probe is reflected in different ways by the different tissues. Thus with accurate measurement of the signal relative to the depth penetrated, the thickness of the fat at the predetermined position can be measured. Distance from the skin surface (depth) is measured by means of a spring loaded base plate which can move in relation to the probe but which always makes contact with the skin/carcass surface during operation.

The first probes to utilise this principle were the Ulster Probe (UP) and the fat depth indicator (FDI). Three more recent versions of the automatic light probes are the Hennessy Grading Probe (HGP) (Kempster, Chadwick, Jones, &

Cuthbertson, 1981; Kutsley, Murphey, Smith, Savell, Stiffler & Terrell, 1982; Fortin, Jones & Howorth, 1984; Kirton, Feist, Duganzich, Jordan, O`Donnel & Woods, 1987), which uses light in the green-yellow range (=570nm) The Fat-O-Meter (FOM) (Kempster *et al.*, 1981; Fortin *et al.*, 1984), which uses light in the near-infrared range (=915nm) and the Destron Probe (DST) which uses light in the near-infrared range. The FOM differs from the other two in that electronic signals are transmitted along a cable connecting the probe to a microprocessor, keyboard and display. In the HGP and DST, the microprocessor is an integral part of the probe and the relevant information, (tissue depth, lean percent) are displayed on the probes themselves. The DST also has a keyboard in the probe body.

2.3.4 Ultrasound Techniques

Ultrasound waves are sound waves with frequencies above the range of the human ear (Simm, 1983). The sound waves can be propagated through solids, liquids and gasses and behave in a similar fashion to light waves in that they displayed both refraction and reflection at boundaries between substances of different acoustic density (Terry, Savell, Recio, & Cross, 1989). The major tissues and organs of the body have characteristically different acoustic densities and there are at least three techniques, which utilise this principle: Pulse - echo ultrasound, velocity of sound (VOS) and real time imaging ultrasound (RTU) (Fortin, 1980; Simm, 1983).

2.3.5 Pulse-Echo Ultrasound Techniques

A pulse generator sends electrical pulses that are converted into sound (ultrasound) signals in the transmitter. These signals are then passed through the tissues until they are reflected at an interface (Fortin, 1980). The reflected signals are picked up by a receiver and can be amplified and shown in a visual form by an oscilloscope (Tong & Malcolm, 2002).

The A-mode ultrasonic machines display echo amplitude against time, which is shown on the screen as peaks super imposed on a time base line. The

distance between the peaks represents the thickness of the tissues being measured. The A-mode machines, initially developed for medical diagnostic purposes, were used to take leaner fat depth measurements, and are still in use today (Tong & Malcolm, 2002).

For the B-mode machines, the signals are shown on a cathode ray tube as a series of bright spots. The distance between successive bright spots represents the thickness of the tissue. These machines were developed to produce two-dimensional scans either by movement of the probe along a curved track (as in the scanogram) or by firing an array of transducers in sequence (as in the Danscanner). From these two-dimensional scans, eye muscle and fat areas in addition to leaner fat depth may be calculated (Alliston, Barker, Kempster, & Arnall, 1981).

2.3.6 Velocity of Sound

Miles & Fursey (1974) reported an ultrasound technique, which overcomes some of the problems in applying pulse echo techniques to predicting carcass compositional trades in live sheep and cattle. Compared with pigs, sheep and cattle deposit relatively less of the fat subcutaneously and relatively more in the intramuscular fat depot. This is probably the main reason for the lower correlations found in sheep and cattle between subcutaneous fat depths and area measurements and carcass lean or fat content. Correlations can be improved by using the inter- and intramuscular depots in addition to the subcutaneous fat by propagating a wave of ultrasound completely through the body and measuring its velocity. The principle described by Miles, Fursey & York (1984), is that ultrasound waves travel slower through adipose tissue than through lean. The time taken to travel a known distance through a mixture of lean and fat is therefore related to the proportions of the two tissues in the line of flight.

The equipment consists of a transmitter and receiver held facing each other by a steel frame. The distance between the two is adjustable to accommodate various animal sizes. Having selected a site where the passage

of the wage will be unimpeded by bone an ultrasound pulse is propagated and the time taken to travel a known distance between the two transducers is recorded electronically and the reciprocal of the velocity is computed and displayed. The precision of this technique was compared by a visual assessment of fatness in the carcass as a predictor of the composition by McKenzie, Rafferty & Beckett (1998). Measurement of the speed of ultrasound at two locations in the hind limb was almost as good a predictor of carcass composition as the mean fat score given by two experienced judges, and was more highly correlated with total fat content of the carcass than was the mean of three fat depths taken on the carcass over *M. Longissimus dorsi* (r=0.60).

In another study measurements of the speed of ultrasound at two sites gave an RSD for adipose tissue proportion in the side comparable to that achieved with a scanogram pulse echo technique (0.0227 compared to 0.0223) and a further significant reduction in the RSD was achieved when the two were used together to predict fatness (Miles, Fursey & Pomeroy, 1983b). The speed of ultrasound through hind leg gave as precise a prediction of carcass lean weight and almost as precise a prediction of carcass lean percentage as two B-mode real time scanners (technicare and vetscan).

Despite its apparent benefits, it is yet to receive much acceptance in the abattoir, because of its cost (approximately double that of the probe) with no significant increase in performance. It is prone to error due to sight location although in the hands of a skilled operator, it is a very effective instrument. To achieve optimum results, the manually operated ultrasound technique takes a considerable period of time, 30 to 60 seconds, to accurately locate the site, activate the device and take the readings. Good coupling, between the device and the surface of the animal, is also required for the system to work efficiently. Warm soft tissues at the surface of the lambs are mobile and this may interfere with coupling. Also air pockets in the surface fat layers of lambs and cattle may impair coupling (Miles *et al.*, 1983b).

2.3.7 Real Time Imaging Ultrasound (RTU)

Real time machines produce a practically instantaneous picture by rapid electronic switching from element to element. The principle involved is similar to that described in pulse echo ultrasound, except that movement of the tissue can be seen because of the continuous nature of the picture. The Dan scanner that was already referred to under B-mode scanners is an example of a real time imaging ultrasound system (RTU).

RTU creates cross-sectional and longitudinal images at various carcass/body locations to facilitate the measurement of fat depth, muscle depth, or muscle area without cutting the carcass (Forrest, 1995). The interpretation of results for B-mode and RTU machines usually requires the tracing of depths and areas of pictures. The disadvantages of ultrasound imaging include the skill required to obtain a good image, the skill required to interpret and measure the image and the speed with which all of this can be accomplished in an on line situation. There are, however, microprocessors for computers, which may facilitate interpretation, and light pen and mouse techniques for establishing area measurements, which should speed up the process, although no fully automatic systems, are commercially available yet. It has been stated, "the human is still the best interpreter of current ultrasound images" (Forrest, 1995).

Miller, Cross, Smith, Baker, Beyers & Recio (1986) and Recio, Savell, Cross & Harris (1986) showed that RTU measurements obtained by very experienced operators could accurately predict carcass composition traits. The RTU live measures of *M. Longissimus dorsi* area, 12th rib, and shoulder fat thickness were significantly correlated to comparable carcass measurements. Adjusted fat thickness was the single most useful carcass measurement for predicting percentage carcass fat.

2.3.8 Electrical Methods

2.3.8.1 Electromagnetic Scanning

Electromagnetic scanning often referred to as TOBEC (total body electrical conductivity) is a method of compositional analysis by means of an

instrument called the electronic meat measuring equipment (EMME). This equipment measures the fat and lean content in live pigs (model SA-1). EMME SA1 was later modified for the measurement of packaged, boxed and boneless meat. The EMME/TOBEC HA-1 also obtained in-vivo measurements in humans, which is the prototype to the new HA-2 (Domermuth, Veum, Alexander, Hedrick, Clark, & Eklund, 1976).

The theoretical basis of the method is that conductivity of electricity through lean tissue or the fat free body (FFB) exceeds that through fat tissue by about 20 fold (Lenkins, Leymaster & Turbington, 1988). This is due to the high water electrolyte content found in the tissue and extra cellular water making up the FFB. Current flow induced in a biological system is a function of conductive and dielectric properties. The conductive properties are related to the intra- and extracellular ionic content, and the dielectric effect is associated primarily with capacitance related to cell membranes. Impedance to current flow in the system revolves in an irreversible loss of energy as heat. This energy is related to the conductive mass. The dielectric or capacitance properties of current flow represent the reactive part of impedance in which energy transfer is reversible due to temporary storage of electrical energy. Capacitance is partly determined by the geometry of the conductor, which may produce an effect whereby capacitance increases as cross-sectional area, length, or both, increase. While theoretically both electrical properties define the flow of current in a conductive mass, the conductive properties appear to exert a more dominant effect in estimating FFB mass (Lenkins *et al.*, 1988).

Electromagnetic scanners consists of a Cu wire, solenoid coiled around a glass fibre (Plexiglas) tube which forms a scanning chamber large enough to accommodate pork and lamb carcasses or beef hind quarters. When current is applied it induces an electromagnetic field in which the body is statically situated (HA-1) or scanned (HA-2). The conducting mass passing through the electromagnetic field absorbs heat energy, thereby perturbing the electrical field of the coil. The loss of energy detected in the coil is an index of the conductive mass of the body. The oscillating current frequency applied to the coil is an

important aspect of the measurement, since the degree of separation in the conductivities of FFB and fat is frequency dependent. This first TOBEC model (HA-1) used 5-Mhz oscillating coil current and required a 0.5 second measurement on a statically situated carcass/body. The new TOBEC HA-2 instrument uses 2.5-Mhz and subjects move through the coil at a constant rate. It requires about 40 seconds for one measurement. The change in coil energy as the body moves through the length of the coil is detected as change in conductance and capacitance relative to an empty coil. The measured conductance and capacitance of the conductor (subject) is reflected in a phased angle/distance curve. The area under the curve is an index of total body conductivity (Domermuth *et al.*, 1976)

The precision of TOBEC appears to be excellent relative to that of other techniques for the assessment of body composition. Domermuth *et al.* (1976) measured 12 pigs 14 times a day for two days and found an average coefficient of variation (CV) among the animals of 4 percent. Bracco, Yang, Segal, Hashim, & Van Itallie (1983) observed a high association between TOBEC values and 30 live rats and FFB estimated by densitrometry and by chemical analysis of the carcass. High linear correlations were also observed between TOBEC and total protein (r=0.95) and total body water (r=0.98) (Bracco *et al.*, 1983)

Domermuth *et al.* (1976) reported on the relationship between TOBEC and other body composition estimation methods including total potassium and carcass analysis in pigs. Two experiments were conducted, one with 42 pigs and the other with 35 pigs, in which the animals were fasted for 16 to 18 hours to obtain a empty body weight before being measured by TOBEC and total potassium. The animals were killed and their carcasses analysed for specific gravity and fat, water, and protein content. The linear correlations between live animal TOBEC readings and potassium measurements were 0.75 and 0.81 for experiments 1 and 2 respectively.

Electromagnetic scanning of the full pork carcass side under laboratory conditions accurately measured lean mass in the carcass (r=0.90 RSD = 1.64

kg), dissected lean meat percentage (r=0.70, RSD=2.38 %), and lean mass within individual primal cuts from full carcass scans (Domermuth *et al.*, 1976).

Electromagnetic scanning can be applied to uneviscerated warm carcasses, eviscerated warm carcasses, or chilled carcass sides with comparable accuracy. However, scanning warm, pre-rigor, whole carcasses may be the most practical procedure.

In a study where beef hind- and forequarters were scanned separately, the correlation for predicted dissected lean weight in the hind quarter ranged from 0.91 to 0.94, with RSD=1.6 to 1.3 kg. Prediction of dissected lean in the forequarter ranged from r=0.86 to r=0.91 with RSD=2.27 to 1.81 kg. Full beef carcasses could be scanned if the chamber size were enlarged. In a study in which 22 lamb carcasses were scanned to predict total lean in the pre-rigor carcass resulted in a correlation of 0.98 and a RDS of 0.35 kg, with warm carcass weight, carcass length, and 1 TOBEC reading as the independent variables.

The system suffers from a number of practical drawbacks. It is considerably more expensive compared to probes and is relatively slow, even the current fastest throughput speed would limit carcass numbers to approximately 200 to 250 carcasses per hour. The system also requires the object to pass through in a horizontal position, whereas most abattoirs are built around a vertical hanging system. The technique gives no indication of fat depths, which for practical purposes could be important in determining individual carcass applications. Each EMME machine also has to be calibrated and a formula established for this specific machine. Temperature and humidity can also influence the results. The optimum application of this technology requires constant sample positioning, constant sample temperature, a constant feed through the system and calibration that takes account of sample geometry (Domermuth *et al.*, 1976).

2.3.8.2 Bioelectrical Impedance Analysis (BIA)

Bioelectrical impedance analysis (BIA) operates on the same principle as Electromagnetic Scanning in that there is a difference in conductivity between fat tissue and the fat free mass/body (FFB). As carcass fatness increases, the impedance to the flow of electricity increases. The current is applied through an array of electrodes placed on the surface of the body.

BIA has been shown to be highly accurate in predicting the fat free soft tissue content of lamb carcasses (Swantek, Marchello, Crenshaw, Lukaski, & Lewis, 1989). Fat free mass in warm lamb carcasses was predicted using warm carcass weight, carcass length, resistance, reactance and carcass temperature. The best four variable equation utilising BIA measurements on chilled carcasses included warm carcass weight, carcass length, and two bioelectrical impedance parameters (Forrest, 1995).

When a single fat depth measurement was placed in a four variable equation with warm carcass weight and two bioelectrical impedance parameters, the precision of prediction increased while the RSD decreased. This result suggests that, where practical, combinations of technologies could/should be explored. The relatively low cost of bioelectrical impedance instruments makes it a good candidate for combination with optical probe or ultrasound systems (Forrest, 1995).

2.3.8.3 X-Ray Computed Tomography (CT)

CT makes use of the differential that exists between the rates at which the tissues of the body attenuate x-rays, in much the same way as conventional film based radiography. In CT however, a two-dimensional image is produced by a 360-degree rotation of an x-ray source around the body or carcass of the animal. An arc-array of highly sensitive detectors measures the attenuation of the radiation beam as they rotate in synchrony with the source. During the rotation pulses of radiation are fired at discrete intervals (usually every degree or half degree of rotation) and each detector signals to the computer the amount of radiation received. The computer processes the data from the large number of

crossing pathways to produce a matrix of attenuation values for the target body. The matrix is displayed as an image on a monitor. By this technique, the density (CT number) of different body tissues at different distances from the x-ray source can be calculated (Groeneveld, Kallweit, Hemming, & Pfau, 1984).

All available machines have been designed for use in human diagnostics. The patient is laid on a table, which is then moved through an aperture housing the radiation source and detectors. The size of the aperture restricts the technique to small-to-medium sized animals such as poultry, goats, sheep and pigs. Even if the financial incentives existed for a larger purpose built machine to scan cattle there are technical barriers to such a scaling-up. As it is important to reduce movement to a bare minimum during scanning, all animals have to be restrained in a cradle, and pigs must be anaesthetised, thereby reducing the speed of the throughput. A typical scanning procedure begins by transporting the animal through the aperture with the x-ray source stationary, but firing constantly. This results in a topogram, a longitudinal image of the body in which the skeleton is readily identifiable. By this method anatomical locations for tomograms (slices through the body) may be located precisely. Once a procedure has been established, requiring for example two tomograms, 20-30 sheep or 10-15 pigs per hour could be scanned. The amount of various tissues (muscle, bone, fat and water) can be predicted from these cross sections (Allen, & Vagen, 1984).

Radiation is, of course highly dangerous, but since the equipment has been designed for use on humans the dose levels are low and can be considered harmless even for breeding animals. Operators are protected, by having the operating console in a room separate from the lead-shielded room housing the source (Groeneveld *et al.*, 1984).

2.3.8.4 Nuclear Magnetic Resonance Imaging (NMR) and Spectroscopy

The NMR method for estimating body composition is based on a strong static magnetic field and pulsed radio waves that induce resonance of protons in the tissues of the measured carcass or living body (Allen, 1990). When the

subject is placed in the strong magnetic field, atomic nuclei with an odd number of protons and/or neutrons - the hydrogen atom with its single proton being the most common of these in the body - align with the field and spin at resonant frequencies determined by the type of nuclei and the field strength (Mitchell, Wang & Elsasser, 1987). The electromagnetic signals emitted from the body, yield information on the concentration and distribution of these nuclei. The signals are produced as a reaction of the body to the high-frequency disturbance, and are therefore a product of the matter itself. The intensities of the signals will depend on the proton spin densities and the molecular structure of the tissue (Fuller, Foster & Hutchison, 1984).

In NMR systems a strong magnetic field is produced by a large annular electromagnet or superconducting electromagnet with an aperture large enough for the subject to pass through. A secondary changing field is superimposed on the main field by electric currents passing through coils near the subject. The strength and orientation of the magnetism is changed in a regular pattern in order to map the locations of the spinning nuclei in the desired plane, cross-sectional, longitudinal, transverse, or oblique. A full cross-sectional image can be made on any plane in the carcass or live animal. Discrimination between muscle and adipose tissue results from their different proton densities (Fuller, Foster & Hutchison, 1984).

As the superimposed changing tilts the magnetic field the angular momentum of the protons delays the return of the field to its equilibrium position. The delay is known as relaxation of which two components can be measured. The "spin-lattice" time (T1) is the longitudinal component due to the interaction of the nuclear spin system with the surrounding "lattice". The transverse component due to the interactions of neighbouring spins is known as the "spin-spin" relaxation time (T2). The magnitude of these components depends on the chemical structure of the tissue, in particular the relative amounts of water and triglyceride. The high water content of muscle results in a moderate relaxation time (T1) whereas high triglyceride content gives fatty tissue a shorter T1 value. A range of images may be formed by combining the T1 and T2 measurements

with proton density information, and with different weightings given to the relaxation times (Mitchell *et al.*, 1987).

A few seconds are required to produce an image with NMR, so that the technique is relatively "immune" to movement. As with x-ray CT, however, animals would have to be anaesthetised and strapped to some form of cradle or table. Unlike x-ray CT, there are no moving parts with NMR and the technique does not use ionising radiation. There is no known health hazard from the magnetic fields of the strength employed, except to human patients with certain types of cardiac pacemaker. The equipment is very expensive and the method is very complex; its future will depend on the amount of resources available for its development as an agricultural tool (Mitchell *et al.*, 1987).

2.4 Comparison and Selection of Techniques

There are several problems in making definitive statements about the relative merits of the techniques studied to predict body composition. Firstly, only a small number of trials were studied where a range of techniques has been compared on the same group of animals. Secondly, in many trials relatively complex methods have not even been compared with simple, readily available indicators of composition such as live weight, sex and growth rate. Many trials, particularly those involving new techniques, have been carried out using animals with much wider variation in age, weight and composition than would be the case in practice. Making comparisons between techniques across different studies is also complicated by factors such as differences in the experience of operators, the choice of dependant variables, the size and variability of the sample and the presentation of the results (Fahey *et al.*, 1977).

The main criteria for selection of a technique are cost, practicability, precision and accuracy. Total cost includes running, as well as capital costs. Practicability includes factors such as mobility, physical requirements such as size, power supply, shielding (both operators and animal/carcass), simplicity of operation and the speed of throughput. Public acceptability is also included in the list. Precision refers to the RSD of the predicted characteristic and accuracy is

the lack of bias in predicting carcass characteristics, when different groups of animals are to be evaluated by different investigators (Fahey *et al.*, 1977). The data thus obtained must be of comparable accuracy in order to validate comparisons of populations from different areas and at different times. The various techniques are listed below, and "scored" for the important criteria.

Table 1.2. Summary of techniques to determine body composition in animals

Method	Cost	Portability	Simplicity	Potential precision	Species availability	Potential application
Ultrasonic scanning	4	5	4	4	C,P,S	F,M,B,E
VOS	5	5	5	3	C,P,S	F,M,B,E
X-Ray CT	1	1	1	5	P,S	B,E
NMR	1	1	1	5	P,S	B,E
Electrical conductivity	2	2	2	3	P,S	B,E
Probes	6	6	6	4	C,P,S	F,M,B,E
KFI	6	6	6	2	C,P,S	F,M,B,E
BMI	6	5	6	2	C,P,S	F,M,B,E
Back fat	6	6	6	2	C,P,S	F,M,B,E
Abdominal fat	6	6	6	2	C,P,S	F,M,B,E
Visceral fat	6	6	6	2	C,P,S	F,M,B,E
Live weight ratio	6	6	6	1	C,P,S	F,M,B,E
Girth	6	6	6	1	C,P,S	F,M,B,E
Leg fat	6	6	6	1	C,P,S	B,E
Blood	6	2	5	1	C,P,S	B,E
Adrenal index	6	6	6	1	C,P,S	B,E
BCS	6	6	6	2	C,P,S	F,M,B,E
Weight height ratio	6	6	6	1	C,P,S	F,M,B,E

Scores: 1=least favourable, 6=most favourable
F= on farm; M= market and slaughter houses; B= breeding programs; E=experimental stations
VOS = Velocity of Sound
X-Ray CT = X-Ray Computed Tomography
NMR = Nuclear Magnetic Resonance Imaging and Spectroscopy
KFI = Kidney Fat Index
BMI = Bone Marrow index
BCS = Body Condition Score (Fahey *et al.*, 1977; Eveleigh, Thwaites, Hassab, Paton, Smith, & Upton, 1985)

Table 1.3. The advantages and disadvantages of different methods of body composition estimation

METHOD	ADVANTAGES	DISADVANTAGES
KFI	Enables different sized animals to be compared on a uniform basis. Measurement over a wide range.	Does not measure complete range of condition.
BMI	Condition assessment can be done on animals dead several weeks or months.	Poor for measuring changes in the upper parts of the condition scale.
Back fat	Changes in condition can be detected in top condition animals.	Different sized animals not placed on a comparable basis. Measurement of condition restricted seasonally due to inability to measure the lower part of the condition scale. The scale has a narrow range
Abdominal fat	Measures entire range of condition. Rates different sized animals on a comparable basis.	Scale is narrow. Rating is subjective.
Visceral fat	Simple affordable objective rating.	Time and energy consuming.
Live weight ratio	Affordable objective rating.	Animals need to be restrained
Girth	Simple and affordable.	Animals need to be restrained More a measure of size than of condition.
Leg fat	Accurate measure of condition.	Time consuming.
Blood	Could prove to be ingenious in condition estimation	Lack of information pertaining to blood constituents compared with condition.
Adrenal index	Convenient measure of adrenal cortex hypertrophy.	Time lag between environmental stress and its effect on adrenal gland.
BCS	Animals do not need to be restrained. Non invasive, easily	Subjective estimate of condition. No standard system has

	obtainable estimate of fat stores, allowing for frequent evaluation.	been devised.
Weight height ratio	Affordable objective rating.	Only dependable within breed or biological type.
Probes	Affordable, easy to standardise Reasonably accurate, rapid.	Animals need to be restrained Too slow for large numbers of animals
Ultrasonics	Relatively affordable, portable Simple to use, high precision	Need direct contact with sample surface through sound conducting medium Need efficient operators for max. Contact Need interpretation of images Needs 30-60 sec. For reading
VOS	Affordable, simple, precise	Bone interferes with measurement All disadvantages listed for ultrasonics
X-Ray CT	High precision	High cost, slow throughput, animals need to be anaesthetised.
NMR	High precision	High cost, slow throughput, complex, animals need to be anaesthetised.
Electrical conductivity	Relatively precise	High cost, constant sample positioning, constant temperature required.

KFI = Kidney Fat Index
BMI = Bone Marrow index
BCS = Body Condition Score
VOS = Velocity of Sound
X-Ray CT = X-Ray Computed Tomography
NMR = Nuclear Magnetic Resonance Imaging and Spectroscopy
(Fahey *et al.*, 1977; Eveleigh *et al.*, 1985)

ADDENDUM
CV = Variance / Population average
r = Covariance of x and y / (variation of x *variation of y)
SD = √ Variance
RSD = Standard deviation after treatment effects have been removed.