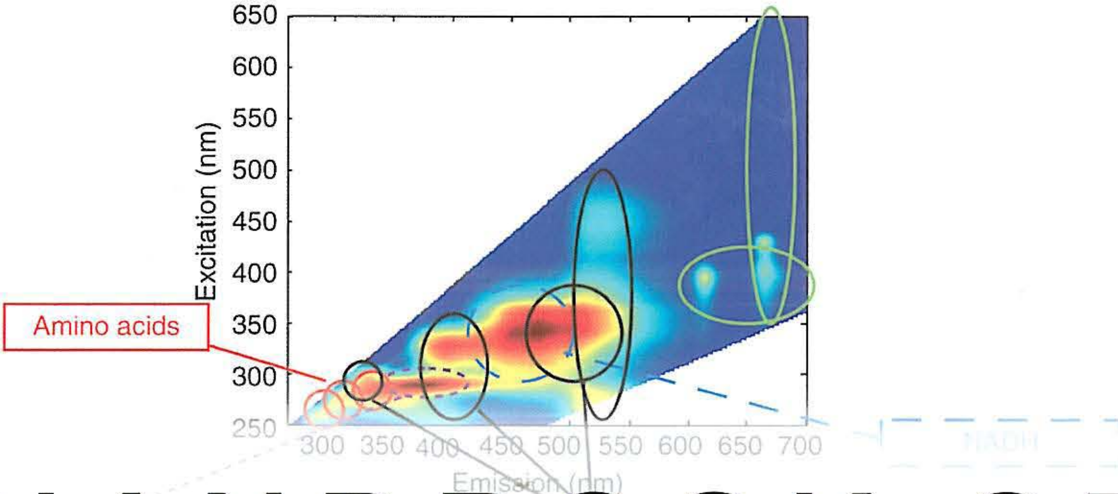

HANDBOOK OF Muscle Foods Analysis

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Chapter 17

Basic Composition: Rapid Methodologies

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Contents

17.1 Introduction

Meat is a protein source with an important role in the human diet. Despite the great number of possible sources of meat, cattle, sheep, goats, pigs, and poultry are the most important meat producers' species. Differences between species exist in terms of the principal tissues (muscle, fat, and bone), and within the same species the content of these components differs according mainly to breed, age, sex, commercial category, and production or feed system.

Normally the word meat means the flesh of animals used as food for consumers. Some consumers associate meat with the negative image of fat consumption, high cholesterol levels, and heart disease, but adipose tissue in meat is not altogether undesirable or wasteful. Subcutaneous fat in appropriate quantity is desirable in terms of carcass conformation; also, for example, the fat deposited inside the muscles, the intramuscular fat commonly known as marbling, confers juiciness, improves the flavor, and makes meat tender and more succulent when cooked. Although a minimum level of fat is required to assure juiciness and flavor, from the point of view of human health, consumers have an increased concern for their diet and in general show preferences for leaner meat, with less or no fat. Consequently, in terms of carcass value, a knowledge of tissue composition, distribution, and partitioning of fat and muscle units has become more and more important for consumers, packers, processors, retailers, and producers.

"Meat quality" animals should be evaluated with reference to two important factors:

1. Quality parameters such as tenderness, muscle and fat color, flavor, and marbling
2. Composition such as saleable meat or tissue proportions (muscle, fat, and bone)

The attempt to assess body or carcass composition has a long history. Several methodologies have been tried and tested, mainly with objectives related to genetic improvement and commercial carcass classification.

17.2 General Methodologies

Body and carcass composition, particularly fat deposits, can be assessed using several methodologies, including subjective measurements, live or carcass weight, linear measurements, the use of carcass joint compositions as predictors, the number and size of adipocytes, dilution techniques, underwater weighing, optical probes, video image analysis (VIA), total body electrical conductivity, bioelectrical impedance analysis (BIA), ultrasounds, computer tomography, and magnetic resonance imaging. Although there are different levels of accuracy in tissue prediction and different relations between weak and strong points, all methodologies are valuable; however, only some of them can be considered rapid methodologies.

The dilution techniques for estimating body water using radionucleotides [1] or urea [2] as well as the method of underwater weighing [3], deuterium oxide [4], or the number and size of adipocytes [5] require an amount of time only suitable under specific experimental conditions and research studies.

The dissection of small carcass joints as predictors of carcass or body composition [6–8], while precise, requires time, and the regression equations to predict overall composition should be determined for each breed and should be used only under the same environmental and experimental conditions.

Of all the cited methods, computer tomography and magnetic resonance imaging are the most accurate in predicting composition in live animals, but the high cost of the equipment relative to other methods, and the exposure of the subject to radiation, limit the use of these technologies in animal science. Furthermore, the use online of computer tomography or magnetic resonance imaging takes time not compatible with a slaughter line in an abattoir. Nevertheless, in breeding programs, computer tomography scanning of elite animals presents a clear and convincing case for supplementation of ultrasound scanning, improving the genetic process [9,10].

To respond to consumer demand, it is becoming increasingly important to provide adequate information about carcass composition such as saleable meat, fat, muscle, and bone composition. There is an increasing need for more accurate, rapid, and inexpensive methods to assess body and carcass composition for all species. It is the purpose of this chapter to review the methodologies used to assess the basic body or carcass composition in such a way as to find the most appropriate, efficient, rapid, and inexpensive procedure.

17.3 Rapid Methodologies

Efforts to predict body or carcass composition of live animals have been made over a long period of time. The first attempts to determine the general condition of animals amounted to the use of methodologies such as subjective measurements of live weight.

The preliminary use of new electronic methods to predict body or carcass composition of live animals has had limited success because of the dynamic of body composition as the result of growth, feeding systems, and variability between and within species.

Our understanding and quantification of the rapid advances in electronic and computer sciences have advanced and significantly stimulated some methods as tools to assess carcass or body composition in live animals. The relation between cost and ease of use, and the suitability to the meat industry or slaughter line of the abattoir, are probably the most important factors for the success of a methodology to quickly assess basic composition.

17.3.1 Subjective Measurements

Visual assessment, body dimensions, and handling of the live animals in association with a body condition score are the most rapid and cheapest methods for predicting the body composition *in vivo* [11,12]. These do not require transportation of the animals or the use of special equipment. They are useful for all people interested in meat production and commercialization, and are practised under several environmental conditions, including in the field under farm conditions [6,8].

The major problems with these techniques are related to the difficulty of distinguishing between lean and fat, and of assessing fat deposition in the different physiological conditions of the animal, especially in those that are associated with mountain grazing, which are involved in fat mobilization or deposition periods, and lactation or pregnancy periods. The precision obtained by these techniques is very variable and is particularly influenced by the degree of fatness or the conformation of the animals. As several authors have demonstrated, conformation is related to fatness, and normally animals with good conformation are fatter than others. In spite of the number of standardized methods developed, these methodologies still have great variations due to the subjectivity of the operators, low incidence of repeat measurements between different operators, and the accuracy with which the measurements or the evaluations are taken.

The visual assessment of fatness using different photographic reference scales is a cheap method to predict the fat content of beef and sheep carcasses, and it is used in commercial abattoirs in several countries as a method of commercial carcass classification. Despite all attempts at standardization, the accuracy of the method as a predictor of carcass composition is still largely subjective, mainly due to the experience of the judges and the environmental conditions under which evaluations are made. As a result, visual scoring assessments are only appropriate under commercial conditions to classify carcasses for payment.

17.3.2 Live and Carcass Weight

The importance of live weight stems from the general knowledge that as an animal grows, its body or carcass composition changes; for example, fat normally increases in relation to muscle and bone. In several experiments across all species, and according to different feed or rearing systems, live weight shows a positive correlation with fatness independent of the variation in live weight or body condition [6].

Live weight is a predictor with negligible cost, is available in many circumstances in which it is easy to use, and is included in prediction equations that use other variables as predictors. In most experimental situations, live weight is the first variable in association with other variables in multiple regression equations. One of the most important problems affecting the use of live weight is its dependence on the way the animals are fed, the environmental conditions in which they are reared, the existence of any disease that alters the growth rate, the gut content (there is a close relationship between level of feed intake and the live weight gain/loss and the weight of some noncarcass organs according to Aziz et al. [13]) and the stage of growth of the animal.

In addition to live weight, carcass weight can be used as a predictor of carcass composition. Easy and cheap to use in abattoir conditions, carcass weight is normally included as a first independent variable in association with other kinds of predictors in multiple regression equations.

17.3.3 Electronic Technologies

Optical reflectance probes [14], BIA [15–19], electromagnetic scanning [20,21], fiber-optic spectroscopy [22–24], and real-time ultrasonography (RTU) [25–29] have been tested in several species for assessing body or carcass composition. Most of these technologies have been used mainly to assess carcass composition; Table 17.1 shows the accuracy obtained with different methods in several species. Cross and Belk [30] reviewed several technologies and objective measurements of carcass and meat quality and stated that some may be ready for commercial use, but that others required further evaluation. To evaluate fat and muscle quality for market, a rapid and cheap method is required. Further tests of all of these technologies should be made in an industrial setting before the adoption of any particular one, testing to their usefulness and adaptability to the slaughter line in an abattoir, cost of the equipment, scanning time required, speed, repeatability, and accuracy of estimation.

Recently, whether to assess body composition in live animals or carcass composition, new methods (sometimes based on old ones), easily performed and nondestructive to live animals, have been developed for rapid evaluation. In addition to the use of the correct technology, the use of advanced statistical analyses such as multiple regression, neural networks application [31,32], or support vector machines [33] may also improve the precision of predictions.

Backfat probes have been used, first in live pigs, to measure fat thickness. The oldest techniques used on live hogs are scalpel and ruler; a small incision on the back of the animal is required to insert a metal ruler. For animal welfare reasons, this procedure is no longer permitted in several countries.

The increasing need for an objective carcass grading system for market evaluation, to estimate carcass composition, and to assess fat and meat quality has led in recent years to the development of equipment that is objective, rapid, compatible with slaughter time, and able to measure fat and muscle thickness in intact carcasses. Several technologies have been evaluated to determine their accuracy and precision in predicting carcass components; some of them are utilized as probes in commercial carcass grading and classification systems such as (see Figures 17.1 and 17.2): hand-held

Table 17.1 Different Rapid Methodologies to Assess Body and Carcass Composition in Several Species

References	*Animals*	*Methodology*	*Prediction*	R^2	*Error*
Gresham et al. [64]	Swine	Ultrasound + BW	Body lean (live)	.56	RSD = 3.84
			Body lean (carcass)	.61	RSD = 3.61
			TOTLLEAN (live)	.60	RSD = 3.70
			TOTLLEAM (carcass)	.64	RSD = 3.52
			KGEEFAT (live)	.57	RSD = 2.75
			KGEEFAT (carcass)	.60	RSD = 2.65
Berg et al. [20]	Lambs	BIA + BW	FFM (live)	.78	RMSE = 1.04
			FFM (hot)	.78	RMSE = 1.04
Berg and Marchello [15]	Lambs	BIA + BW	FFST (live)	.78	RMSE = 1.77
			FFST (hot)	.79	RMSE = 0.92
Berg et al. [20]	Lambs	TOBEC + HCW	Lean weight	.98	RMSE = 0.35
			% Dissected lean	.79	RMSE = 1.39
Kirton et al. [35]	Lambs	HGP + HCW	% Fat	.47	RSD = 3.07
			% Water	.44	RSD = 2.39
		Aus-Meat + HCW	% Fat	.38	RSD = 3.25
			% Water	.34	RSD = 2.62
		Ruakura probe + HCW	% Fat	.31	RSD = 3.46
			% Water	.28	RSD = 2.77
Berg et al. [26]	Lambs	Ultrasound + HCW	Lean weight	.48	RMSE = 1.25
			Fat-free lean weight	.41	RMSE = 1.29
		Optical grading probe + HCW	Total dissected lean	.55	RMSE = 1.02
			Fat-free lean	.53	RMSE = 1.06
		BIA + HCW	Total dissected lean	.81	RMSE = 0.89
			Fat-free lean	.78	RMSE = 0.94
		TOBEC + HCW	Total dissected lean	.88	RMSE = 0.73
			Fat-free lean	.88	RMSE = 0.71
Swantek et al. [18]	Pigs	BIA + BW	Fat-free mass (live)	.98	RMSE = 2.83
Velazco et al. [19]	Steers	BIA + BW	Fat-free mass (live)	.98	SEE = 9.03
Irie [22]	Porcine	Fiber-optic spectroscopy	SFAC	.73	
			MFAC	.68	
			PFAC	−.76	
Marchello et al. [48]	Beef	BIA + BW	% Fat of beef trim	.80	RMSE = 6.64
Delfa et al. [102]	Goats	Ultrasound + BW	Carcass fat weight	.92	RSD = 0.22
			Body fat weight	.94	RSD = 2.01
Schinckel et al. [43]	Pork	Ultrasound + BW	Fat-free mass weight	.83	RSD = 2.58
			Lipid-free soft mass	.91	RSD = 2.13
			Dissected lean mass	.90	RSD = 1.76
			Total fat mass	.88	RSD = 3.20
Steiner et al. [117]	Beef	VIA	M. longissimus area	.93	RSD = 3.48
Steiner et al. [118]	Beef	CVS	Fat PSPC	.51	RSD = 0.022
		VIASCAN	Fat PSPC	.46	RSD = 0.023
Johnson et al. [40]	Pork	FOM + HCW	Fat-free lean weight		RSD = 3.57
		UFOM			RSD = 3.62
		Ultrasound scan			RSD = 3.06
		AUS			RSD = 3.46

Table 17.1 (Continued)

References	*Animals*	*Methodology*	*Prediction*	R^2	*Error*
Silva et al. [28]	Lambs	Ultrasound + BW	Fat weight	.90	RSD = 0.76
			Protein	.83	RSD = 0.40
Bergen et al. [82]	Beef bulls	Ultrasound	Lean meat yield	.63	RSD = 18.9
Teixeira et al. [29]	Lambs	Ultrasound + BW	Muscle weight	.96	RSD = 0.21
			Carcass fat weight	.88	RSD = 0.07
Aass et al. [85]	Cattle	Ultrasound	CHIMF %	.48	RMSE = 0.46

Note: BW, body weight; TOTLLEAN, fat-free soft tissue; KGEEFAT, total ether-extractable fat; BIA, bioelectrical impedance analysis; FFM, fat-free mass; FFST, fat-free mass soft tissue; TOBEC, total body electrical conductivity; HCW, hot carcass weight; HGP, Hennessy grading probe; SFAC, saturated fatty acid content; MFAC, monounsaturated fatty acid content; PFAC, polyunsaturated fatty acid content; VIA, video image analysis; CVS, computer vision system; Fat PSPC, fat from the subprimal cuts; FOM, Fat-O-Meter; UFOM, UltraFOM; AUS, automated ultrasonic system; CHIMF, chemical analysis of intramuscular content.

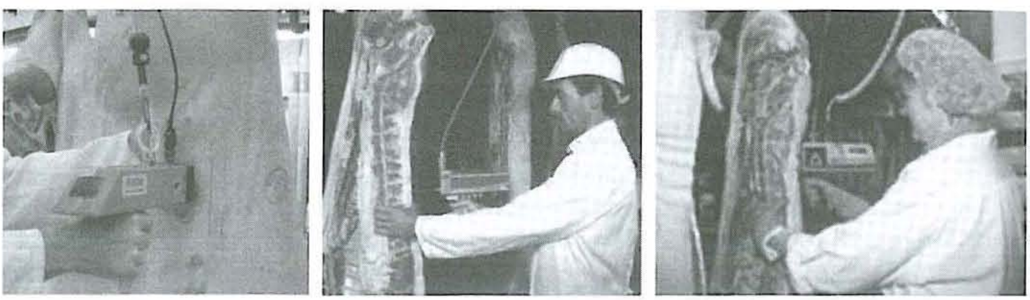

Figure 17.1 Different electronic probes: Hennessy Grading Probe (by Hennessy Grading System Ltd., with permission), CGM Probe (by Sydel, with permission), and Fat-O-Meter (by SFK Technologies, with permission).

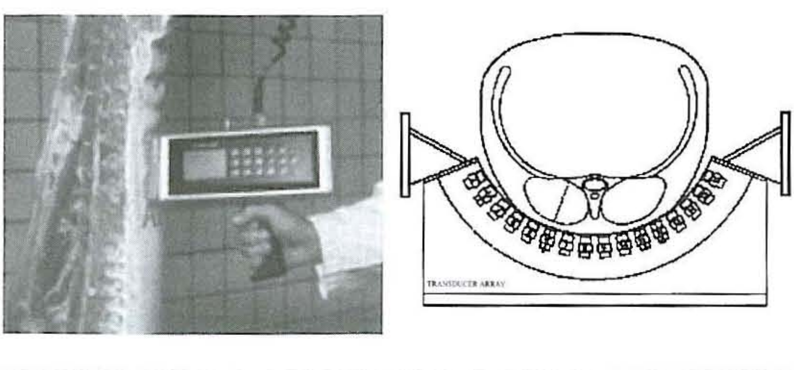

Figure 17.2 Ultrasound probes: UltraFOM 300 and the AutoFOM scheme by SFK Technologies, with permission.

optical probes (Fat-O-Meter [FOM]; SFK Technologies, Herlev, Denmark); the reflective spectroscopy probes, such as the Hennessy Probe (Hennessy Grading Systems Ltd., Auckland, NZ); the PG-100 electronic Pork Grader and the CGM version 01-A by Sydel; the AUS-Meat Sheep Probe (SASTEK, Hamilton, Queensland, Australia); the automated ultrasound scanning devices (AutoFOM; SFK Technologies); and bioelectrical impedance, total body electromagnetic conductivity (TOBEC), and ultrasonic scanning. Some of these have been tested at slaughter chains as noninvasive systems.

TOBEC (Meat Quality Inc., Springfield, IL) is a large and relatively expensive piece of equipment that requires a large space on the line where carcasses are scanned; it may require operators to detach and attach the gambrels when the animals enter and leave the equipment [34]. These considerations limit the potential of the system to assess basic composition as a rapid, automated, and inexpensive method.

17.3.3.1 Electronic Probes

Optical probes objectively measure fat and muscle depth and improve quality control and the grading of fresh meat because they are better than electrical probes [21]. They are mainly used to assess meat quality in swine carcasses for backfat and longissimus dorsi muscle measurements (see Table 17.1). A great variety of instruments have been used in various circumstances, as can be seen on Figures 17.1 and 17.2. Fiber-optic methodologies are useful for the evaluation of porcine fat quality [22] and for estimation of bovine fat quality [24] using the optical method (HRS-6500, Optoelectronics, Tokyo, Japan); this was the same system as used previously in the study of porcine fat.

Some probes, such as the UltraFOM and CSB Ultra-Meter, ultrasonically measure backfat and longissimus dorsi depth (eye muscle) in pig carcasses. The AutoFOM ultrasound (SFK Technology) (see Figure 17.2) is a completely automatic scanner system based on ultrasound technology, providing a sophisticated system of pig carcass classification with great accuracy in assessing lean meat distribution and the different fat depots throughout the carcass. In pig carcasses with a clear separation between fat and lean compared to other species, this machine is very efficient.

Some of these probes have been used for sheep carcass evaluation. Three commercial probes—the Hennessy Grading Probe, the AUS-Meat Sheep Probe, and the FTC Lamb Probe (FTC Sweden, Upplands Väsby, Sweden)—were used by Kirton et al. [35] for classifying lamb carcasses and to compare accuracies in predicting GR fat measurement and carcass composition. Small differences were found between probes overseas, where probes are in use for objectively grading the carcasses of meat animals [35]. Jones et al. [36] used the Hennessy lamb grading probe for online grading in Canada. The AUS-Meat Sheep Probe (SASTEK) was tested for its ability to test 9–10 carcasses per minute [37]. Another probe tested in sheep carcass evaluation [35] was the Ruakura GR Lamb Probe (Hamilton, New Zealand). Hopkins [38] tested the Hennessy Grading Probe for measuring fat depth in beef carcasses. The fat probes created and used for pork meat evaluation have been of little use for beef or for sheep. In fact, the irregularity of the fat layer in these species is very high in comparison to pigs, and Chadwick and Kempster [39] have applied different probing instruments in subcutaneous fat measurements taken on the intact carcass, using them to estimate beef carcass composition. These authors concluded that the best fat thickness measurements taken by probe can provide a prediction of carcass lean percentage as precise as visual fat scores given by experienced operators. Later on, new techniques were found to assess rapidly beef carcass quality or composition, including BIA, RTU, and, more recently, VIA.

According to Swatland [21], one problem in predicting meat yield from fatness is to find a simple yet reliable measure of carcass fatness. Most of the backfat or longissimus dorsi measurements are principally used in prediction equations to assess the quality of meat; recent studies have shown that there could be more potential if they were taken after carcass chilling. Fat depth is a simple linear measurement, while total carcass fat is a complex anatomical volume, and it would be surprising if the former were a perfect indicator of the latter [21]. Johnson et al. [40] have developed different equations for predicting fat-free lean in swine carcasses and have estimated the prediction bias due to genetic group, sex, and dietary lysine level. They concluded that research is needed to develop new procedures and additional variables that can be measured at normal line speeds of packing plants to decrease the bias in prediction. In this regard, Schinckel [41], in a critique of evaluation procedures to predict fat-free lean in swine carcasses, said that the magnitude of the biases must be compared with the actual genetic population, gender, or treatment differences. Furthermore, as Gu et al. [42] and Schinckel et al. [43] reported, if the equations are to be used in the future, it is important to know what percentage of the total variation among the genetic populations is expected to be predicted, and also whether the prediction equations developed over larger body weight ranges can have a greater magnitude of body weight range and interaction between live weight and sex or genetic population range biases.

17.3.3.2 Bioelectrical Impedance Analysis

BIA is a simple, objective, and inexpensive method of analyzing body composition and measuring body fluid volumes. Essentially, the method uses the resistance of electrical flow through the body to estimate body fat and measure lean content, depending on the different electrical properties of lean and fat tissues. In the beginning, BIA was not generally accepted as an accurate methodology to assess body composition. The technological improvements made at the end of 1980s and the beginning of the 1990s made BIA a more reliable and acceptable methodology to predict body composition (see Table 17.1).

The four-terminal plethysmograph (BIA; Model BIA-101, RJL Systems, Detroit, MI) introduces a constant alternating current that provides a deep homogeneous electrical field in the body. A constant alternating current of 800 μA at 50 kHz is introduced into the body via transmitter terminals and received by detector terminals [44]. The alternating current is transmitted from each of the two outer electrodes to its respective opposite inner detector electrode. The voltage drop is measured with a high-input impedance amplifier [45]. The electrodes (21-gauge needles) may be located in an anterior to posterior sequence along the full length of the animal's back with 10 cm separation between transmitter and detector electrodes at each end [16].

Swantek et al. [46] evaluated the bioelectrical impedance in swine to predict body and carcass composition using the four-terminal plethysmograph (BIA; Model BIA-101, RJL Systems) with results indicating the excellent potential of BIA as a rapid and nondestructive procedure for the prediction of fat-free mass in live pigs and chilled pork carcasses. Berg and Marchello [15] reported that initial findings indicate that BIA had excellent potential as a way of predicting lean body mass in commercial situations, given its precision, simplicity, and portability. Marchello and Slanger [47] researched the potential of BIA to predict muscle and fat-free weight of beef cows, concluding that the system could be used as a value-based marketing tool and had potential in the genetic selection of superior animals.

The adequacy of the method in evaluating body composition in abattoir conditions has been debated by several authors. Working with lambs, Berg and Marchello [15], using BIA, concluded that the system could be incorporated easily into existing industrial packing plants; if adapted for online usage, the system could be more rapid for the analysis of carcasses than probing for fat depth. The prediction equations, as well as other methodologies, use live weight and carcass weight as independent variables in the regression models to estimate fat-free mass or fat-free soft tissue, and although higher coefficients of determination are reported and lower residual mean square errors are much larger, their total sample variation was explained by live weight or carcass weight. Swatland [21] pointed out that some type of penetration electrode was required in online measurements of carcasses. According to this author, two parallel needle electrodes (two pairs of detector and transmitter electrodes) are inserted in such a way that, in a system for online use, it is important to find the electrode orientation that responds most readily to the subject of measurement and then to standardize it rigorously. Berg et al. [17,26] said that one of the advantages of BIA is that measurements can be made in live animals and on carcasses, but the invasiveness of the procedure, as well as its low precision, would not favorably compare with other relatively inexpensive *in vivo* methods such as ultrasound. The usefulness of BIA methodology was examined by Velazco et al. [19] in determining the soft tissue composition of Holstein steers; they concluded that more research was needed to determine the effects of electrode placing as well as the magnitude and type of the electric impulse. Studying whether bioelectrical impedance could predict fat content of ground beef and pork, Marchello et al. [48] verified that it provides a system whereby a company can use marketing strategies to provide consumers with the type of product they want to purchase.

17.3.3.3 Ultrasound

Like other technologies such as bioelectrical impedance, ultrasound was first developed for human medicine. The first application of ultrasound technology in animals was probably for medical reasons, before it was recognized for its potential to predict carcass composition in animals and used extensively in pig breeding schemes and research. Stouffer [49] reported pioneering work in measuring the backfat thickness on beef cattle with a somascope unit by Temple et al. [50] and in pigs using an A-mode ultrasonic metal flaw detection device by Dumont [51] and Claus [52]. In 1959 Stouffer [53] recognized the necessity of measuring muscle mass (rib eye depth or area) in addition to backfat thickness for improving accuracy in predicting body composition in a series of A-mode measurements with the Sperry Reflectoscope (Sperry Company, Danbury, CT) in beef cattle.

With constant advances in technology, a range of ultrasonic equipment, from simple machines to more complex ones, have been developed and tested by researchers after being commercialized by the industry. Essentially, an ultrasonic machine consists of a pulse generator, a transducer probe, receiving circuits, and a display [54]. The transducer converts electrical pulses from ultrasound pulses that are traveling through the body with a velocity characteristic of the tissues they pass through, and sends a reflected pulse to the transducer when an interface between two different tissues (fat and muscle) is reached. The transducer reconverts this reflected pulse into an electrical pulse. The reflected waves picked up by the probe are relayed to the machine, which display the distances and the intensities of the echoes on the screen, forming a two-dimensional image. Generally two types of ultrasound equipments are used:

1. A-mode machines, which measure the amplitude of echo in function of time. These are now obsolete in medical imaging.
2. B-mode or real-time machines, which measure echo intensity in a two-dimensional scan, showing all the tissues screened by the ultrasound beam. Some machines have incorporated another imaging mode, the M-mode, which is another method to visualize the movement,

in which the result is a line with an abdominal standard sound with a high sampling frequency useful in cardiac and fetal imaging.

In fact, RTU is a version of B-mode, creating images which are seen instantaneously and changing as the position of the transducer changes. Several electronic companies have produced different scanners for human medicine that can be adapted and used for scanning farm livestock, machines that are cost-effective, reasonably robust, have great versatility, portability, are capable of automatic calibration, wide probe ranging, and provided with functions of measurement and calculation. Modern machines are equipped with some practical functions such as the split screen (allowing the observation of two images simultaneously or, for example, the observation of the longissimus muscle in beef cattle, which is greater than the width of the transducer), freeze frame (the possibility of freezing one image for a detailed study later), and a disk storage device. Most studies have been using another computer with an interpreting and analyzing image system, although modern machines have this facility built in.

RTU can be used in live animal evaluation because it uses a noninvasive technology, and carcass quality and composition can be assessed without damage to the carcass and the corresponding reduction in its market value.

To operate ultrasound equipment there are some factors that should be taken into account, including:

1. Animal conditioning is one of the most important factors in obtaining a good-quality ultrasound image. If the objective is to scan a live animal, it is essential to provide a system to keep the animal relaxed and not to modify the normal anatomical structure of the animal tissues. The animal surface must be completely clean of dirt or foreign material as well as air bubbles to avoid interference with the acoustics of the sound waves.
2. The operators should have a good knowledge of the anatomical points where the transducer will be placed. Live animal or carcass evaluations involve several fat thickness measurements in different parts of the body (the lumbar, rump, or brisket regions) and muscle area determinations in distinct anatomical points, and the accuracy and repeatability of these measurements depend upon a thorough knowledge of animal morphology and anatomy on the part of the operators. The placement of the transducer is an important factor to be taken into account, and operators should be able to find the rib and the corresponding vertebrae to place the transducer parallel to the ribs and close to the backbone, rump, or parallel to the brisket in each point they want to measure fat thickness, the area of the longissimus dorsi muscle (rib eye area), or to assess intramuscular fat deposition.
3. The transducer is one of the most important components of the ultrasound equipment. Modern transducers using piezoelectric material convert electrical energy to ultrasound. Then they transmit ultrasound and receive the reflected waves. Depending on the species (cattle, swine, sheep, or goats) the market offers a wide range of sizes and frequencies. A 7.5 MHz device has a short wavelength, low tissue penetration, and high resolution; it is used mainly to measure slight body tissues such as the subcutaneous fat thickness in sheep and goats. Otherwise, a 3.5 MHz transducer has a long wave with deep penetration and is normally used for live beef cattle carcass imaging and to collect images for estimation of carcass composition.
4. A couplant agent should be applied between the transducer and the tissue or body surface to be scanned to provide an efficient medium of transmission of sound waves and obtain a good quality image. Many couplant agents can be used, including a simple water bag, vegetable oil, paraffin oil, or a specific ultrasonic gel. The couplant should be at the same temperature as the external body temperature of the animal.

5. The velocity or speed of ultrasound waves increases with tissue density. The denser tissues such as bone reflect more of the sound waves than soft tissues such as fat and muscle. Most RTU machines are calibrated for average velocity in soft tissues or water.
6. Overall gain adjusts for the brightness of the image. Machines have two gain settings, proche/near and distal/far, and are normally automatic. Nevertheless, if the objective is to assess marbling in beef or intramuscular fat, gain settings should be standardized.

Basically, ultrasounds are used to assess carcass composition and quality, assessing the following factors:

1. Backfat determination on subcutaneous fat thickness
2. Loin eye muscle area or longissimus dorsi area
3. Percentage of lean
4. Percentage of carcass fat
5. Intramuscular fat estimation or muscle quality (marbling)

Real-time scanning has been one of the most frequently used technologies in recent years, as is shown in Table 17.1. Developed for use in human medicine to enable the possibility of rapid observations of internal physiological movements of organs, tissues, or fluids, such as the growth of a fetus inside a uterus, blood flow, or the beating of the heart, it was used for the first time to scan livestock by Horst [55], according to Kempster et al. [54], despite the fact that Stouffer et al. in 1961 [56] had shown the superior performance of the mechanical B-scan over A-mode technology for measuring fat thickness and the rib eye area in cattle and hogs.

Over the history of the application of ultrasonic technology to livestock, it has become evident that it has not always been either useful or applicable to assessing body or carcass composition. In the beginning some difficulties were found, related to the performance of the machines, particular circumstances of experiments, the scanning technique used, and the experience of the operator, but mainly with the animal species being studied. The effectiveness of ultrasound was not the same for all animal species. Houghton and Turlington [57] have published a review article about the application of ultrasound for feeding and finishing animals; they indicate that ultrasound is of potential use in educational and research efforts for swine, sheep, and beef cattle.

The results obtained in sheep have not been as successful as with other species as swine and beef. Particularly in goats, we had to wait until 1995 to see the first papers published with reference to the use of ultrasound to predict carcass composition [58–62]. Most of the accuracy of the use of ultrasonics in live animals depends on the relationship between small sections of the animal body and overall carcass composition.

In summary, advances in technology have meant that RTU is now the most common method used in livestock.

17.3.3.3.1 RTU in Swine

Houghton and Turlington [57] have suggested that ultrasound is useful in swine under field conditions. Producers, abattoirs, and retailers have been interested for many years in the ability to produce carcasses with a composition and quality consistent with consumer interests. Studying the commercial adaptability of ultrasonography to predict pork carcass composition from live animal and carcass measurements, Gresham et al. [63] have calculated regression equations for predicting carcass composition from ultrasonic carcass measurements and also from live animal ultrasonic measurements. The authors concluded that ultrasonography can have a place in a value-based marketing system, and the results have shown the potential of the methodology to estimate composition of both the live animal and the carcass. Using a single longitudinal ultrasonic scan, Gresham et al. [64] confirmed the accuracy (see Table 17.1) of the technique to be automated in providing information to predict carcass composition on live pigs as well as in the carcass. Ultrasound measurements on live pigs are taken anywhere from the first rib to the last lumbar vertebrae, with carcass measurements at the 10th or last rib being the most often used [64–66]. But Johnson et al. [40], in a recent study of predicting fat-free lean in pork carcasses, verified that the use of ultrasound and optical probe instruments to measure fat and muscle depth off the midline were more reliable than a single measurement of fat depth at the last rib.

17.3.3.3.2 Use of RTU in Cattle

During the last 20 years, a considerable amount of research and practical work with RTU has been made in cattle to assess composition and quality of live animals and carcasses. As in other species, the technology has used an offline computer image interpreting system for determining composition [67,68] and muscle quality [31,69]. Whittaker et al. [69] have also found that ultrasound was a promising technology for the development of an automated, quantitative grading system for beef animals. The effectiveness of ultrasound for measuring fat thickness, and the fact that this measurement can be combined with other live measurements to estimate percentage of fat, weight of carcass fat and lean, and percentage of carcass bone in beef finishing programs, was pointed out by Houghton and Turlington [57]. During the past 10 years, RTU has been used in beef cattle research and industry, in the evaluation of fat thickness and rib eye area, to predict intramuscular fat percentage in live animals, to predict carcass retail products, or to predict tenderness in carcasses [70–76]. Herring et al. [77] compared different RTU systems for predicting intramuscular fat in beef cattle; the most precise were the CPEC (Oakley, Kansas, developed by Kansas State University) and the CVIS (Critical Vision, Inc., Atlanta, GA). The potential for the use of ultrasound as a predictor of carcass quality or composition, and the application of ultrasound in high-speed slaughter operations, depends on the automated ultrasonic measuring equipment, as was concluded by Griffin et al. [27] in their study with beef cattle. The RTU offers the ability to assess accurately subcutaneous fat, which is the prime contributor to variations in lean composition of animals of similar weights [78]. Therefore, Tait et al. [79] have found that the inclusion of a linear measurement, gluteus medius muscle depth, could help the prediction of retail product with the aim of looking at the prediction of lean in the carcass using live ultrasound measurements. One of the most important factors affecting meat quality is related to the quantity of intramuscular fat. Two types of RTU equipment were evaluated to predict the percentage of intramuscular fat in live cattle [80]; the authors have verified that the technology tested did not differ in the accuracy of the prediction, which was accurately done. Discussion around the accuracy of predicting carcass composition using ultrasound and live animal measurements was conducted by Greiner et al. [81], who found that ultrasonic measurement of rump fat and body wall thickness are easy to obtain on the live animal, increasing the capability of the other traditional ultrasound measurements, such as the fat thickness on 12th rib or longissimus muscle area. In the same vein, Bergen et al. [82] have concluded that equations based on those live measurements provide more accuracy to predict the lean meat yield of young beef bulls. Ribeiro et al. [83] concluded from the results obtained in their experiment that RTU is an accurate tool to measure body composition in beef feedlot heifers, as did Wall et al. [84] in their study using ultrasound in the feedlot to predict body composition changes in steers at extended periods before slaughter. Knowledge of intramuscular fat is one of the most important factors related to meat quality, because it is the best indicator of marbling. Aass et al. [85]

conducted a study of the accuracy and precision of intramuscular fat prediction by ultrasound in live cattle with low fat levels; the results were promising and strongly indicate the potential of the technology for this purpose.

In conclusion, and as a result of rapid advances in the last two decades, ultrasonic technology has become more and more important in all sectors of the beef industry:

- As a noninvasive method for live estimating of fat and muscle deposition and body composition
- To evaluate and estimate carcass quality and composition
- To predict breeding values for carcass traits
- To collect data on live animals through progeny testing
- As a tool to evaluate growth and predict the optimal time for slaughter

According to Williams [86], the most common and accurate measurements include

- Backfat thickness: subcutaneous fat thickness between 12th and 13th rib over the longissimus muscle
- Longissimus muscle area: a cross-sectional area of longissimus muscle at a point between the 12th and 13th rib
- Intramuscular fat: percentage of intramuscular fat measured in the longitudinal image of the longissimus muscle over the 11th, 12th, and 13th rib, providing an estimation of the degree of marbling

Greiner et al. [87] have suggested the following measurements:

- Rump fat thickness: rump fat thickness taken parallel to the vertebral column in the junction of the biceps femoris and gluteus medius between the ischium and ilium
- Gluteus medius muscle depth: measurement taken from the same image of rump fat thickness
- Body wall thickness: fat thickness between the 12th and 13th ribs 4 cm ventral to the longissimus muscle, perpendicular to the external body surface

17.3.3.3.3 Use of RTU in Sheep and Goats

In the beginning, the use of ultrasound in sheep was not as successful as in other species. The early studies for predicting body or carcass composition [88–91] were not promising. The small amount of subcutaneous fat, the great mobility of the skin, the lack of sufficient variation in the fat thickness, and the presence of wool were the main limitations to the use of ultrasound technology. Initially, the measurements taken, as in other species, were of the fat thickness over the m. longissimus between the 12th and 13th ribs, and longissimus muscle depth and area at the same point. The prediction models included the live or carcass weight as independent variables in multiple regression equations and, although reflecting acceptable accuracy, they indicated the necessity of finding and investigating other areas of the animal. In spite of this, subcutaneous fat thickness measured between the 3rd and 4th lumbar vertebrae was used as a predictor of carcass composition in a study of the lamb and mutton carcass grading system in South Africa by Bruwer et al. [92]. In the same vein, Stanford et al. [62] found a good predictor of saleable meat yield using an ultrasound measurement of subcutaneous depth taken at the first lumbar vertebrae. Also, Young et al. [93], studying the factors affecting the repeatability of measuring tissue depth by real-time ultrasound, concluded that the measurements could be accurately assessed from one ultrasound measurement. Previous studies in some Mediterranean sheep breeds [29,94–100] have shown the usefulness of ultrasound measurements taken between the 3rd and 4th lumbar vertebrae to predict carcass composition and suggested that ultrasound fat thickness measurements with live weight could be good predictors of carcass and body composition.

In the several studies, measurements were taken in a position perpendicular to the dorsal medium line between 12th and 13th ribs and in the 1st or between the 3rd and 4th lumbar vertebrae at the level of the largest depth of the muscle or at 3/4 position of the carcass midline. Frequencies of 5 and 7.5 MHz were the probes commonly used.

One of the principal factors influencing the accuracy of the different predictions obtained was the different ultrasonic measurement procedures related to the wool. Undoubtedly, to obtain better images, it is necessary to shear and clip the animals' wool, as per the procedure proposed by Silva et al. [100]. Nevertheless, Teixeira et al. [29], working with unshaven animals and using portable RTU equipment, obtained, *in vivo*, good predictions of fat thickness of the carcass, reporting that it is possible to do the work at the abattoir as well as under field conditions (Figure 17.3). The procedure of shearing the wool, clipping, or shaving the skin is incompatible with evaluation in a commercial slaughterhouse.

In goats, the first studies of the use of real-time ultrasound to predict carcass or body composition were published in 1995 by Delfa et al. [58] and Stanford et al. [62]. In addition to the normal anatomical points for taking the subcutaneous fat measurements (between the 12th and 13th ribs or lumbar vertebras) [101,102], the sternum region has been suggested as the most useful part of the body to assess subcutaneous fat in goats. Indeed, goats have a lower fat deposition on the back in contrast to the breastbone, where the amount of subcutaneous fat is considerably deeper and variable [7]. Furthermore, the breast of goats is practically hairless and perfectly suitable for placing the probe, allowing complete contact with the body surface, so that a fat measurement can be taken rapidly and efficiently.

Measurements taken between the 3rd and the 4th sternebrae were the most suitable for assessing fat thickness [59,60]. To predict muscle weight, Delfa et al. [58,61] suggested the longissimus muscle depth measurement be taken between 3rd and 4th lumbar vertebrae in multiple regression with live weight. Nevertheless, for young animals with less fat deposition, the muscle depth assessed in the sternum region is a better predictor than the other muscle measurements [102]. Globally, authors consider that RTU fat thickness measurements taken in the breastbone could be useful in the prediction of carcass and body composition of goats, improving the accuracy of estimates with live or carcass weight as independent variables in multiple regression equations.

17.3.3.4 Video Image Analysis

The use of VIA to predict carcass composition has recently been researched. Recent advances in computer science and video processing have generated new ways to analyze and monitor quality in the meat industry. In the beginning, VIA was a system described as capable of objectively assessing carcass conformation and evaluating beef quality, particularly to determine marbling and the color of meat.

Essentially, VIA involves taking an image of the whole carcass with a video camera and then analyzing the image for dimensional measurements related to carcass quality or composition. The images are transmitted to a computer to be digitized, and fat and muscle measurements are taken electronically.

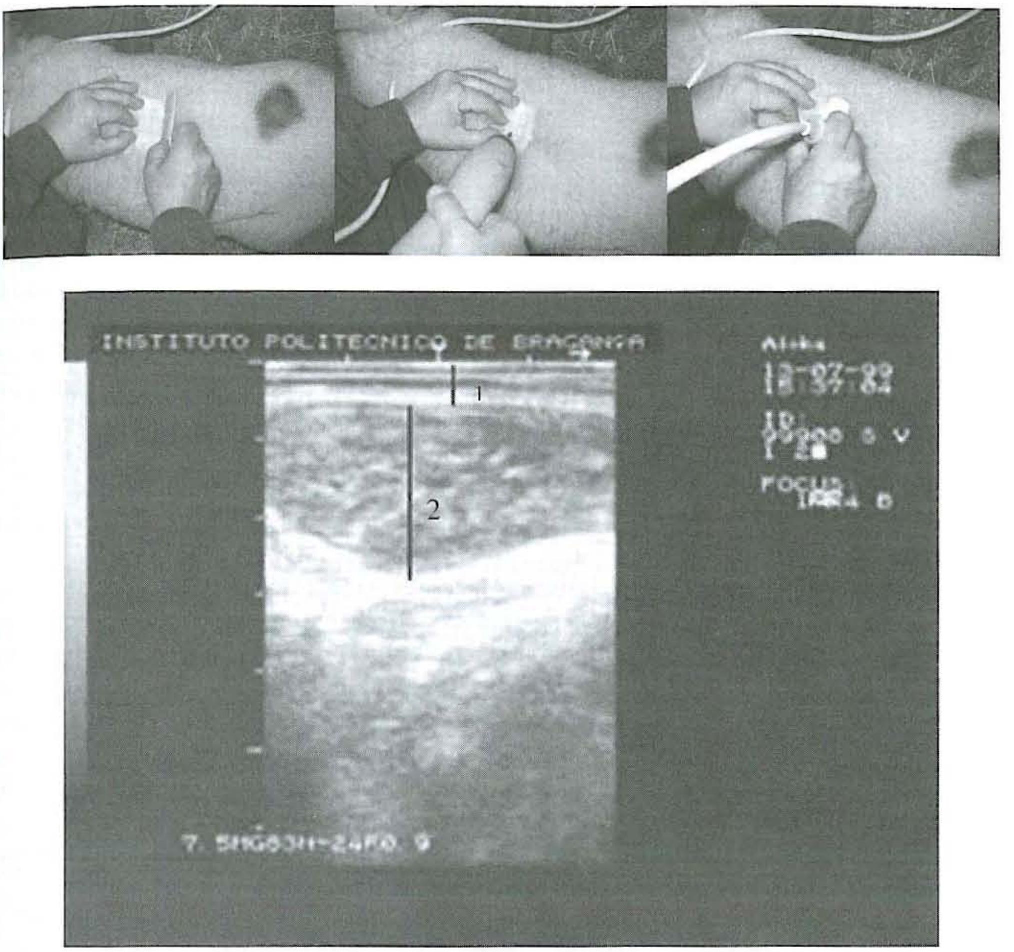

Figure 17.3 Example of sheep RTU measurements of fat thickness (1) and longissimus dorsi depth (2) between 12th and 13th rib with 7.5 MHz probe with an ALOKA SSD-500V scanner. (Adapted from Teixeira, A., Matos, S., Rodrigues, S., Delfa, R., and Cadavez, V., *Meat. Sci.* 74, 289, 2006.)

Images taken in the slaughter line at an abattoir could also be used for a carcass grading system classification. An experiment conducted by Gerrard et al. [103] has reported that image analysis could be used to quantify the marbling and determine the color of the beef longissimus muscle. Basset et al. [104] have used photographic image analyses for the classification of bovine meat according to such factors as muscle type, age, and breed. A study by Shackelford et al. [105] to determine whether image analysis of the 12th rib cross-section, used for tenderness classification of beef, could accurately evaluate carcass cutability, longissimus area, and subprimal cut weights; they concluded that the technology could be used in the beef industry. Later, the same authors [106] evaluated under commercial beef processing conditions, with some success, the ability of the U.S. Meat Animal Research Center's beef carcass image analysis system to predict calculated yield grade, longissimus muscle area, preliminary yield grade, and adjusted preliminary yield grade, but with low expectation of accuracy in the prediction of marbling score.

The VIAscan® was an objective grading tool utilizing the VIA technology to rapidly and accurately assess lamb and beef carcass characteristics. VIAscan was developed by Systems Intellect Pty. Ltd. and VQA Australasia as part of the Australian Meat Research Corporation's Objective Carcase Measurement Program [107,108]. The system analyzed a video image of a whole carcass and of a cross-section at the ribbing point to calculate fat content and meat color, from which yield and quality were predicted. The system has been developed to assess carcass quality attributes as well as saleable meat yield, based on analysis by computer video images. To evaluate beef carcasses there are two versions: a video camera (chiller assessment system [CAS]) to collect images of the rib area of the carcass such as rib eye area, fat thickness, marbling, and fat or muscle color; and another video camera (hot assessment system [HAS]) to take images online at slaughter of the surface fatness of the carcass, carcass measurements, and color of fat and muscle [109]. Hopkins [110] used the VIAscan system to predict lamb carcass muscularity and confirmed that the system had potential for online classification of lamb carcasses and could be used to predict the proportion of leg and shoulder primal cuts [111]. Later, Hopkins et al. [112], working at an Australian commercial abattoir, demonstrated that the system offers potential for predicting meat yield, using computing facilities allowing predictions in real time and a link to carcass ticketing technology.

At Colorado State University and Hunter Associates Laboratory (Reston, VA), they have developed a prototype video imaging system (prototype BeefCam) as a noninvasive technology to analyze beef carcasses. Wyle et al. [113] published the results of a study conducted to determine the effectiveness of this equipment in classifying beef carcasses by palatability and concluded that further development of a commercial BeefCam system was warranted. Research Management Systems USA (RMS Inc., Fort Collins, CO) has incorporated into the system a Computer Vision System (CVS); Cannell et al. [114,115] have tested its usefulness in predicting the composition of beef carcasses under commercial conditions, using the Dual-Component CVS, which consists of one video camera (Hot camera) to obtain images of the outside surface and for computer analysis of carcass shape, dimensions, and fat distribution; and a second video camera (Cold camera) that records images of the exposed 12th–13th rib interface, allowing computer analysis of different fat thickness measurements and rib eye area. The two video image analyses together correspond to CVS Dual-Component VIA System developed by RMS Inc. As a predictor of beef carcass meat yield and for an "augmentation application" of USDA yield grades, the cited authors [114], tested the VIAscan in its two versions (Dual-Component VIA System). With the same objectives, Cannell et al. [115] tested the system of image analysis in the CVS, studying the ability of the equipment to predict beef carcass red meat yields, and the "augmentation application" of USDA yield grades to beef carcasses, not only at chain speeds, but also as a fully online, installed commercial system in a commercial packing plant. The authors found in both studies that the two systems (VIAscan and CVS) allowed a more accurate prediction of yields than those achieved by online whole number yield grades alone. In commercial packing plants, Vote et al. [116] have evaluated online the effectiveness of the CVS BeefCam in predicting the tenderness of beef steaks, verifying that the system was useful. In subsequent studies [117,118], Steiner and collaborators used the two systems (VIAscan and CVS) to ascertain whether the accuracy of USDA yield grade at chain speeds could be improved, reporting that the VIA systems could operate with accuracy and could be used to assess longissimus muscle area with high levels of accuracy and repeatability.

The VIA has not been used to predict pork carcass composition as other methodologies discussed before. To predict pork carcass cutability, McClure et al. [119] have tested the video image system VCS2001 (E+V, Oranienburg, Germany). Authors found that the VCS2001 is similar to Fat-O-Meter in predicting the weight of total saleable meat but did not provide an estimate of percentage of carcass lean as the Fat-O-Meter did; further development is needed to make the VCS2001 a viable commercial tool.

Colorado State University and Mountain States Lamb Cooperative developed the lamb carcass scanning hardware and software for a Lamb Vision System (LVS; RMS Inc.); Brady et al. [120] investigated whether the LVS could be used for accurate prediction of lamb carcass cutability, and subsequently carcass value, in a commercial setting. The authors found that the online LVS combined with hot carcass weight could be used to accurately sort carcasses into cutability classes—and do better in the prediction of saleable meat yield than expert USDA graders. In another study, also by Brady et al. [121], to determine if the LVS saleable meat yield prediction could be used to predict carcass value with accuracy and precision, they concluded that LVS provides lamb producers and packers with several opportunities to objectively assess lamb carcass value. Later, Cunha et al. [122] validated the regression equations developed by Brady et al. [120] to predict lamb carcass fabrication yields and identified possible improvements to the accuracy of the equations using the two components of LVS: the hot carcass (LVS-HCC) and the chilled imaging system (LVS-CCC). The authors referred to also assessed the repeatability of longissimus muscle area using the LVS system. The results suggested that the LVS system could be a valuable tool for assisting in a value-based pricing system for sheep in the United States.

The carcass assessment unit of the LVS consists of a stationary camera with a lighting processor, a computer processor, and a monitor housed in a stainless steel cabinet. LVS software operates by (1) recording an image of a background, (2) recording an image of the carcass, and (3) subtracting the carcass image from the background image to provide a defined image of the carcass [120]. The software recognizes all anatomical points that are needed to make carcass measurements, and online images are obtained with a speed of approximately 450 carcasses/h [122]. Carcass measurements were used to describe shape and size of the carcass as well as muscularity and fat or lean proportions and are used as independent variables in different regression models.

The different studies on the use of VIA suggest that it is a valuable and accurate tool to assess carcass quality, and further development and improvement of hardware and software used in taking and interpreting the images are needed.

17.4 General Conclusion

All methodologies for assessing carcass quality or composition have strong and weak points, and, depending on the species concerned and different work conditions, the selection of the appropriate one should be made with reference to the following factors: (1) accuracy of the method in making different predictions; (2) precision of prediction models; (3) appropriateness to working conditions such as working in the field, in the abattoir, on slaughter or cutting lines, or in an industrial plant; (4) rapidity of the methodology and speed of measurement; (5) cost of the equipment; (6) ease and ability to operate with good repeatability; (7) possibility of standardization; and (8) robustness and portability of the equipment.

TOBEC, ultrasound, and VIA would seem to be the most suitable technologies for commercial classification. VIA is a recent technology that has been seen as the most promising by many scientists and meat industry policy makers.

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