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Real-time ultrasound (RTU) imaging methods for quality control of meats

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Abstract: In this chapter the use of real-time ultrasonography to predict *in vivo* carcass composition and meat traits will be reviewed. The chapter begins by discussing background and principles of ultrasound. Then aspects affecting the suitability of real-time ultrasonography and image analysis for predicting carcass composition and meat traits of meat producing species and fish will be presented. This chapter also provides an overview of the present and future trends in the application of real-time ultrasonography in the meat industry.

Key words: meat quality, ultrasound, carcass, image analysis.

11.1 Introduction

Carcass composition and meat traits are important aspects of animal science relating to food production. This knowledge is fundamental to the study of genetics, nutrition, physiology, to marketing based on carcass value, as well as for monitoring body fat reserves. Dissection and chemical analysis have traditionally been used as the standard methods for determining carcass composition. However, these procedures are expensive, laborious and destructive (i.e., an animal or carcass can be used only once). Non-destructive techniques are often required to test valuable animals or when sequential study of the animals is necessary or desirable (Fuller *et al*., 1990). The search for non-destructive methods of estimating carcass composition or meat traits has led to the evaluation of numerous techniques such as real-time ultrasound (RTU), computer tomography (CT), magnetic resonance imaging (MRI), dual-energy X-ray absorptiometry (DXA), whole-body ^{40}K counting, total body electrical conductivity (TOBEC), dilution techniques, bioelectrical impedance and neutron activation analysis. These techniques have been reviewed by several researchers, including Allen (1990), Fuller *et al*. (1994), Stanford *et al*. (1998), Szabo *et al*. (1999), De Campeneere *et al*. (2000), Mitchell and Scholz (2005) and Teixeira (2009). Of the techniques mentioned above, only those based on RTU will be outlined in this chapter. Techniques based on ultrasound have had great success in the fields of medical and animal science, as they are non-invasive, non-destructive and do not cause pain to the animal. For over 50 years, ultrasound techniques have been used to predict carcass composition and meat traits *in vivo*. Since its initial use, and especially in the last two decades, RTU has been demonstrated to be a valuable tool for the estimation of carcass composition and meat traits in living animals. The recent interest in the technique is almost certainly a result of the application of technology originally developed for computers, whereby a digital image formation process provides good quality black and white images. Furthermore, modern equipment is robust, easy to use and portable, and offers accurate imaging with great repeatability at relatively low cost, while also being well accepted by the public (Allen, 1990; Stanford *et al*., 1998). This chapter presents an overview of the use of RTU in predicting carcass composition and meat traits in meat-producing species and fish.

11.2 Historical background on ultrasound use for carcass composition and meat traits evaluation

The roots of the use of ultrasound techniques for animal science purposes can be identified in several discoveries throughout history and are closely connected to the same developments in the medical field. The discovery of the piezoelectric properties of certain crystals in 1880 by the Curie brothers is one major milestone in the development of ultrasound (Woo, 2006) (Table 11.1). Since then, the applications of ultrasound have expanded rapidly in the fields of navigation, medicine (Thwaites, 1984; Szabo, 2004) and non-destructive testing in industry (Bray and McBride, 1992; Chen, 2007).

Mankind has always had a fascination with the idea that it might be possible to look inside objects and, with sonar and radar as models, it was established that pulse-echo techniques had the potential to be used for medical purposes (Szabo, 2004). After five years of work on ultrasound principles and equipment development, the first diagnostic ultrasound study was published (Dussik, 1942). Some years later, Wild (1950) presented the first use of ultrasonic pulses for the measurement of biological tissues and the detection of tissue density with ultrasound equipment. This equipment contained a transducer that sent a sequence of repetitive ultrasonic pulses into a material or a body (Wells, 1991; Whittaker *et al*., 1992). Echoes from different target objects and boundaries were received and amplified so that they could be displayed on an oscilloscope as an amplitude-versus-time record (Thwaites, 1984; Wells, 1991; Whittaker *et al*., 1992). This

Table 11.1 Milestones for ultrasound development and application in animal science

Discovery or application	Year	Author	Description	Reference
Eco-localization	1790	Lazzaro Spallanzani	In 1790 Lazzaro Spallanzani experimented with bats and found that they manoeuvred through the air using their hearing rather than sight	Kane *et al*. (2004)
Piezoelectric proprieties	1881	Pierre Curie	In 1881 Pierre Curie found a connection between electrical voltage and pressure on crystalline material. This was the breakthrough that was needed to create the modern ultrasound transducer	Turner *et al*. (1994)
Using ultrasound in submarine warfare	1916		The first recorded detection and subsequent sinking of a German U-boat (UC-3) using a hydrophone	Kane *et al*. (2004)
First report of ultrasound use for medical purposes	1942	Karl Dussik	Karl and Friederich Dussik used the first medical application of ultrasound when they localized brain tumours by measuring the sound transmission through the skull and brain	Weinstein *et al*. (2006)
Ultrasound propagation speed in body tissues	1950	Ludwig	Ludwig (1950) made a number of time-of-flight measurements of sound speed through arm, leg, and thigh muscles. He found the average to be 1540 ms^{-1}, which is the standard value still used today	Ludwig (1950)
First article showing the utility of ultrasounds for soft tissues	1950	Wild	The first scientific proof of sonic energy reflection from within soft tissue histological elements, using 'A' mode readout	Wild (1950)
First B-mode	1952	Wild and Reid	The B-mode scanner became one of the first to differentiate between abnormal tissue	Wild and Reid (1952)
First animal evaluation publication using ultrasounds	1956	Temple *et al*.	First ultrasound animal evaluation publication in the United States	Temple *et al*. (1956)

(*Continued*)

Table 11.1 Continued

Discovery or application	Year	Author	Description	Reference
First B-mode study with animals	1959	Stouffer	Cross-sectional image of beef rib eye produced by an early mechanical B-scan system improved by mounting the transducer on a carriage that moved along a fixed, shaped, curved guide	Stouffer *et al*. (1959)
A reference study	1961	Stouffer	Study with hogs, cattle and sheep showing the superior performance of mechanical B-scan over the A-mode	Stouffer *et al*. (1961)
First real time	1965		Appearance of Vidoson from Siemens, the first real-time mechanical commercial scanner	Szabo (2004)
Scanogram	1969	Stouffer	Scanogram, commercial mechanical B-scanner, second generation, produced by Ithaco Inc, 1969	Stouffer (2004)
First RTU application for carcass traits evaluation	1976	Hans Busk	Use of the RTU Danscanner in breeding programmes for pigs, cattle and sheep	Busk (1984)
First 3-D	1987		First 3-D ultrasound	Szabo (2004)

type of display became known as the A-mode, with A standing for amplitude (Szabo, 2004). The distances between successive peaks represent the thickness of the different tissues. In animal science, the horizontal axis of the oscilloscope is calibrated in millimetres, allowing for a direct reading.

After the first medical applications, this ultrasound technique was immediately recognized as a potential tool for animal science, as shown by the work published in the late 1950s on animal carcass evaluation (Stouffer, 2004). These publications reported research results showing the feasibility of using ultrasound to evaluate carcass composition in live cattle (Temple *et al*., 1956), swine (Claus, 1957; Dumont, 1957; Hazel and Kline, 1959) and sheep (Campbell *et al*., 1959).

Despite the encouraging findings, the accuracy of the early A-mode, a single-transducer device, was often quite variable (Stouffer, 2004). Moreover, the A-mode display has limited use, because it lacks anatomical information, meaning that it is difficult to identify the anatomical sources of the echoes (Ophir and Maklad, 1979), and that it is impossible to trace area measurements from images of organs or tissues (Thwaites, 1984). To overcome these limitations, the B-mode presentation ('B' meaning brightness) was introduced. B-mode is an image display created by integrating multiple A-mode signals (Amin, 1995). In B-mode, the brightness of the dots is proportional to the amplitude of the echoes. The display consists of time traces running vertically (top to bottom) to indicate depth.

By the early 1960s a pioneering technique in the use of ultrasound for animal science purposes was introduced: a continuous mechanical scanning procedure (Stouffer *et al*., 1961). An electric motor was mounted on a thick rubber belt that was placed on the animal's back. The motor moved a transducer horizontally as it was held vertically by an operator, and was synchronized to keep the lens open for the duration of the 10 s scan in order to capture the image. The image on Polaroid film was developed in about 1 min, and the image data was then evaluated and measured. In the same period, the first commercialized contact B-mode mechanical scanners became available for medical purposes (Szabo, 2004). At the end of the 1960s, a commercial unit of the primary system was introduced for live animal evaluation, using similar technology (Stouffer, 2004). This equipment – the Scanogram – produced in 1969 by Ithaco Inc. (Ithaca, NY), was in use until the mid-1980s for the majority of *in vivo* carcass evaluation studies using ultrasound (Miles *et al*., 1972; Shelton *et al*., 1977; Kempster *et al*., 1982; Andersen *et al*., 1983; Simm *et al*., 1983). However, one of the major limitations of B-mode mechanical scanners for animal applications was the movement of the animal, which, being random, was the cause of inaccuracy of images and low repeatability of measurements (Hedrick *et al*., 1962; Gooden *et al*., 1980; Stouffer, 2004).

The launch of RTU systems with good image quality marked the end of the mechanical B-scanners, which had completely disappeared by the late 1980s (Klein, 1981; Szabo, 2004). RTU systems are based on the B-mode technique, and use multiple-crystal transducers to display an image on the screen that is constantly updated. The entire image frame must be displayed in 33 ms or less in order to be able to update the information at real-time frame rates (Insana, 2006).

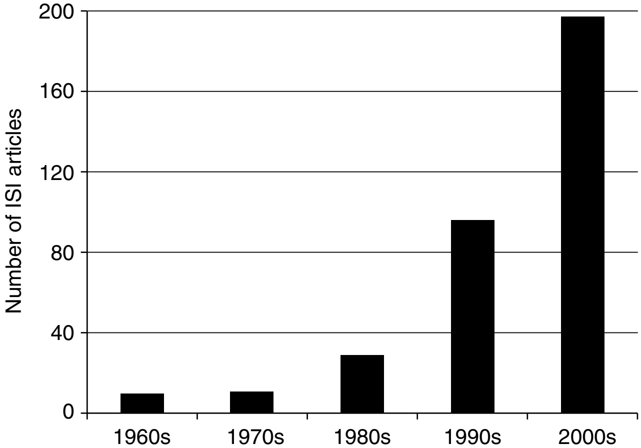

Fig. 11.1 Number of articles in main animal science journals (ISI indexed) using ultrasound to evaluate carcass traits.

RTU reduces the time required to produce and record an image, which greatly enhances the use of this technique in live animal evaluation.

Since the first attempts to image carcass traits using the RTU technique in the late 1970s (Kempster *et al.*, 1979) and early 1980s (Kempster *et al.*, 1982), significant advances in hardware and software have allowed the initial obstacles – animal movement and long acquisition times – to be overcome. In recent years, RTU has become a crucial tool in many routine carcass evaluations for animal production, and offers the advantage of providing data not only on carcass traits but also on a multitude of meat and fat deposits, which are similar to or even superior to those provided by more expensive imaging tools. The features of the ultrasound equipment, combined with the possibility of differentiating tissues and organs in the image, form the basis of the huge success that this technique has achieved in medicine and in animal science.

There has been a radical increase in the use of RTU imaging in animal science in the last 20 years, due to significant technological improvements and the availability of more accurate and less costly equipment. During this period, RTU has been widely used in the prediction of carcass traits, as shown by the numerous works found in the major animal science journals (Fig. 11.1).

11.3 Basic ultrasound imaging principles

Ultrasound is sound waves that have a frequency beyond the range of human hearing (above 20 kHz). These acoustic waves propagate through body tissues via compression and expansion of the tissues, and during propagation small particles of the material move back and forth in order to generate the compressions and expansions of the acoustic wave (Mannion, 2006). In soft tissues (biological tissue), these particles move back and forth in the same direction that the acoustic wave is travelling (Prince and Links, 2006). The particles themselves merely oscillate or are displaced locally; it is the wave that travels from source to detector, not the particles (Leighton, 2007). The ultrasonic waves have different propagation properties and can be characterized by the following formula

$$v = f\lambda \qquad [11.1]$$

where λ is the wavelength, f is frequency and v is velocity. The acoustic impedance Z is a fundamental property of the tissue and is related to the density ρ and the velocity

$$Z = \rho v \qquad [11.2]$$

The fraction of energy reflected, R, at the normal interface of two different tissue types is

$$R = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1} \right)^2 \qquad [11.3]$$

where Z_1 and Z_2 are the impedance of the tissues in the interface (Seidband, 1998). The acoustic signals decrease as a result of attenuation by the medium, and the signal intensity I is given by

$$I = \frac{Ioe^{-\alpha r}}{r^2} \qquad [11.4]$$

where α is the coefficient of attenuation, I_0 is the incident signal intensity and r is the distance (Seidband, 1998). Most biological tissues have high coefficients of attenuation, which increases as frequency increases (Seidband, 1998). Thus, it is important to establish the thickness of the tissue at which the attenuation of the medium decreases the signal by half (half-value layer, HVL) (Seidband, 1998). Ultrasound of higher frequencies provides higher resolution, yet the increased HVL reduces the depth of penetration. The acoustic properties of some tissues at 1.0 MHz are presented in Table 11.2.

In soft tissues, the ultrasound waves propagate at a velocity of about 1500 m/s. Each change of tissue type causes a reflection and the greater the difference in acoustic impedance between the tissues the greater the proportion of the ultrasound wave to be reflected. For example, more energy is reflected in the passage from muscle to bone than from muscle to fat. The time taken for the echoes to reach the transducer is directly proportional to the thickness of the medium and inversely proportional to the velocity of ultrasound in that particular tissue. Thus, the time delay between the transmitted pulse and its echo is a measure of the depth

Table 11.2 Acoustic proprieties of some tissues at 1.0 MHz

Material	*v* (m/s)	*Z*	HVL (cm)	Interface	*R*
Water	1496	1.49	4100	Air/water	0.999
Fat	1476	1.37	3.8	Water/fat	0.042
Muscle	1568	1.66	2.5	Water/muscle	0.054
Brain	1521	1.58	2.5	Water/brain	0.029
Bone	3360	6.20	0.23	Water/bone	0.614
Air	331	4.13	1.1	Tissue/air	0.999

Source: adapted from Seidband (1998).

of the tissue interface (Seidband, 1998). The tissue thickness can be estimated on the basis of the time difference between the generation of the ultrasonic wave and the reception of the echoes (Thwaites, 1984).

11.3.1 Ultrasound transducers

Ultrasound transducers make use of the piezoelectric properties of ceramics such as barium titanate: such ceramics have the ability to generate an electric potential when mechanically strained, and conversely an electric potential can cause physical deformation of the ceramic (Peura and Webster, 1998). This ability to transform electrical energy into mechanical energy and vice versa is called the piezoelectric effect (Szabo, 2004).

The piezoelectric effect enables an ultrasound transducer to act simultaneously as a transmitter and a receiver of ultrasound energy. The transducer converts electrical signals to acoustic signals (ultrasound), which are sent to the animal's body. The tissue boundaries then produce echoes by reflecting and scattering the ultrasound waves, which turn back and are detected by the transducer, which in turn converts this acoustic signal to an electric signal (Prince and Links, 2006). Thus, with appropriate electronic circuits, the ceramic can be pulsed to transmit a short burst of ultrasonic energy as a miniature loudspeaker and then switched to act as a microphone to receive signals reflected from the interfaces of various tissue types (Seidband, 1998).

11.3.2 Ultrasound imaging of tissues

When ultrasonic waves are generated by a transducer and applied to the skin of an animal, the transducer receives the reflected waves and converts them into electrical power, which is then displayed on a screen in several ways, as outlined previously. Thus, ultrasound imaging systems capture the reflected energy (echoes), which is used as an indication of the position of the interface between two tissues (Goddard, 1995). The reflected sound can be used to obtain a spatial distribution of the tissues through which the ultrasonic wave has passed, and of the interfaces at which part of the ultrasonic wave was reflected. The ultrasound imaging systems process the echoes and present an image of the tissue anatomy on a display, in which each point in the image corresponds to the anatomical location of an echo-generating structure, with its brightness corresponding to the echo strength (Prince and Links, 2006).

The spatial resolution of an image produced by ultrasound is limited by the wavelength of the ultrasound. The wavelength decreases with the increase in frequency: for example, at 2, 5 and 7.5 MHz the wavelength is approximately 0.77, 0.31 and 0.21 mm, respectively (Mannion, 2006). The best resolution is obtained with higher frequencies, since these are associated with a higher attenuation by biological tissues (Goddard, 1995). Thus, the choice of ultrasonic frequency should be based on two factors: (1) the desired resolution – the minimum number of elements to be differentiated – as the resolution power varies along with the ultrasound frequency; and (2) energy absorption by the medium, which increases very rapidly with the increase in ultrasound frequency, and high-frequency waves are less penetrative (Goddard, 1995; Mannion, 2006). The choice of ultrasound frequency must take into account the compromise between the type and thickness of the tissue to be analysed. For animal science, the ultrasound frequency range used is between 1 and 10 MHz (Stouffer, 2004; Silva *et al*., 2006a).

11.4 Applications of real-time ultrasound (RTU) to predict carcass composition and meat traits in large animals

The ability of RTU to measure carcass composition and meat traits in cattle, swine, sheep and goats has been the subject of a number of studies. This section presents a comprehensive review of the methods used, degree of precision achieved and the factors affecting the use of RTU for predicting the carcass composition and meat traits of those species *in vivo*.

11.4.1 Use of RTU to predict carcass composition and meat traits in cattle and swine

Since the first reports on the use of ultrasound to predict carcass composition and meat traits in cattle (Temple *et al*., 1956) and swine (Claus, 1957; Dumont, 1957), it was understood that these two species would be the main target for this technology. Although cattle and swine are very different species, it has been shown that RTU can be used to assess carcass composition and meat traits in both, as will be discussed in this section.

The RTU imaging system allows the collection of anatomical measurements in live animals; these measurements, when combined with other sources of information, represent a good basis from which to estimate carcass composition (Paisley *et al*., 2007). During the last decade, RTU has increased in popularity and, today, has a great impact on the beef cattle and swine industry through two principal applications: as a selection tool for genetic programmes to improve the quality of the carcass and meat traits (e.g., Wilson, 1992) and as a management tool to optimize time of slaughter (Hassen *et al*., 1998, 1999a; DuPonte and Fergerstrom, 2006).

The use of ultrasound as a selection tool involves the collection of data relating to the carcass and meat traits of cattle (yearling bulls and heifers) and swine. This information is then used to select the best breeding animals in genetic improvement programmes (Wilson, 1992). Traits such as *Longissimus thoracis et lumborum* muscle area (LMA) and subcutaneous fat depth (SFD), usually over the 12th–13th rib, and intramuscular fat have been used as selection criteria. However, in this section, attention will be focused on the use of RTU as a management tool to improve carcass and meat quality for consumers, who are the ultimate evaluators of meat quality.

The use of RTU to measure SFD and LMA in live animals has been thoroughly documented (Perkins *et al.*, 1992a; Greiner *et al.*, 2003, and these two carcass traits are good estimators of lean meat yield in beef cattle (Hamlin *et al.*, 1995; Griffin *et al.*, 1999; Hassen *et al.*, 1999a; May *et al.*, 2000; Suguisawa *et al.*, 2003) and in swine (McLaren *et al.*, 1989; Moeller, 1990; Gresham *et al.*, 1994; Morlein *et al.*, 2005; Olsen *et al.*, 2007). Similarly, ultrasound has been used to estimate intramuscular fat (marbling), which is the principal criterion determining meat quality in beef cattle and swine, and will be discussed later in this chapter. The ability to model and predict the composition of the carcass is the basis for a decision support system that allows the producers to adjust animal feeding and handling strategies according to their specific needs.

Several studies have been carried out to analyse the efficacy of ultrasound as a predictor of carcass composition prior to slaughtering in beef cattle (Perkins *et al.*, 1992b; Smith *et al.*, 1992; Delehant *et al.*, 1996; Ragland *et al.*, 1997; Griffin *et al.*, 1999; Wall *et al.*, 2004) and in swine (McLaren *et al.*, 1989; Terry *et al.*, 1989; Gresham *et al.*, 1992, 1994; Ragland *et al.*, 1997; Newcom *et al.*, 2002). Optimum composition means the highest lean meat proportion, and optimum organoleptic properties. When a carcass meets these requirements, it should be sold for the highest price; if, on the other hand, the composition and organoleptic properties are not optimal, its price will be lowered. Predicting the composition of a carcass is therefore key in determining its value at the slaughter line. A low-cost and expeditious method for predicting carcass composition can be used for carcass classification at the slaughter line (Smith *et al.*, 2008a), and for determining the price along the commercialization chain.

The methodology used to predict carcass composition should be accurate, fast and automated, and the first step in developing these prediction models is to achieve accurate measurement of the SFD and LMA, since these are the most frequently used predictors of carcass composition and quality (Perkins *et al.*, 1992b; Delehant *et al.*, 1996; Griffin *et al.*, 1999; Hassen *et al.*, 1999a; Suguisawa *et al.*, 2003; Wall *et al.*, 2004), and are the main price drivers for the value-based marketing system used by the meat industry. The use of RTU to measure both SFD and LMA in live animals has been well documented for both swine and beef cattle (e.g., Houghton and Turlington, 1992), and several studies have shown that it is an accurate method if the images are taken and interpreted by a trained technician (McLaren *et al.*, 1991; Perkins *et al.*, 1992b; Herring *et al.*, 1994; Hassen *et al.*, 1998). SFD is principally used to predict the lean meat content of carcasses of similar weights (Faulkner *et al.*, 1989), while LMA is also used to predict the carcass composition (Perkins *et al.*, 1992b; Hassen *et al.*, 1998). The evaluation of the accuracy of ultrasound measurements of SFD and LMA is the first step in assessing the applicability of the technology (Robinson *et al.*, 1992) for this purpose. Several articles have focused on the accuracy of the measurement of these carcass traits in beef cattle and in swine. Table 11.3 summarizes the values of correlation coefficients (*r*) and confidence interval (CI) between SFD and LMA measured by ultrasound and the homologous measurements taken on the carcass for beef cattle and swine.

In cattle, the correlation coefficients between SFD and LMA measured by ultrasound and the homologous measurements taken on the carcass range from 0.70

Table 11.3 Correlation coefficients (*r*) and confidence interval (CI) between SFD and LMA measured by ultrasound and the homologous measurements taken on the carcass attained by several authors for cattle and swine

Species	Reference	SFD		LMA	
		r	CI (95%)	*r*	CI (95%)
Cattle	Hedrick *et al.* (1962)	0.71	0.56–0.81	0.88	0.81–0.92
	Davis *et al.* (1964)	0.90	0.84–0.93	0.87	0.79–0.82
	Henderson-Perry *et al.* (1989)	0.86	0.82–0.89	0.76	0.69–0.81
	Brethour (1992)	0.90	0.88–0.91	0.58	0.48–0.66
	Perkins *et al.* (1992a)	0.75	0.71–0.78	0.60	0.54–0.65
	Robinson *et al.* (1992)	0.91	0.74–0.93	0.88	0.76–0.94
	Smith *et al.* (1992)	0.82	0.75–0.87	0.63	0.52–0.72
	Hassen *et al.* (1998)	0.70	0.61–0.77	0.48	0.35–0.59
	Griffin *et al.* (1999)	—	—	0.52	0.10–0.78
	May *et al.* (2000)	0.81	0.76–0.85	0.61	0.52–0.69
	Silva *et al.* (2004)	0.86	0.76–0.92	—	—
	Fixed effect model	0.84	0.78–0.88	0.66	0.63–0.68
	Random effects model	0.84	0.78–0.88	0.72	0.62–0.80
Swine	Busk (1986)	0.90	0.86–0.93	—	—
	McLaren *et al.* (1989)	0.55	0.40–0.67	0.61	0.48–0.72
	McLaren *et al.* (1991)	0.86	0.74–0.93	0.80	0.63–0.89
	Gresham *et al.* (1992)	0.49	0.34–0.62	—	—
	Ragland *et al.* (1997)	0.84	0.81–0.87	0.74	0.69–0.78
	Moeller and Christian (1998)	0.87	0.85–0.88	0.74	0.71–0.77
	Fixed effect model	0.85	0.84–0.86	0.72	0.70–0.74
	Random effects model	0.82	0.74–0.88	0.70	0.64–0.75

to 0.91 and from 0.48 to 0.88, respectively. For swine, the correlation between ultrasound and the homologous carcass measurements are very similar (0.49–0.90 and 0.61–0.80 for SFD and LMA, respectively).

Although these correlations are generally significant, the data presented in Table 11.3 shows some variation in the correlation coefficients between different studies and species. This variation is influenced by several factors, namely the ultrasound equipment used, differences between animal and carcass position after slaughter, methods for RTU image analysis and operator training (Robinson *et al*., 1992; Herring *et al*., 1994; Stouffer, 2004). All these factors contribute to reducing the accuracy of the RTU technique (Houghton and Turlington, 1992). However, in recent years, important advances have been made in ultrasound technology, which allow for increasing accuracy and reliability in measuring the SFD and LMA (Lusk *et al*., 2003). Moreover, efforts have been made to improve image acquisition protocols by certified independent technicians (Stouffer, 2004). Additionally, the captured RTU images can be sent to a central laboratory and analysed by trained staff (Greiner *et al*., 2003). Similar procedures could be adopted to optimize the use of the RTU technique in swine (Moeller, 2002; Schwab *et al*., 2010).

11.4.2 Use of RTU to predict carcass composition and meat traits in sheep and goats

One of the first ultrasound scanning examinations to predict the composition of sheep carcasses was reported in the late 1950s (Campbell *et al*., 1959). Since then, numerous studies have been carried out with the aim of predicting carcass composition and meat traits in small ruminants (Table 11.4). The application of RTU technology to small ruminants has been centred on the development of genetic improvement programmes for fat reduction and on the prediction of carcass composition (e.g., Simm, 1987; McEwan *et al*., 1989), which also proved useful in marketing decisions (Alliston, 1980; Leeds *et al*., 2007). Particularly in sheep, an excess of fat in the carcass is a major problem that reduces the commercial value of the animal (Sañudo *et al*., 2000). To overcome this problem, the use of RTU technology has been shown to be very effective in the evaluation of carcass fat levels (Simm *et al*., 2002; MacFarlane and Simm, 2008). In addition, for sheep and goats, RTU shows great potential for *in vivo* evaluation of carcass composition and meat traits. In recent years, several works have been published that clearly show that the RTU technique allows good estimates of the composition of the carcass to be obtained. These studies aimed to predict carcass composition in adult animals (Hopkins *et al*., 2007; Teixeira *et al*., 2008), market lambs (Teixeira *et al*., 2006; Leeds *et al*., 2008; Orman *et al*., 2008; Thériault *et al*., 2009; Emenheiser *et al*., 2010; Orman *et al*., 2010) or light carcasses (Ripoll *et al*., 2009). Although the results obtained were generally good, attention must be paid to the factors that lead to inaccuracy in the RTU technique when used for small ruminants. These factors include wool or hair, identification of measurement points, fat level and image interpretation and analysis.

Table 11.4 Summary of studies conducted with sheep and goat for predicting *in vivo* carcass traits using the RTU technique

Species	Reference	Equipment	Objective
Sheep	Kempster *et al*. (1982)	Danscanner	Predicting carcass composition
	McEwan *et al*. (1989)	Aloka; 3 MHz and Toshiba SAL 22; 5 MHz	Accuracy of RTU measurements and predicting carcass composition
	Ramsey *et al*. (1991)	Toshiba SAL 32B; 5 MHz	Predicting carcass composition
	Young *et al*. (1992)	Aloka SSD-210 DXII; 5 MHz	Predicting carcass composition
	Delfa *et al*. (1995a)	Toshiba SAL 32B; 5 MHz	Accuracy of RTU measurements and predicting carcass composition
	Stanford *et al*. (1995a)	Aloka SSD 500V; 2 MHz	Accuracy of RTU measurements and predicting carcass composition
	Glasbey *et al*. (1996)	Vetscan MKI; 5 MHz	Accuracy of RTU measurements
	Hopkins *et al*. (1996)	Aloka 500V; 3.5 MHz	Accuracy of RTU measurements and predicting carcass composition
	Fernández *et al*. (1997)	Toshiba SAL 32B; 5 MHz	Accuracy of RTU measurements
	Silva *et al*. (2005)	Aloka 500V; 7.5 MHz	Predicting body and carcass chemical composition
	Silva *et al*. (2006a)	Aloka 500V; 5 and 7.5 MHz	Predicting carcass composition
	Teixeira *et al*. (2006)	Aloka 500V; 5 and 7.5 MHz	Predicting carcass composition
	Hopkins *et al*. (2007)	Honda HS-1201; 5 MHz	Accuracy of RTU measurements and predicting carcass composition
	Silva *et al*. (2007a)	Aloka 500V; 7.5 MHz	Predicting carcass composition
	Leeds *et al*. (2008)	Aloka 500V; 3.5 MHz	Accuracy of RTU measurements and predicting yields
	Orman *et al*. (2008)	Dynamic imaging, 7.5 MHz	Accuracy of RTU measurements
	Ripoll *et al*. (2009)	Aloka SSD 900; 7.5 MHz	Accuracy of RTU measurements and predicting carcass composition
	Thériault *et al*. (2009)	Ultrascan 50; 3.5 MHz	Accuracy of RTU measurements
	Emenheiser *et al*. (2010)	Aloka 500V; 3.5 MHz	Accuracy of RTU measurements
	Orman *et al*. (2010)	Dynamic Imaging, 7.5 MHz	Accuracy of RTU measurements
	Ripoll *et al*. (2010)	Aloka SSD 900; 7.5 MHz	Accuracy of RTU measurements and predicting carcass composition

(*Continued*)

Table 11.4 Continued

Species	Reference	Equipment	Objective
Goat	Delfa *et al*. (1995b)	Toshiba SAL 32B/5 MHz	Accuracy of RTU measurements and predicting carcass composition
	Stanford *et al*. (1995b)	Keikei CS-3000/3.5 MHz	Accuracy of RTU measurements
	Delfa *et al*. (1996)	Toshiba SAL 32B/5 MHz	Accuracy of RTU measurements and predicting carcass composition
	Mesta *et al*. (2004)	Aloka 500, 5 MHz	Accuracy of RTU measurements
	Teixeira *et al*. (2008)	Toshiba SAL 32B/5 MHz	Accuracy of RTU measurements and predicting carcass composition
	Monteiro (2010)	Aloka 500, 5 MHz	Accuracy of RTU measurements and predicting carcass composition

The value of clipping or shearing the wool or hair at the measuring points of sheep and goats is a controversial issue. One perspective is that the procedure is useful, as it helps to avoid aberrant echoes caused by air bubbles trapped between the conductive medium and wool or hair (Kempster *et al*., 1982; Stouffer, 1991, Silva *et al*., 2006a; Leeds *et al*., 2008). Air bubbles are the cause of low quality images because the ultrasonic beams can dissipate quickly in the air. The necessity of shearing animals was verified by McLaren *et al*. (1991): after studying data from seven sheep that had not been shorn, an increase from 0.15 ($P > 0.05$) to 0.59 ($P < 0.01$) was observed for the correlation between fat thickness measured with ultrasound and fat thickness measured in carcass. The main argument against shearing is the need for the whole ultrasound examination process to be carried out quickly (Hopkins *et al*., 1996; Teixeira *et al*., 2008). This issue can be of great economic importance when RTU examinations are performed in a large number of animals, as is the case in commercial herds. Poor acoustic contact between the probe and skin may cause RTU measurements to be underestimated, and it is therefore necessary to increase the pressure on the probe, which causes a deformation of superficial tissues (McEwan *et al*., 1989; McLaren *et al*., 1991). To overcome this problem, Ramsey *et al*. (1991) and Young and Deaker (1994) pointed out the possibility of following the tissue deformation through the image on the monitor, allowing it to be immediately corrected. Using a greater amount of conductive medium and the use of a standoff pad between probe and skin are other procedures that can reduce the tissue deformation problem.

In most studies involving sheep and goats, ultrasonic measurements are carried out along the midline of the thoracic and lumbar regions, usually between the 12th thoracic vertebra and 4th lumbar vertebra, using the *Longissimus thoracis et lumborum* (LTL) muscle and thoracic and lumbar vertebrae for orientation. Subcutaneous fat depth above the LTL muscle and muscle depth and area are the parameters usually measured in RTU examinations. A large number of studies (McEwan *et al*., 1989; Silva *et al*., 2006a; Teixeira *et al*., 2006; Hopkins *et al*., 2007; Silva *et al*., 2007a; Leeds *et al*., 2008; Teixeira *et al*., 2008; Thériault *et al*., 2009; Emenheiser *et al*., 2010; Orman *et al*., 2010) have found a significant correlation ($r > 0.6$; $P < 0.01$) between both fat and muscle RTU measurements and the corresponding carcass measurements in those regions. The placement of the probe at reference points must be correct, since SFD and LTL muscles vary significantly over short distances either cranio-caudally (Delfa *et al*., 1991; Silva *et al*., 2007a) or medium-laterally (Simm, 1983; Korn *et al*., 2005). In addition, anatomical distortions arising from the position of the animals and skin flexibility may also contribute to discrepancies between RTU and carcass measurements (Thwaites, 1984; Leeds *et al*., 2008). This problem is more evident in young animals, in which the skin is more flexible and the thickness of tissues is lower (Thwaites, 1984; Silva *et al*., 2006a; Ripoll *et al*., 2009).

Ultrasound measurements of other regions are also carried out, including over the sternum (Delfa *et al*., 1996, 2000; Silva *et al*., 2005; Teixeira *et al*., 2008) and grade rule (GR) measurement, which is taken between the 11th and 12th ribs at a lateral distance of 11 cm from the spine (Hopkins *et al*., 1993; Thériault *et al*., 2009). The sternum region is particularly appropriate for the assessment of fat thickness in goats (Delfa *et al.*, 1996, 2000). In fact, in this species the subcutaneous fat layer in the thoracic and lumbar regions is usually very thin, and is therefore more difficult to measure (Teixeira, 2009).

It has been observed that the accuracy of subcutaneous fat thickness measurements is higher in fatter animals within the same species and between different species (McLaren *et al.*, 1991; Stouffer, 2004; Silva *et al.*, 2006a). In general, RTU measurements obtained in lambs (Young and Deaker, 1994; Silva *et al.*, 2006a; Ripoll *et al.*, 2010) or in kids (Stanford *et al.*, 1995b; Monteiro, 2010) lead to difficulties in SF measurement due to the lower thickness of this tissue. One way to overcome the problem of thin subcutaneous fat is the use of higher-frequency probes, as demonstrated by Silva *et al.* (2006a) and Teixeira *et al.* (2006), who showed that a frequency of 7.5 MHz outperformed 5 MHz in measuring SFD. The 7.5 MHz probe showed higher resolution and lower penetration (Silva *et al.*, 2006a). Generally, the first 6 mm are the focus of attention, comprising skin and subcutaneous fat (Gooden *et al.*, 1980). Therefore, the interface between skin and subcutaneous fat should be located with precision, because the fat is only a few millimetres thick (Gooden *et al.*, 1980; McEwan *et al.*, 1989). The difficulty of determining the interface between skin and subcutaneous fat led some authors to include the skin in the measurement of SFD (Kempster *et al.*, 1982; Silva *et al.*, 2005; Thériault *et al.*, 2009).

Accurate depth measurements require clear identification of the tissues and their interfaces. RTU equipment usually contains an internal measurement system that typically has a resolution of 1 mm (McEwan *et al.*, 1989; Fernández *et al.*, 1997). This resolution, as discussed previously, undermines the accuracy of SF measurements when lean animals are examined (Fernández *et al.*, 1997; Silva *et al.*, 2006a) or when it is necessary to monitor variations of tissue thickness in growing animals (Hamby *et al.*, 1986; Silva *et al.*, 2005). This resolution issue was reported by Young *et al.* (1992) who took fat and muscle thickness measurements in a group of sheep using an RTU associated with a video system for image recording and an image analysis programme. Young *et al.* (1992) observed superior measurement repeatability with their approach, including image recording and analysis, compared with measurements performed directly on the equipment monitor. The difference in repeatability of the two approaches was connected to the resolution, which was 0.1 mm on the image analysis system and 1 mm on the monitor. Similar results were also observed by Silva *et al.* (2005) in a study with growing lambs. They report that better results were obtained when a high-frequency probe (7.5 MHz) was used, allowing an image resolution of 0.2 mm, which was capable of detecting differences in SFD between animals. This is undoubtedly a strong justification for recording ultrasonic images for later analysis. Other factors that justify the recording of images and their subsequent analysis are the shorter time required to evaluate the animals (Glasbey *et al.*, 1996; Silva *et al.*, 2006a); the possibility of obtaining several measurements from the same image including irregular areas (Silva *et al.*, 2007a); and improvements in repeatability, since the interpretation of the images is more important than its acquisition (McLaren *et al.*, 1991).

Problems in identifying tissue interfaces may also arise in fat animals. Indeed, in fat lambs, two or even three layers of subcutaneous fat can be formed, which can be problematic for the interpretation of images taken at the interface between skin and subcutaneous fat (Miles *et al*., 1972; Silva *et al*., 2005; Thériault *et al*., 2009) and can lead to an underestimation of SFD. This underestimation can have serious implications when the RTU measurements aim to select animals with lean carcasses (Gibson and Alliston, 1983; Brethour, 1992).

Over the years, several reports have shown that RTU is a suitable technique for predicting carcass composition both in sheep (Kempster *et al*., 1982; McEwan *et al*., 1989; Ramsey *et al*., 1991; Young and Deaker, 1994; Silva *et al*., 2005, 2006a; Teixeira *et al*., 2006; Hopkins *et al*., 2007; Ripoll *et al*., 2009) and goats (Delfa *et al*., 1995a, 1996; Teixeira *et al*., 2008). In general, these studies develop models which are able to explain the variation in carcass composition in terms of muscle, fat and bone content. Very often, the best models include RTU measurements and body weight. For example, Silva *et al*. (2006a) and Ripoll *et al*. (2009) used models for lambs that included the body weight and one or two RTU measurements, which demonstrate 59–99% and 51–98% of the variation in muscle and fat content, respectively. For goats, Teixeira *et al*. (2008) also observed the value of body weight in combination with RTU measurements to predict carcass muscle content ($r^2 = 0.90$; $P < 0.01$), carcass fat ($r^2 = 0.92$; $P < 0.01$) and total body fat ($r^2 = 0.92$; $P < 0.01$).

11.5 Applications of RTU to predict carcass composition and meat traits in small animals and fish

This section presents an overview of the research conducted with RTU to measure carcass composition and meat traits in poultry, rabbits and fish.

11.5.1 Use of RTU to predict carcass composition and meat traits in poultry

Intensive research into the quality of poultry meat began after World War II, mainly in industrialized countries (Grashorn, 2010). Since then, the successful application of science (health, management, nutrition and genetics) to business in a challenging industry has led to astounding changes in the final product (Boyle, 2006). In the 1950s, to grow a 1.8 kg broiler, it took 90 days (20 g body weight gain day^{-1}), with a consumption of 3.6 kg of feed kg^{-1} of body weight gain, producing about a breast meat yield of approximately 12%. Today, to grow a broiler with the same body weight takes less than 39 days (46 g body weight gain day^{-1}), with less than half the feed used previously (1.7 kg of feed kg^{-1} of body weight gain) and with a breast meat yield of 19% (Arthur and Albers, 2003; Boyle, 2006). These changes have mostly been implemented through selection methods that efficiently improved the yield of the carcass, particularly the breast and leg muscles (Berri *et al*., 2005; Duclos *et al*., 2006). As stated in several papers, the breast is the most valuable part of a poultry carcass (Silva *et al*., 2006b; Larivière *et al*., 2009) and the breast muscle thickness is a good indicator of poultry carcass composition (Michalik *et al*., 1999, Rymkiewicz and Bochno, 1999). Poultry carcass traits have therefore been measured with both invasive (slaughtering and dissection of progenies/sibs) or *in vivo* non-invasive methods (Zerehdaran *et al*., 2005; Larivière *et al*., 2009). The latter are particularly relevant when serial determinations of carcass traits in the same animal are required. For poultry, as for other species, numerous studies have described non-invasive methods for the evaluation of carcass composition and meat and fat traits. For example, methods, such as TOBEC (Latshaw and Bishop, 2001), DXA (Mitchell *et al*., 1997; Swennen *et al*., 2004), MRI (Mitchell *et al*., 1991; Kallweit *et al*., 1994; Kövér *et al*., 1998a; Scollan *et al*., 1998; Davenel *et al*., 2000) or CT (Bentsen and Sehested, 1989; Svihus and Katle, 1993; Andrassy-Baka *et al*., 2003) have been shown to be useful for poultry research. Among these techniques, MRI and CT have been identified as being particularly accurate. However, the high cost of the equipment required for these techniques, combined with the fact that the equipment is not portable, severely limits their routine application in poultry research. Real-time ultrasonography has been used for several years in poultry science studies to predict carcass composition and meat traits (Bochno *et al*., 2000; Melo *et al*., 2003; Silva *et al*., 2006b; Larivière *et al*., 2009). Ultrasound studies on broiler chickens to predict carcass traits were focused mainly on abdominal fat (e.g., Melo *et al*., 2003; Arceo *et al*., 2009) and breast measurements (e.g., Silva *et al*., 2006b; Kleczek *et al*., 2009). The results obtained using RTU to predict poultry carcass traits are given in Table 11.5.

In general, the results show that RTU measurements are useful for developing models of broiler breast and leg cuts and lean tissue. It has also been observed in several studies that the best models combine body weight (BW) with RTU measurements (Konig *et al*., 1998; Melo *et al*., 2003; Silva *et al*., 2006b; Oviedo-Rondón *et al*., 2007). The use of BW in combination with RTU measurements in models for predicting carcass composition is a common practice since BW is closely related to key carcass traits and there are minimal costs associated with its measurement. Using BW combined with RTU measurements for chicken breast, it was possible to account for between 85% and 97% of the observed variation in breast yield and between 63% and 99% of the observed variation in total lean meat content. Based on these results, it is understandable that some reports recommend the use of this non-invasive technique as a valuable tool for selection schemes in broiler breeding (Zerehdaran *et al*., 2005; Oviedo-Rondón *et al*., 2007). Ultrasound is also recognized as being sufficiently accurate to monitor the changes in breast yield that occur over the course of a bird's growth; it will therefore prove to be a powerful tool for making the necessary adjustments in feeding regimes to enhance productivity (Dixson and Teeter, 2001; Oviedo-Rondón *et al*., 2007) and in deciding the optimal weight for slaughter (Oviedo-Rondón *et al*., 2007). Nevertheless, ongoing study of the use of RTU in poultry research is necessary in order to optimize methods and equipment. Several RTU variables such as breast thickness (e.g., Dixson and Teeter, 2001), breast area obtained both

Table 11.5 Summary of trials with broilers for prediction of carcass traits from breast measurements obtained by RTU alone or associated with body weight (BW)

Reference	Equipment	Probe	*n*	Dependent variable	Independent variables	r^2
Konig *et al*. (1998)	Aloka 500V	5 MHz, linear	150 male	Breast yield, %	2 Breast area measurements	0.54
			108 female	Breast yield, %	2 Breast area measurements	0.50
Michalik *et al*. (1999)			77 male	Total lean, g	BW + Breast thickness	0.64
			76 female	Total lean, g	BW + Breast thickness	0.59
Rémignon *et al*. (2000)	Toshiba SAL38B	5 MHz, linear	48	Breast, g	BW+ Breast cross-sectional area	0.89
				Breast yield, %	BW+ Breast cross-sectional area	0.63
			104	Breast, g	BW+ Breast cross-sectional area	0.80
				Breast yield, %	BW+ Breast cross-sectional area	0.60
Dixson and Teeter (2001)				Breast, g	Breast thickness	0.90
				Total lean, g	Breast thickness	0.90
Melo *et al*. (2003)	Ekhoson 500V	7.5 MHz, linear	96	Breast, g	BW + Breast thickness	0.85
Silva *et al*. (2006b)	Aloka 500V	7.5 MHz, linear	103	Breast yield, %	BW + Breast volume	0.52
				Breast, g	BW + Breast volume	0.92
Oviedo-Rondón *et al*. (2007)	Aloka 500V	3.5 MHz, linear		Breast, g	BW + Breast area	0.97
				Legs, g	BW + Breast area	0.98
				Total meat, g	BW + Breast area	0.99

(*Continued*)

Table 11.5 Continued

Reference	Equipment	Probe	*n*	Dependent variable	Independent variables	r^2
Kleczek *et al*. (2009)	Dramiński Animal Scanner	7 MHz, sector	40 male	Breast, g	Breast thickness	0.22
			40 female	Breast, g	Breast thickness	0.45
Larivière *et al*. (2009)	Pie Medical 100	5 MHz, linear	24	Breast, g	Breast thickness	0.62

by perpendicular (e.g., Silva *et al*., 2006b) or longitudinal scanning (e.g., Oviedo-Rondón *et al*., 2007), or breast volume (e.g., Silva *et al*., 2006b) have been used as independent variables in linear regression equations for *in vivo* estimation of the total breast muscle content. The fact that these variables are of different origins underlines the need for the selection of one site and a specific scanning procedure. There are also concerns related to the choice of equipment: some studies use a linear probe whereas others use a sector probe. The images resulting from breast scanning with a sector probe (Fig. 11.2a) are very different from those obtained with a linear probe (Fig. 11.2b). This difference causes additional difficulties in the interpretation of tissue interfaces. The frequency and length of the probe are also sources of inaccuracy. Using a 3.5 MHz with 17.5 cm length probe, as is usually employed in large animals, allows a wider ultrasonic window to be examined, which in turn allows better identification of the anatomical site and hence a consistent measurement of the muscle area (Oviedo-Rondón *et al*., 2007). If small probes are used, the anatomical site must be correctly identified before ultrasound image acquisition can be carried out (Konig *et al*., 1997; Silva *et al*., 2006b). On the other hand, the high probe frequency reported by Silva *et al*. (2006b) is potentially more useful in monitoring small changes in breast muscle thickness, particularly in smaller birds, because, as a result of a direct relationship between frequency and attenuation, a lower-frequency probe is more appropriate for deep tissue examinations, whereas a high-frequency probe is better suited to the examination of superficial structures (Goddard, 1995; Silva *et al*., 2006b).

From a practical point of view, the time needed to acquire a RTU image is very important (Silva *et al*., 2006b; Oviedo-Rondón *et al*., 2007). The correct placement of the probe at the anatomical site, along with proper acoustic contact between the probe and bird are crucial for image quality (Konig *et al*., 1997, 1998; Silva *et al*., 2006b; Oviedo-Rondón *et al*., 2007). In the studies just listed, 50–76 birds were examined per hour, and the RTU images were captured with minimum stress, as only manual restraint was necessary, with no detached feathers. Additional time is necessary for image analysis. Two different procedures can be followed: the first takes advantage of the equipment callipers and software, with

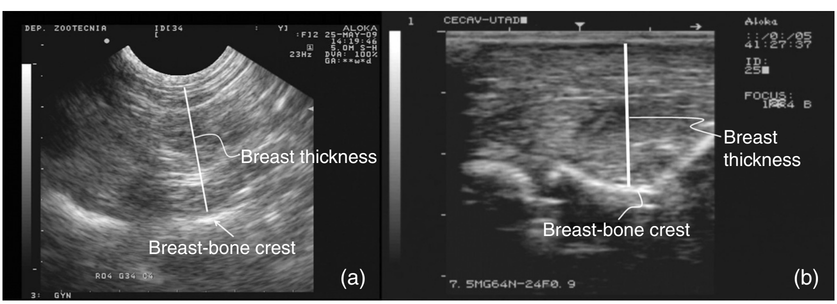

Fig. 11.2 RTU images obtained from cross-sectional view of broiler chicken breast muscle: (a) with a 7.5 MHz sector probe and (b) with a 7.5 MHz linear probe. Breast bone crest and breast thickness were represented.

measurements taken during the image capturing session (Kleczek *et al.*, 2009); in the second, images are stored for subsequent image analysis (Konig *et al.*, 1997; Rémignon *et al.*, 2000; Silva *et al.*, 2006b; Oviedo-Rondón *et al.*, 2007; Larivière *et al.*, 2009). In the latter process, a higher-resolution power is expected, with the result that the measurements obtained are more accurate (Young *et al.*, 1992).

11.5.2 Use of RTU to predict carcass composition and meat traits in rabbit

Rabbit meat is an important product in the Mediterranean areas of Europe, and is also popular in other parts of the world (FAOSTAT, 2010). In recent years, several studies have focused on rabbit meat and carcass traits (Hernández *et al.*, 2004; Larzul *et al.*, 2005). A relationship has been established between growth rate on the one hand, and carcass characteristics and meat quality on the other (Gondret *et al.*, 2005; Pascual and Pla, 2007). Moreover, rabbit is a good experimental model for meat carcass traits because experiments on rabbits can be performed more quickly and at a lower cost than those on other species (Hernández *et al.*, 2006). To further current understanding of rabbit carcass and meat traits, several studies have called for techniques that can evaluate these features *in vivo* (Szabo *et al.*, 1999). Although several non-invasive techniques have been successfully used to evaluate carcass composition in rabbits, such as CT (Szendrö *et al.*, 1992, 2008; Romvári *et al.*, 1996), MRI (Kövér *et al.*, 1998b) and TOBEC (Fortun-Lamothe *et al.*, 2002), only a few studies have been conducted using RTU. Some of these studies are related to the prediction of fat deposits (Pascual *et al.*, 2000, 2002, 2004; Dal Bosco *et al.*, 2003; Castellini *et al.*, 2006; Quevedo *et al.*, 2006) while others are related with carcass and meat traits (Silva *et al.*, 2007b, 2008a, 2008b, 2009). In the pioneering study by Pascual *et al.* (2000), it was shown that RTU was suitable for fat deposit evaluation. A method based on the measurement of perirenal fat thickness at a fixed anatomical location (8th–9th thoracic vertebrae) was developed and accurate results for predicting carcass perirenal fat weight ($r^2 = 0.95$; $n = 42$) and total fat weight ($r^2 = 0.93$; $n = 42$) were obtained.

In rabbits, the ability to assess the fat content of the carcass is of little value because this species has only a small dissectible fat content (Pascual and Pla, 2007). For rabbit carcasses, the evaluation was mainly focused on meat percentage and muscularity, defined as the ratio between meat and bone (Lukefahr and Ozimba, 1991). Several reports have shown that muscularity or cutability attributes may be improved through selection programmes (Lukefahr *et al.*, 1982, 1983).Thus, the development of *in vivo* measurements of muscularity and carcass composition in rabbits using RTU has potentially useful applications in genetic improvement programmes or simply in economic carcass evaluation (Silva *et al.*, 2009). In rabbits, good results were achieved in studies using live body measurements to predict the muscle percentage and muscularity in the carcass (Lukefahr *et al.*, 1982; Lukefahr and Ozimba, 1991; Michalik *et al.*, 2006). Lukefahr and Ozimba (1991); it was found that the lean cut weight (measure of cutability) of the loin was accurately predicted using body weight and loin width ($r^2 = 0.797$).

Several recent studies have assessed the suitability of *in vivo* RTU measurements for assessing rabbit carcass composition and muscularity of loin and leg (Silva *et al.*, 2007b, 2008a, 2008b, 2009). The results reported by these studies clearly showed that measurements obtained from RTU images could account for a large amount of the variation observed in carcass composition and muscularity traits. By employing a 7.5 MHz probe and carrying out image analysis using Image J software for RTU images, 51–94% of the variation in carcass chemical composition (Silva *et al.*, 2007b) and 49–77% of the variation in carcass meat and bone weight (Silva *et al.*, 2009) could be explained with LTL muscle measurements (Fig. 11.3). These results are close to those obtained with CT (Szendrö *et al.*, 1992). Silva *et al.* (2007b, 2009) pointed out that with this system it was possible to estimate the amount of loin muscle ($r = 0.80$; $P < 0.01$).

Moreover, after RTU image analysis, it was possible to predict the LTL muscle volume of the carcass from the *in vivo* LTL volume ($r^2 = 0.81$), which can be calculated from area measurements obtained with multiple scanning images and by using Cavalieri's principle (Silva *et al.*, 2008a). As stated previously, muscularity is an important trait in rabbit carcasses and *in vivo* RTU is able to accurately estimate loin muscularity (r between 0.76 and 0.81; $P < 0.01$) (Silva *et al.*, 2009). However, for leg muscularity, lower coefficients of correlation (r from 0.15; $P >$ 0.05–0.46; $P < 0.01$) were found (Silva *et al.*, 2008b). These results highlighted the need to improve the procedures related to RTU and carcass measurements so that increased accuracy can be achieved when using RTU to determine hind leg

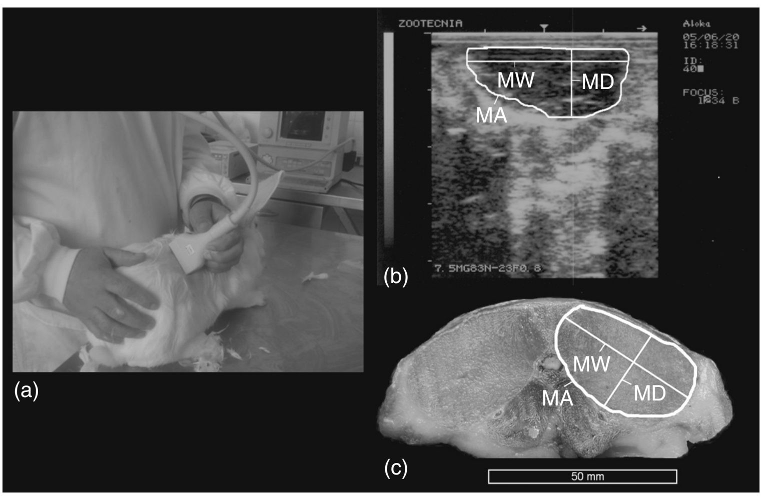

Fig. 11.3 (a) RTU image acquisition procedure with a linear probe placed over loin region between the 6th and 7th lumbar vertebrae. Note the hair clipped close to the skin. (b) RTU image taken *in vivo* showing the representations of *longissimus thoracis et lumborum* muscle area (MA), width (MW) and depth (MD) measurements. (c) Carcass cut section at homologous anatomical position showing the representations of equivalent *longissimus thoracis et lumborum* muscle measurements.

muscularity. Nevertheless, the results obtained from these studies are encouraging as far as the use of *in vivo* RTU to predict rabbit carcass traits is concerned; further research is necessary to improve the practicability of RTU and image analysis for extensive use in the evaluation of rabbit carcasses, since other attributes such as animal restraint, equipment mobility, ease of use and non-invasive nature have already been well established for this technique. The need for the removal of hair from the ultrasound measurement site is also inconvenient, and this problem will need to be addressed in order to improve the practicability of the technique in rabbits.

11.5.3 Use of RTU to predict carcass composition and meat traits in fish

An understanding of the carcass composition, and particularly the fat content, of live fish is important for feeding, breeding and genetics, and for increasing the meat yield of the carcass. It is also an important factor in consumer acceptance (Probert and Shannon, 2000; Romvári *et al*., 2002; Veliyulin *et al*., 2005). Traditionally, carcass composition in fish was determined by comparative slaughtering followed by chemical analysis (Oberle *et al*., 1997). Other methods such as ultrasound velocity (Suvanich *et al*., 1998; Sigfusson *et al*., 2000) or near-infrared techniques (Wold and Isaksson, 1997) are based on fillet samples or dead fish. However, fish production is heavily dependent on quick, accurate and, above all, non-invasive methods to predict carcass composition in live fish (Probert and Shannon, 2000; Veliyulin *et al*., 2005; Silva *et al*., 2010a). Comprehensive studies using image techniques such as CT (Romvári *et al*., 2002; Hancz *et al*., 2003; Kolstad *et al*., 2004), MRI (Collewet *et al*., 2001; Veliyulin *et al*., 2005) and RTU (Bosworth *et al*., 2001; Rodrigues *et al*., 2010; Silva *et al*., 2010a) have shown that these techniques are able to predict carcass traits in fish. From a practical point of view, CT has several characteristics that make it the preferred technique for *in vivo* evaluation of carcass composition in fish. In fact, RTU is a simple, rapid and reasonably priced technique (Stouffer, 2004). Additionally, as water is an excellent coupling medium between transducer and fish, the RTU images can be captured when the fish are in the water (Crepaldi *et al*., 2006). Over the years, this technique has been shown to be sufficiently precise and accurate to be used as a tool for carcass composition studies (e.g., De Campeneere *et al*., 2001). Despite these attributes, little information is available about the use of RTU to predict carcass composition in fish. Examples of studies that use RTU images to predict fish carcass composition traits are summarized in Table 11.6.

The results of these studies are reliable. In farm-raised catfish, Bosworth *et al*. (2001) reported that ultrasound measurements of muscle area in live fish are strongly correlated with the equivalent measurements take on the carcass (r = 0.84–0.94; $P < 0.001$), but in meat yield measurements there was only moderate correlation between the two. A single transverse ultrasound scan accounted for 40–50% of the variation in meat yield traits in female catfish, and 16–23% in male catfish (Bosworth *et al*., 2001). In the same study, using multiple regressions, Bosworth *et al*. (2001) found a three-variable model using ultrasound and

Table 11.6 Examples of studies for predicting fish carcass traits using RTU technique

Reference	Objective	Results	Equipment	Notes
Probert and Shannon (2000)	Low intensity ultrasound to determine fish composition, particularly the fat content	Encouraging results	2.0 MHz convex	Freshly killed fish
Bosworth *et al*. (2001)	Determine the relationships between meat yield traits with body shape traits and transverse ultrasound images of muscle area measured in live catfish	A single ultrasound measurement explained 40–50% and 16–23% of the variation in meat yield traits of females and males, respectively The best three variable models using ultrasound and body shape traits explained 48–56% and 31–38% of the variation in meat yield traits in females and males, respectively	Toshiba Echocee; 7.5 MHz convex	Fish were tranquilized
Bosworth *et al*. (2001)	Study with 30 market weight channel catfish to compare muscle area measured from transverse ultrasound images with muscle area measured in fish	Correlations between 0.84 and 0.94 for ultrasound muscle area with equivalent carcass measurement	Aloka 1700; 5 MHz linear	

(*Continued*)

Table 11.6 Continued

Reference	Objective	Results	Equipment	Notes
Silva *et al*. (2010a)	Develop a rapid non-destructive and non invasive method to predict fillet volume of *Solea senegalensis* individuals from volume measurements obtained *in vivo* after RTU image analysis	The best model explains 98% of the fillet volume variation and was obtained by stepwise procedure with S3, S2 and S4 cross-sectional slices volumes	Aloka 500V; 7.5 MHz linear	Fishes under anaesthesia
Rodrigues *et al*. (2010)	Relationship between the traditional solvent-extraction fat determination method with RTU measurements	Preliminary results with RTU images clearly support the preferential accumulation of fat in subcutaneous tissues of Senegalese sole	Aloka 500V; 7.5 MHz linear	

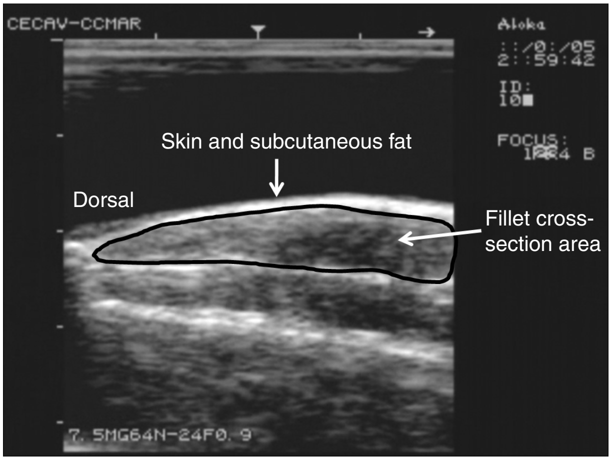

Fig. 11.4 Example of RTU image showing a fillet cross-section area obtained after image analysis.

body shape variables that accounted for 48–56% and 31–38% of the variation in meat yield traits in females and males, respectively. On the other hand, Silva *et al.* (2010a) scanned flat fish (*Solea senegalensis*) with an RTU ultrasound with a 7.5 MHz probe to capture ten cross-sectional slices (Fig. 11.4), from which fillet volume measurements were obtained after image analysis. The best model accounted for 98% of the fillet volume variation and was obtained through volume measurements of three cross-sectional slices.

In fish species processing errors combined with potential errors in RTU image capture and image analysis may limit the accuracy of models for predicting tissues and yield in live fish. For example, fish movement during ultrasound scanning is one drawback that limits the use of RTU in fish farms (Probert and Shannon, 2000). In general, the use of an anaesthetic (Bosworth *et al.*, 2001; Silva *et al.*, 2010a) or, more radically, the use of freshly killed fish (Probert and Shannon, 2000) were reported to reduce fish movement. The need to use these procedures, especially the latter, has restricted the use of this technique in fish farms. Fish size is another limiting factor: the RTU technique is less effective with small fish (Bosworth *et al.*, 2001). However, the use of high-frequency probes (7.5–10 MHz) overcomes this problem because clearer images can be obtained from proximal anatomical structures.

11.6 Using real-time ultrasonography to predict intramuscular fat (IMF) *in vivo*

It is recognized that fat plays an important role in the eating quality of meat (Wood *et al.*, 2008; Kouba and Sellier, 2011). Intramuscular fat (IMF) content, particularly in cattle and swine, affects meat quality, especially the sensory properties of juiciness and flavour (Huff-Lonergan *et al.*, 2002; Thompson, 2004; Skiba, 2010). Some studies have shown that IMF or marbling is essential for meat acceptability by consumers (Shi-Zheng and Su-Mei, 2009) and for meat industry grading (Smith *et al*., 2008a). Before reviewing the use of ultrasound technology to examine these features, the differences between IMF and marbling should be outlined. IMF refers to the chemically extractable fat in a muscle (Shi-Zheng and Su-Mei, 2009) and is an objective measurement, whereas marbling, assessed visually, refers to the appearance of evenly distributed white flecks or streaks of fatty tissue between bundles of muscle fibres (Tume, 2004) and can be subjectively assessed with grading scores or objectively assessed when image analysis is used (e.g., Faucitano *et al*., 2005; Jackman *et al*., 2008). Both are relevant for meat quality evaluation and are closely related to each other (correlation coefficients of up to 0.8 in Savell *et al*., 1986; Devitt and Wilton, 2001; Kemp *et al*., 2002). In general, the percentage of IMF is taken as the reference trait (Brethour, 1994), while marbling proves useful in understanding the size and distribution of IMF deposit in meat (Ferguson, 2004). These attributes are relevant and reinforce the value of using image analysis techniques to evaluate marbling (Du *et al*., 2008).

The IMF trait has been extensively studied in swine and cattle (Pethick *et al*., 2006). It is now generally agreed that the IMF content accounts for a significant amount of the genetic variation in the eating quality of meat of these species (Shi-Zheng and Su-Mei, 2009; Schwab *et al*., 2009, 2010). In addition, IMF is one of the meat quality traits that has the potential to be measured in live animals (Newcom *et al*., 2002; Aass *et al*., 2009). Thus, a cost-effective and accurate method for quantifying IMF *in vivo* is needed, because repeated measurements are necessary on one animal, if it is intended for breeding (Williams, 2002; Parnell, 2004). Furthermore, it is possible to establish the optimal point at which the animal should be sold with the greatest economic benefit (Houghton and Turlington, 1992; Rimal *et al*., 2006). To achieve this goal, experimental work was conducted to predict IMF *in vivo* through RTU and image analysis (e.g., Brethour, 1990; Amin *et al*., 1997). This technique was found to be particularly promising since it is relatively cheap, easy to use and animal-friendly (Stouffer, 2004). Even though the majority of the studies using ultrasonography to estimate the percentage of IMF date from the 1990s (e.g., Brethour, 1990; Sather *et al*., 1996), the technique has been used since the 1960s to estimate fat thickness in the back and the rib eye area, and by then it was already perceived as a technique with the potential for use in IMF prediction (Hedrick *et al*., 1962; Davis *et al*., 1964).

The use of ultrasound image analysis to predict marbling in beef cattle was first attempted by Haumschild and Carlson (1983). This study had only marginal success and was considered too inefficient to have any practical significance. Later on, a number of authors (e.g., Brethour, 1994; Hassen *et al*., 1999b; Newcom *et al*., 2002) reported results which undoubtedly suggest that IMF was accurately predicted with RTU and image analysis.

In the early 1990s, Wilson (1992) stated that considerable research and development was needed before ultrasound could be effectively employed in cattle production and breeding. Since then, ultrasound technology has become a well-established and widely accepted method for predicting IMF in live cattle and swine (i.e., Brethour, 1994; Herring *et al*., 1998; Hassen *et al*., 1999b, 2001; Chambaz *et al*., 2002; Newcom *et al*., 2002; Bahelka *et al*., 2009; Schwab *et al*., 2010). Recently, the RTU technology for predicting IMF was chosen as one of the *100 Innovations from Academic Research to Real-World Application* (AUTM, 2007). This report recognized the work developed by Professor John Brethour from Kansas State University, which changed the beef industry by allowing producers to employ a cost-efficient method for measuring intramuscular fat in livestock. Nonetheless, ultrasound technology can still be further optimized for IMF prediction, by improving RTU image analysis and image acquisition (Shi-Zheng and Su-Mei, 2009).

11.6.1 Using RTU image analysis for IMF prediction

The IMF is primarily determined by the distribution pattern of fat flecks in a cross-section of the LTL muscle, usually between the 12th and the 13th thoracic vertebrae (Fig. 11.5a). Although IMF is present in other muscles, the assessment generally is performed on a LTL muscle section. The IMF consists of deposits that occur within the muscle, which are irregular either in form or in their dispersal. These deposits represent a cluster of IMF cells. Individual cells can be very small (40–60 μm) and are not visible to the human eye (Anon., 2004). The rough surface and small size of IMF deposits cause sound waves to scatter (Brethour, 1990; Whittaker *et al*., 1992), producing spots on RTU images that are referred to as speckles (Fig. 11.5b). This is why ultrasound techniques have the potential to predict IMF *in vivo* after RTU image analysis (Brethour, 1990; Whittaker *et al*., 1992).

The RTU image analysis for predicting IMF or marbling has been carried out in a number of ways over the years. Early studies were conducted to predict marbling scores from a subjective analysis of the RTU image features (coherent speckle, attenuating and reverberation) from which a speckle score was obtained (Harada and Kumazaki, 1979; Brethour, 1990). Speckle scores were estimated visually and corresponded subjectively to a point classification scheme. This procedure had the benefit of allowing an immediate estimation of the marbling score and, thanks to the portability of the ultrasound equipment portability, could be used for farm animals (Brethour, 1990). However, it is subjective, and dependent on beam geometry and machine calibration. Furthermore, an understanding of the classification scheme and calculation of the score can be difficult for a technician to acquire (Brethour, 1990). These negative aspects led Brethour (1990) to observe that ultrasound speckle was a 'quick and dirty' way to estimate the marbling score of a carcass and that, consequently, further improvements were necessary to reduce the subjectivity of RTU images. Although a skilled ultrasound technician can visually interpret an RTU image and estimate marbling in a live animal with fair accuracy (Brethour, 1990, 1994), it was recognized that research using mathematical models for RTU image analysis was imperative (Amin *et al*., 1993; Kim *et al*., 1998).

11.6.2 Mathematical modelling approaches from RTU image analysis

Since the early studies (Harada and Kumazaki, 1979; Brethour, 1990), several papers have dealt with the assessment of IMF content and marbling by RTU

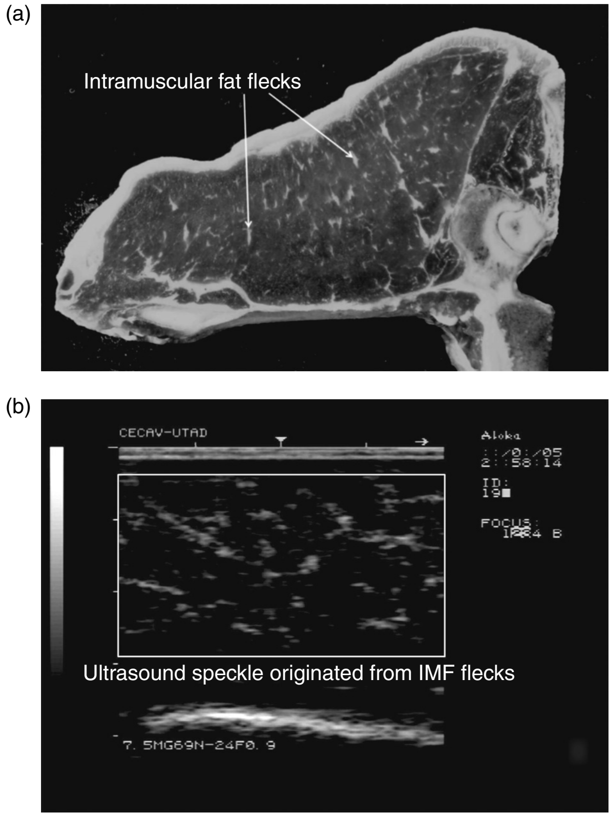

Fig. 11.5 (a) Image from a cattle lumbar cut section showing LTL muscle and intramuscular fat flecks and (b) RTU image of the LTL muscle showing speckle originated from IMF.

computer image analysis (Brethour, 1994; Hassen *et al*., 2001; Harron and Dony, 2009). On the whole, results obtained with mathematical procedures were superior to the subjective RTU image evaluation, even when this task was conducted by an experienced individual (Raeth *et al*., 1985; Couto *et al*., 2011). Since the first attempt was made to predict IMF using RTU image analysis, significant advances have been possible as a result of developments in equipment and software. Table 11.7 summarizes some studies that have used RTU images to predict IMF and marbling score.

The algorithms used to predict the IMF percentage of live animals were based on regression analysis (Whittaker *et al*., 1992; Amin *et al*., 1993; Newcom *et al*., 2002; Li *et al*., 2009); neural network (Brethour, 1994; Amin *et al*., 1992; Harron and Dony, 2009; Li *et al*., 2009) or support vector machine (Harron and Dony, 2009), among others. These algorithms were developed from textural RTU image features such as a histogram of pixel grey levels, Fourier-based

Table 11.7 Summary of trials to predict intramuscular far percentage or marbling score from RTU image analysis in cattle and swine

Reference	RTU equipment	Probe	*n*	Species	Anatomical position	Y	X	r^2	RSD	Statistical analysis
Brethour (1990)	Aloka 210	3 MHz, 107 mm	40	Cattle	12th rib, parallel and perpendicular	Marbling score	Speckle patterns	0.45	0.36%	Regression
Amin *et al*. (1993)	Aloka 500	3.5 MHz, 172 mm	126	Cattle	Across 12th and 13th ribs	IMF%	Image texture features		1.39 and 1.42%	Regression
Brethour (1994)	Aloka 210	3.5 MHz, 125 mm	53 and 108	Cattle	12th rib, parallel and perpendicular	Marbling score	Image texture features	0.53		Neural network
Kim *et al*. (1998)	Aloka 500	3.5 MHz, 125 mm	207	Cattle	Across the 11th and 13th rib	IMF%	Image texture features		1.4%	
Hassen *et al*. (1999b)	Aloka 500	3.5 MHz, 172 mm	144	Cattle	Across 11th –13th ribs					
Hassen *et al*. (2001)	Aloka 500	3.5 MHz, 172 mm	500	Cattle	Across the 11th and 13th rib	IMF%	Image texture features	0.72	0.84%	Regression
Hassen *et al*. (2001)	Pie 200	3.5 MHz, 180 mm	500	Cattle	Across the 11th and 13th rib	IMF%	Image texture features	0.70	0.85%	Regression
Chambaz *et al*. (2002)	Pie 200	3.5 MHz, 180 mm		Cattle	Across 12th and 13th ribs	IMF%	RTU, hide thickness and liveweight		0.96%	Regression
Aass *et al*. (2006)	Pie 200	3.5 MHz, 180 mm	145	Cattle	12th thoracic and 1st lumbar vertebrae	IMF%	Image texture features	0.48	0.46%	Regression
Aass *et al*. (2009)	Pie 200	3.5 MHz, 180 mm	172	Cattle	12th thoracic and 1st lumbar vertebrae	IMF%	Image texture features	0.80	0.66%	Regression

(*Continued*)

Table 11.7 Continued

Reference	RTU equipment	Probe	*n*	Species	Anatomical position	Y	X	r^2	RSD	Statistical analysis
Harron and Dony (2009)	Aloka 500	3.5 MHz, 172 mm	75	Cattle	Across 12th and 13th	IMF%	Image texture features		1.37%	Recursive least squares filter
Harron and Dony (2009)	Aloka 500	3.5 MHz, 172 mm	75	Cattle	Across 12th and 13th	IMF%	Image texture features		2.67%	Support vector machine
Harron and Dony (2009)	Aloka 500	3.5 MHz, 172 mm	75	Cattle	Across 12th and 13th	IMF%	Image texture features		1.36%	Linear neural network
Harron and Dony (2009)	Aloka 500	3.5 MHz, 172 mm	75	Cattle	Across 12th and 13th	IMF%	Image texture features		1.36%	Multilayer perceptron network
Sather *et al.* (1996)	LS-1000	3.5 MHz	149	Swine	3rd and 4th lumbar	IMF%	Percent object area of muscle	0.012		Regression
Sather *et al.* (1996)	CS-3000	3.5 MHz	240	Swine	3rd and 4th lumbar	IMF%	Percent object area of muscle	0.04		Regression
Newcom *et al.* (2002)	Aloka 500	3.5 MHz, 125 mm	207	Swine	Across 10th to the 13th ribs	IMF%	Image texture features	0.32	1.02%	
Bahelka *et al.* (2009)	Aloka 500	3.5 MHz, 172 mm	144	Swine	Last rib	IMF%		0.38	0.52%	Regression
Schwab *et al.* (2010)	Aloka 500	3.5 MHz, 125 mm		Swine	Across the 10th to 13th ribs	IMF%	Image texture features	0.81		Regression

parameters, gradient-based parameters and co-occurrence parameters (Amin *et al*., 1997; Hassen *et al*., 1999b; Newcom *et al*., 2002; Harron and Dony, 2009). Generally, image features can be calculated after selecting a region of interest (ROI) over the RTU image; the image analysis software then provides an ROI parameter file with the image parameters (Amin *et al*., 1997; Silva *et al*., 2010b).

In parallel to research on RTU image analysis for IMF evaluation, several studies aimed at establishing practical and usable software image analysis for livestock production (Amin *et al*., 1997; Aass *et al*., 2006). For example, the software proposed by Amin *et al*. (1997) was frequently used in both swine (Newcom *et al*., 2002; Schwab *et al*., 2010) and cattle (Hassen *et al*., 1999b). An RTU image acquisition protocol must be followed in order to use this software. For swine, a minimum of four longitudinal images were collected at 7 cm off-midline across the 10th–13th ribs (Newcom *et al*., 2002; Schawab *et al*., 2009, 2010). With cattle, four to six images were taken longitudinally without a wave guide (standoff block) across the 11th–13th ribs of the animal at a position three-quarters of the distance from the medial end of the rib eye area to the lateral end (Hassen *et al*., 1999b, 2001). Currently, most swine and cattle scanning for IMF prediction is carried out using an Aloka 500 V with a 17 cm linear array 3.5 MHz transducer (e.g., Hassen *et al*., 2001; Newcom *et al*., 2002; Schawab *et al*., 2010) or with a Pie 200 SLC with a 18 cm linear array 3.5 MHz transducer (e.g., Aass *et al*., 2009). In either case, ultrasound images of the highest quality must be collected. In fact, it is well established that image quality has an impact on measurement accuracy (Houghton and Turlington, 1992; Spangler and Moser, 2009). For both swine and cattle, a typical image with acceptable quality includes the following features: clearly visible hide and subcutaneous fat layer(s) without any sign of uneven couplant or poor transducer contact; LTL muscle area taken from across the 10th–13th ribs with clearly visible rib-shadows; even speckle or texture pattern in the muscle area; and ROI box area completely free of deficiencies (Amin *et al*., 1997; Hassen *et al*., 1999b; Newcom *et al*., 2002). It is also important to correctly distinguish the various tissue types – subcutaneous fat, muscle, blood capillaries, intramuscular fat and bones – for ROI box selection and subsequent use of computer image analysis (Amin *et al*., 1997). During the image analysis process, attention must be paid to all these aspects since they affect the nature of the ultrasonic backscattered signal and consequently the quality of the image (Amin *et al*., 1992). For each image, parameters were generated using texture analysis from a 100 × 100 pixels ROI box (Amin *et al*., 1997; Hassen *et al*., 2001; Newcom *et al*., 2002).

Two observations may be made on the basis of the reports on RTU image analysis and IMF presented in Table 11.7. First, the developments in ultrasound technology offer an opportunity to better predict carcass and meat quality with regard to IMF. Second, the developing technology of using ultrasound image analysis for IMF prediction has been successfully transferred from research to the beef and swine industry, which has allowed improvements in carcass quality.

11.7 Optimization of production system and market carcass characteristics

The most important attribute of meat quality is its overall eating satisfaction, which is a function of the combined effects of tenderness, juiciness and flavour (Ferguson, 2004). However, today's meat is usually criticized for its lack of succulence, due to the low levels of intramuscular fat (marbling), which has been the outcome of years of genetic selection that has aimed to reduce the fat content of the carcass. Moreover, the slaughtering of animals either before or after the optimum point is responsible for significant economic losses (Brethour, 2000), and the prediction of the optimum slaughter date is key in maximizing the quality of the meat and the income of the producer (Williams, 2002). RTU can be used to develop a decision support system to sort animals into management groups prior to feedlot feeding, and to predict the optimum slaughter point using computer-based models to assist the management decisions.

11.7.1 Predicting optimum slaughter date

Meat tenderness and juiciness are positively correlated with the proportion of fat in the carcass (Wood, 1990; Bruns *et al*., 2004). Marbling fat has no direct effect on meat tenderness (Renand *et al*., 2003; Thompson, 2004); however, it plays an important role in meat juiciness and overall eating satisfaction. In fact, marbling leads to greater palatability in panel scores (McPeake, 2001) and lower shear force values (Dolezal *et al*., 1982). Carcasses with higher marbling content also have a higher subcutaneous and intermuscular fat content, thus insulating the muscles during chilling and preventing the phenomenon of cold shortening.

The production of carcasses with excessive weight, excessive subcutaneous fat and only a small degree of marbling, as well as a lack of uniformity, is a common problem in meat production systems. The production of carcasses with the correct weight and an optimum amount of subcutaneous fat therefore ensures that the meat is protected during the cooling process and also maximizes the organoleptic properties.

Fatter carcasses undergo a faster drop in pH, which is associated with more tender meat; and slower cooling of fatter carcasses contributes to an increase in the activity of ageing enzymes, leading to greater tenderness (Wood, 1995). Even under normal chilling conditions, carcasses with less than 13 mm of SFD over LTL display reduced tenderness due to the cold shortening effect (Wood, 1995). Ageing a carcass affected by cold shortening will not alleviate the detrimental effects on tenderness. Thus, the SFD is a very important attribute, because it protects the meat from thermal shock during refrigeration, which prevents cold shortening, oxidation of muscles, browning and microbial contamination of meat during skinning.

As stated previously, the ability to measure the SFD, LMA and marbling using ultrasound images taken from live animals provides an opportunity to study the relationship between animal growth and the development of various tissue types.

Thus, for a known feeding strategy, it is possible to monitor the growth of SFD and LMA and the deposition of marbling as the animals grow and during the finishing phase. These data can then be used to project the slaughter date, for a pre-defined subcutaneous fat level (Brethour, 2000). For example, Delehant *et al*. (1996) showed that ultrasound measures, taken on cattle prior to feedlot feeding, combined with performance data collected during the finishing phase, could effectively predict LMA, SFD and IMF percentage at any point during the finishing phase. The ability to predict the optimum slaughter date of a particular animal is an attractive use of ultrasound technology (Lusk *et al*., 2003). The RTU can be used to develop models to predict the number of days necessary to reach a target carcass composition under a defined feeding regime (Hassen *et al*., 1999a), or to develop a feeding regime that maximizes the production of carcasses with a higher-yield or higher-quality grade (Basarab *et al*., 1999).

So far, the use of RTU to optimize the slaughter date has been focused on beef production; however, RTU can also be successfully used for meat species such as swine. RTU is also useful in predicting market-weight slaughter characteristics and in predicting the percentage of lean cuts in market-weight swine. The ability to predict market-weight slaughter characteristics was investigated by Robinson *et al*. (1992). Similarly, McLaren *et al*. (1989) studied 110 barrows and gilts, which were scanned every two weeks from 42 days old up to the point of slaughter to measure SFD at the first rib, last rib and last lumbar vertebrae, and to measure LMA at the 10th rib. They showed that ultrasound measurements were able to estimate lean gain a day early (up to 53 kg BW) immediately prior to slaughter. These authors (McLaren *et al*., 1989) concluded that ultrasound data were useful in early selection decisions and for selections made at market weight for carcass merit in swine. Olsen *et al*. (2007) also used ultrasound for online classification of swine carcasses and showed that live animal ultrasound measurements could predict retail product yield after slaughter.

The implementation of RTU in meat production systems can help to reduce the production of carcasses with either too little or too much subcutaneous fat. This is beneficial for producers – first, as it can lead to reduced feeding costs, and also because it improves the quality of the product presented to consumers.

11.7.2 Sorting animals prior to feedlot feeding

The study by Green *et al*. (2000) found a total of 280 inefficiencies in the US beef industry, and proved that the majority of losses occurred due to excessive fat production, leading to poor consistency in taste. Green *et al*. (2000) concluded that the beef cattle industry needed to improve carcass quality by improving feeding and management practices, as well as by genetic improvement.

Ultrasound technology provides information on the optimum sorting of animals into feedlot groups, based on their body composition predicted by RTU measurements of SFD at the 12th rib level (Houghton and Turlington, 1992; Hassen *et al*., 1999a). This approach for beef cattle was shown to be more accurate than simple visual appraisal (Delehant *et al*., 1996). Sorting meat animals into uniform groups based on frame size, SFD and LMA can help to obtain carcasses with uniform slaughter weight and consistent composition, which can then be sold at the optimal time (Houghton and Turlington, 1992; Wall *et al*., 2004; Rimal *et al*., 2006). When cattle have an average initial SFD of more than 3 mm, ultrasound is useful in projecting the number of days required to reach a target SFD level, which allows animals to be clustered into groups for more effective marketing (Brethour, 2000).

Ultrasound provides information about the carcass of each animal individually, and if the data are collected when animals start on feed, it can also provide information that can be used to sort animals into adequate feeding regimes (Lusk *et al*., 2003). Therefore, RTU contributes to reducing the problem of overfeeding, improves the efficiency of the production system and increases the income of the meat producers (Lusk *et al*., 2003; Pyatt *et al*., 2005). For example, Basarab *et al*. (1999) used ultrasound to sort beef cattle three to four months before slaughter into more uniform groups, and this strategy displayed positive effects on growth rate, feed efficiency, carcass yield and quality grade, as well as increasing the net return by $15–$27 per head slaughtered. Similarly, with swine, Gresham *et al*. (1992) showed that RTU was able to separate either live animals or carcasses using a single SFD measurement along with live or carcass weight. Gresham *et al*. (1992) concluded that RTU can be used in a commercial environment to achieve accurate measurements of carcass value or of compositional differences between the carcasses.

Variation among cattle within a pen diminishes opportunities for precision feeding. If cattle within a pen are more uniform in their characteristics, they can be fed more precisely according to requirements; this is preferable to using an average measurement to determine feeding, as this can overfeed or underfeed a portion of the cattle (Trenkle and Williams, 1997). The costs and the labour required to operate the system remain the main barriers to the adoption of this technology (Basarab *et al*., 1999). However, recent developments in ultrasound equipment, along with remote sensing and infrared technologies, may make the system of sorting cattle for feeding purposes completely non-invasive and also less labour intensive Li, 2010.

11.7.3 Optimizing marketing strategies

A genuine value-based marketing system will necessarily result in some premiums as well as discounts (Trenkle and Williams, 1997); management optimization can contribute to increased economic returns and carcass desirability in the marketplace. The optimization of management can include strategies such as energy concentration in the diets used during growth and in the finishing phase, and the length of feeding, among many others. However, the prediction of carcass composition pre-slaughter allows the identification of animals with higher carcass cutability (Paisley *et al*., 2007), and beef producers are able to provide carcasses according to consumer preferences (Williams and Trenkle, 1997). Thus, RTU will enhance the profitability of meat producers, as it will allow them to raise meat animals that directly correspond to the desired attributes of consumers

(Rimal *et al.*, 2006). The ultrasound data collected from live animals can be used to predict carcass yield and quality grades (Lusk *et al.*, 2003), and to enhance the meat marketing decisions by optimally targeting carcasses to specific market needs. Lusk *et al.* (2003) studied the potential use of ultrasound measurements taken in the feedlot in guiding pricing decisions for cattle. They found that actual carcass merits were reasonably accurately predicted; and that when cattle were sorting for live, dressed, or grid-based pricing, an increase of returns of $25 per head was achieved compared with marketing all cattle on a live-weight basis.

11.8 The future of RTU imaging in the meat industry

There have been remarkable achievements in the development of ultrasound as a tool for the prediction of carcass composition and meat traits in animals since its first application in the late 1950s. The advent of RTU and image analysis have made ultrasound a valuable and reliable tool in animal research and production, with major applications in genetics, nutrition, carcass value-based marketing and monitoring for body fat reserves (Moeller, 2002; Williams, 2002; Parnell, 2004; Schröder and Staufenbiel, 2006). For all these applications, ultrasound technology will continue to expand as a tool for management practices that affect the productivity and profitability of the meat industry (Moeller, 2002; Li, 2010). One good example of this is the use of ultrasound technology, coupled with current selection methods and molecular tools, to speed up genetic progress in meat traits (MacNeil *et al.*, 2010; Nalaila *et al.*, 2011). Despite the impressive advances in ultrasound systems, mainly in the last decade for all meat species, some technological aspects have the potential for further improvement in the near future. As in the past, current developments in ultrasound technology originate in the field of medicine, particularly from the very dynamic and expanding field of image diagnostics (Stouffer, 2004; Thompson, 2010). Although the needs of the medical sector are quite different from those of the animal science sector, the same medical ultrasound equipment can still be easily used animal science protocols (Stouffer, 2004). Therefore, some of the developments in the medical field may be potentially useful for animal science too. Increasing ultrasound processing capability (King, 2006; Wells, 2006), improvements in image quality (Szabo, 2004; Smith *et al.*, 2008b; Whitsett, 2009), better portability (Ault and Rosen, 2010; Thompson, 2010; Bret *et al.*, 2011), capacity for online analysis and image storage (Whitsett, 2009; Li, 2010) and reduction of equipment and operational costs (Szabo, 2004) are the features that will have the biggest impact on the evaluation of carcass composition and meat traits. In fact, these improvements will allow an increase in the speed of the RTU data collection process either on the farm or at the slaughterhouse. Additionally, faster image analysis and accurate results lead to more information being available along the entire production chain (from stable to table), which helps the industry to better understand and accurately describe the meat products, hence driving improvements in meat quality and productivity (Bindon, 2002; Li, 2010).

11.8.1 Prospects for the development of novel ultrasound scanning techniques

Advances in ultrasound such as synthetic aperture focusing, also known as zone sonography (Wells, 2000; Lyons, 2004), and elastrography (O'Brien and Holmes, 2007; Whitsett, 2009) are likely to be employed in animal science in the future. The zone sonography technology allows faster image acquisition and high image quality, which will prove particularly useful in situations in which multiple images of a subject are required during a scanning session. Elastrography is a technology with the potential to improve the accuracy with which marbling can be predicted. The use of three-dimensional (3-D) ultrasonography is another imaging technique with promising applications in the evaluation of carcass composition and meat traits. As stated by several authors (Mitchell *et al.*, 2001; Kvame and Vangen, 2006; Monziols *et al.*, 2006; Alston *et al.*, 2009), the use of volume measurements, along with image techniques such as MRI and CT, is an attractive approach for predicting carcass composition and meat traits. Although 3-D ultrasound is more costly than conventional ultrasound, it is not prohibitively expensive when incorporated into large breeding programmes.

Despite the impressive advances in ultrasound systems, the software and algorithms still need to be constantly reviewed, and comparisons between systems will still be necessary to find the most suitable means of predicting carcass composition and meat traits for all producing species (Williams, 2002). Future developments in molecular genetics, together with more efficient data collection and dissemination using web-based databases, will increase the value of RTU technology for acquiring information on carcass composition and meat traits (MacFarlane and Simm, 2008; Bertrand, 2009).

11.9 Conclusion

Real-time ultrasonography imaging is a versatile and dynamic technology with many current and potential applications in animal science research and animal production. The attributes of the RTU technique have led to its current widespread use in animal science for the *in vivo* prediction of carcass composition and meat traits in several species. The results obtained with RTU are likely to play a major role in the meat industry by providing accurate and objective carcass and meat traits information in live animals. In the future, it is probable that modern ultrasound techniques will continue to be used in animal science, bringing about further advances in value-based marketing and in precision meat production systems. Research will be focused on developments in ultrasound practicability, portability, cost and public acceptability, and the rapidly advancing field of molecular genetics and the dissemination of web-based databases will further expand the capabilities of RTU as a tool for evaluating carcass composition and meat traits.

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