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Looking under the hide of animals. The history of ultrasound to assess carcass composition and meat quality in farm animals

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Resumo

O desafio de saber qual a composição de um animal vivo tem sido perseguido de forma incessante desde os anos 50 do século XX. Ao longo deste tempo, diversas técnicas têm sido testadas como comprovam os numerosos trabalhos científicos sobre o tema nas principais revistas de ciência animal. O objetivo central destes trabalhos é a obtenção in vivo de informação sobre características relacionadas com a carcaça e com a qualidade da carne. As técnicas que empregam ultrassons estão entre as que mais sucesso apresentam. Há ao longo da história vários marcos que são pilares no desenvolvimento dos ultrassons. No século XVIII, o padre e biólogo Lazzaro Spallanzani, intrigado com a capacidade de orientação noturna dos morcegos, descobriu a ecolocalização. Em 1880, os irmãos Curie apresentaram as propriedades piezelétricas de determinados cristais. Mais tarde durante e entre as duas grandes guerras mundiais ocorreram inúmeros desenvolvimentos tecnológicos no campo militar, mas também no campo médico relacionados com ultrassons. Durante a década de 50 foram apresentadas utilizações de ultrassons com imagem. Quase simultaneamente a primeira utilização em animais foi realizada em 1956 nos EUA. Desde então ocorreram enormes desenvolvimentos quer nos equipamentos de ultrassons, quer nas imagens e na sua análise. Atualmente os ultrassons são uma ferramenta precisa e objetiva que apresenta um papel relevante para avaliar in vivo características da carcaça e de qualidade da carne de ovinos, suínos e bovinos.

Palavras-chave*: história, ultrassons, ciência animal, carcaça, qualidade da carne*

Abstract

The challenge of knowing the composition of a living animal has been pursued incessantly since the 1950s. Throughout this time, several techniques have been tested as evidenced by the numerous scientific articles found on the subject in the leading animal science journals. The primary objective of this work is obtaining information in vivo on characteristics related to carcass and meat quality. The techniques that employ ultrasound are among the most successful. Throughout history, several milestones have been found in the development of ultrasound. In the eighteenth century, priest and biologist Lazzaro Spallanzani, intrigued by the nocturnal ability of bats, discovered echolocation. In 1880 the Curie brothers presented the piezoelectric properties of certain crystals. Later during and between the two world wars, numerous ultrasound technological developments occurred in the military field but also the medical field. Ultrasound with imaging was presented during the 1950s. The application of ultrasound to animals has had a very close relationship to medical applications, and almost simultaneously the first use in animals was held in 1956 in the USA. Since then, there have been enormous developments in both the ultrasound equipment and the images and their analysis. Ultrasound is currently an accurate and objective tool that has a relevant role in evaluating in vivo carcass characteristics and meat quality in the main farm species (cattle, swine, goat, sheep and poultry) and fish.

Keywords*: history, ultrasound, animal science, carcass, meat*

INTRODUCTION

The assessment of body composition is a fundamental problem at all levels of animal science. Whether on a farm or research station is describing live animals in terms of their body or carcass composition[1,2] The making and development of accurate techniques for predicting carcass and body composition in meat species are of great importance to implement breeding selection schemes, for performance testing and classification to establish a value-based market system[3]. Although there have been many applied techniques, none have been ideal, although each has made some contribution[4,5]. One of the most widely used has been the ultrasound technique and in particular real-time ultrasound (RTU). For over 60 years, the evolution of equipment, the quality of the images produced and its analysis have allowed the ultrasound technique to be recognized as a fundamental tool in animal science. A long way has been progressed from the earliest equipment derived from metal-flaw detector detection in the late 1950s[6] to modern medical equipment that allows for a multitude of image quality-related features including the possibility of obtaining 4D image[7]. The history of ultrasound applied to animal science is full of examples of transferring both equipment and methodologies from and to the medical field[8,9]. Over this time, extensive work has been done to create or adapt more practical, robust and user-friendly equipment to be employed in the challenging animal science environments. The objective of much of this work was to describe the ability of the RTU to predict non-invasively the body and carcass composition of meat-producing animals[10,11]. The results achieved allow us to understand the relationship between measurements obtained with RTU and body composition and carcass characteristics of the main meat-

[1] Simm, G. "The use of ultrasound to predict the carcass composition of live cattle-a review." *Animal Breeding Abstracts* 51 (1983): 853-875.
[2] Stouffer, J. R. "History of ultrasound in animal science." *Journal of Ultrasound in Medicine* 23 (2004): 577-584.
[3] Scholz, A. M., et al. "Non-invasive methods for the determination of body and carcass composition in livestock: dual-energy X-ray absorptiometry, computed tomography, magnetic resonance imaging and ultrasound: invited review." *Animal* 9 (2015): 1250-1264.
[4] Stouffer, J. R. "Relationship of ultrasonic measurements and X-rays to body composition." *Annals of the New York Academy of Sciences* 110 (1963): 31-39.
[5] Teixeira, A., et al. "Advances in sheep and goat meat products research." *Advances in Food and Nutrition Research* 87 (2019): 305-.
[6] Stouffer, J. R. 1963
[7] Tovoli, F., et al. "What Future for Ultrasound in Medicine?" *Ultraschall in der Medizin-European Journal of Ultrasound* 39 (2018): 7-10.
[8] Stouffer, J. R. 2004
[9] Silva, S. R. "Use of ultrasonographic examination for in vivo evaluation of body composition and for prediction of carcass quality of sheep." *Small Ruminant Research* 152 (2017): 144-157.
[10] Thwaites, C. J. "Ultrasonic estimation of carcass composition - a review." *Australian Meat Research Committee* 47 (1984): 1-32.
[11] Silva, S. R., & V. P. Cadavez. "Real-time ultrasound (RTU) imaging methods for quality control of meats." in *Computer vision technology in the food and beverage industries*, ed. D.W. Sun (Woodhead Publishing, Cambridge, 2012): 277-329.

producing species[12,13,14]. It is in this context that this article aims to present a broad view of the ultrasound history for evaluation of body composition and carcass in farmed animals.

THE EARLY HISTORY IN ULTRASOUND

At the end of the eighteenth century the Italian priest and physiologist Lazzaro Spallanzani (1729-1799), as a result of extensive experiments in bat navigation in complete darkness, is often cited as one of the pioneers of the discovery of ultrasound. In fact in 1794 Spallanzani published a paper in which he concluded that bats do not use their eyes to navigate in total darkness, but rather the meaning involved in that ability was hearing[15,16]. Spallanzani then deduced that bats emit high-frequency sound waves and hear echoes to identify the distance and position of surrounding objects[17,18]. This finding was only experimentally proven in the late 1930s, where it is pointed out that bats emit high-frequency sound from forty-five to fifty kilocycles per second[19]. The human is sensitive to sounds of up to twenty thousand cycles per second - 20 kHz[20]. In 1841, Swiss physicist Jean-Daniel Colladon conducted experiments on Lake Geneva, calculated the speed of sound in water at 1435 m / sec, demonstrating that sound travelled four times faster in water than in air. Later, in 1877, John William Strutt (aka Lord Rayleigh) published The Theory of Sound, which became the basis for the science of ultrasound[21]. Three years later, in 1880, the discovery of the piezoelectric properties of certain crystals by the Curie brothers was a major milestone in the development of ultrasound. In practice, a piezoelectric crystal produces electricity under pressure and exhibits slight movement when an electric field is applied to it[22]. This finding lays the groundwork for subsequent pulse-echo uses during World War I and World War II[23,24], or as a medical diagnostic tool. In

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12 Stouffer, J. R. 2004
13 Scholz, A. M.
14 Silva, S. R.
15 Spallanzani, L., Lettere sopra il sospetto di un nuovo senso nei pipistrelli (Torino, Stamperia Reale, 1794).
16 Riccucci, M. "Lazzaro Spallanzani". *Bat Research News* 49 (2008): 191-194.
17 Galambos, R. "The avoidance of obstacles by flying bats: Spallanzani's ideas (1794) and later theories." *Isis* 34 (1942): 132-140.
18 Dijkgraaf, S. "Spallanzani's unpublished experiments on the sensory basis of object perception in bats." *Isis* 51 (1960): 9-20.
19 Pierce, G. W., & R. G., Donald. "Experimental determination of supersonic notes emitted by bats." *Journal of Mammalogy* 19 (1938): 454-455.
20 Oxenham, A. J. "How we hear: The perception and neural coding of sound." *Annual Review of Psychology* 69 (2018). 27-50.
21 Strutt, J. W., & Baron Rayleigh, The theory of sound. (Dover, New York, 2nd edition, 1945).
22 Manbachi, A., & R. S. C. Cobbold, "Development and application of piezoelectric materials for ultrasound generation and detection." *Ultrasound* 194 (2011): 187-196.
23 Kane, D., et al. "A brief history of musculoskeletal ultrasound:'From bats and ships to babies and hips'." *Rheumatology* 43 (2004): 931-933.
24 Katzir, S. "Who knew piezoelectricity? Rutherford and Langevin on submarine detection and the invention of sonar." *Notes and Records of the Royal Society* 66 (2012): 141-157.

this field, Karl Dussik and his brother the physicist Friederich Dussik, who began their studies in ultrasound in the late 1930s, presented in 1942 the first work with an ultrasound device for medical use to visualize the brain[25]. Although it was possible to have an image of the brain, the machine was unsuccessful because it produced artefacts that interfered with the image quality. Five years later the Dussik perfected a transmission-through technique that produced or echoed images of the ventricles of the brain which led them to think that low-intensity ultrasonic waves could be used to visualize the interior of the body[26]. A few years later, Wild[27] introduced the first use of a pulse-echo technique for measuring biological tissue and detecting tissue density. Two years later, Howry & Bliss[28] presented the equipment called Somascope (tissue vision) that allows obtaining an image of anatomical structures, which was perceived as very useful for medical diagnostic purposes. After these early applications, pulse-echo techniques were immediately recognized with the potential to address some important animal science issues related to animal breeding and animal composition.

ULTRASOUND APPLIED TO ANIMAL SCIENCE

The history of ultrasound applied to animal science can be divided into three phases. The first occurred with pioneering work on the making and development of simple 1D imaging equipment, the second evolved into 2D imaging, and the third when RTU devices were commonly applied and combined with other techniques like the computed tomography.

FROM THE A-MODE MACHINES TO THE MACHINES WITH 2D IMAGES

The first ultrasound studies to evaluate the in vivo carcass composition of meat species were published in the late 1950s. At this time, simple A-mode equipment (A - meaning amplitude) was used. With A-mode equipment, echoes formed from the boundaries of the target tissues and appear as peaks on an oscilloscope screen (Figure 1). The vertical axis represents the height (amplitude) of the peaks. The peak height is related to the acoustic properties of the tissue interfaces[29]. The distances between successive peaks represent different tissues, and often on the A-mode machines screen the horizontal

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[25] Dussik, K.T. "Ube die moglichkeit hochfrecluente mechanische Schwingungen als diagnostiches Hilfsmittel zu verwenden." *Zeitschrift für die Gesamte Neurologie und Psychiatrie* 174 (1942): 153-168.
[26] Shampo, M. A., & A. K., Robert. "Karl Theodore Dussik—pioneer in ultrasound." *Mayo Clinic Proceedings*. 70 (1995): 1136-
[27] Wild, J. J. "The use of ultrasonic pulses for the measurement of biologic tissues and the detection of tissue density changes." *Surgery* 27 (1950): 183-188.
[28] Howry, D. H., & W. R. Bliss. "Ultrasonic visualization of soft tissue structures of the body." *The Journal of Laboratory and Clinical Medicine* 40 (1952): 579-592.
[29] Thwaites, C. J.

axis was calibrated in millimeters so that the thickness of the tissue could be read directly[30]. The first use of ultrasound was performed with live cattle in 1956 by Temple and collaborates of the Colorado State University[31]. They use the sonar ultrasound equipment that was described by Howry & Bliss, Colorado Medical School, in 1952. The Somascope, soma meaning tissue and scope meaning vision. It was used by placing the transducer on the closely shaved back of the animal. A correlation of +0.63 was found between Somascope reading and carcass fat thickness at the same site. About a year later, European researchers reported some studies that measure the backfat thickness on live pigs[32,33] who used metal flaw detection ultrasound equipment.

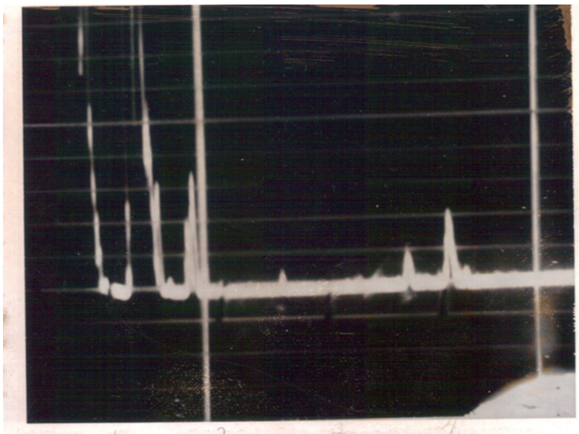

Figure 1. Example of an A-mode image from the Branson Sonoray 5 metal flaw detector scanner (Stouffer J.R. Author's personal collection).

In USA James Stouffer was encouraged by all of these reports and decided to investigate the use of ultrasound for evaluating live animals and carcasses. He was able to get a metal flaw detector ultrasound Reflectoscope, for Sperry Products, Danbury, Connecticut (Figure 2). The Sperry used the Reflectoscope to identify cracks in railroad rails. Early work with A-mode scanners focused on measuring backfat thickness, but it was soon felt the need also to perform muscle measurements such as rib-eye depth or area. To achieve muscle measurements, Stouffer[34] made a series of A-mode measurements at specific

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[30] Simm, G.
[31] Temple, R. S. "Ultrasonic and conductivity methods for estimating fat thickness in live cattle." *Proceedings American Society of Animal Science*, 7 (1956): 477-481.
[32] Claus, A. "The measurement of natural interfaces in the pig's body with ultrasound." *Fleischwirtschaft* 9 (1957): 552.
[33] Dumont, B. L. "Nouvelles méthodes pour l'estimation de la qualité des carcasses sur les porcs vivants. (New methods of estimation of carcass quality on live pigs.). *EAAP Meeting on Pig Progeny Testing, Copenhagen*. 1957.
[34] Stouffer, J. R. "Status of the application of ultrasonics in meat animal evaluation." *Proceedings Reciprocal Meat Conference* 12 (1959): 161-169.

intervals and angles with an A-mode equipment Sperry Reflectoscope equipped with a 1 MHz transducer and the results were plotted in a paper (Figure 3).

Figure 2. Use of Sperry Reflectoscope A-mode on lamb (Stouffer J.R. Author's personal collection).

This procedure provided encouraging results and showed that a multi-position scanning technique would be a step forward in accurately measuring areas with ultrasound, thus opening up the possibility of developing equipment that would allow 2D information.

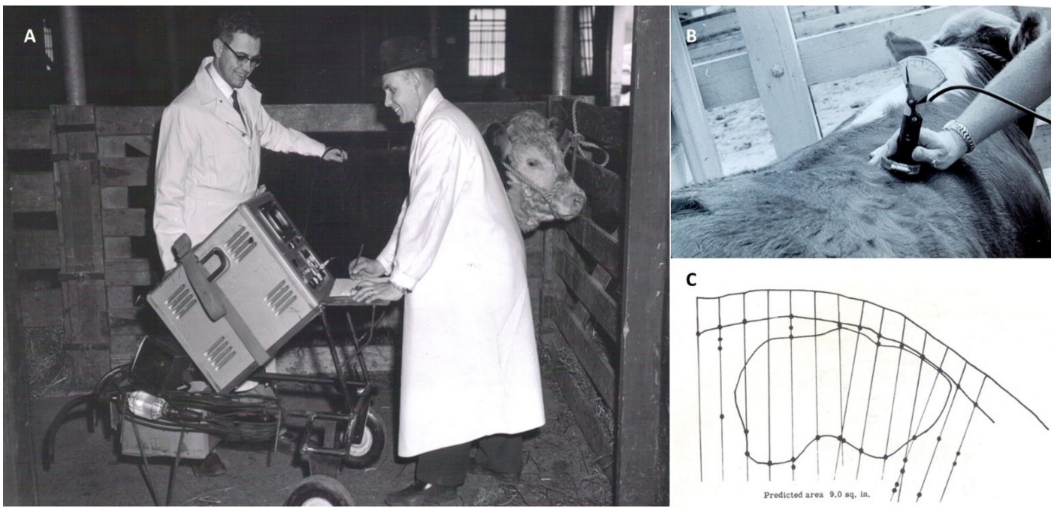

Figure 3. Use of Sperry Reflectoscope A-mode on cattle (A), detail of the transducer with angle measuring device (B) and the plotted on graph paper to produce a cross-sectional outline from which subcutaneous fat depth and muscle measurements (depth and area) could be measured (C) (Stouffer J.R. Author's personal collection).

THE ADVENT OF 2D MACHINES

The A-mode machines can measure tissue thickness but not area measurements. Also, this kind of equipment lacks anatomical information and often the thickness measurements of subcutaneous fat (SF) show erroneous results as a consequence of the formation, in some animals, of SF layers echoes that are confounded with the SF: Muscle interface[35]. To overcome these limitations, the B-mode presentation (B - meaning brightness) was introduced. In the B-mode display, an image of the object was built by integrating multiple A-mode signals[36]. In the late 1950s, Stouffer and his team developed equipment that allowed cross-sectional 2D images (Figure 4). This new approach shows the superior performance of the mechanical B-scan over the A-mode technology that was being used in the early 1960s. For 2D information, Stouffer et al.[37] investigated the possibility of developing a continuous scanning technique that produced a complete cross-section. To achieve this type of images, it was necessary to synchronize the transducer movement, placed on the back of the animal, and that of a camera with lens left open for a time exposure to record the progressive changes of the signals on the cathode ray tube to produce a scan record of the region being analyzed. The completed photograph can be seen after ten seconds of developing time in a Polaroid-Land camera.

Figure 4. First scanner for the rib eye area with A-mode baseline recording using the Sperry Reflectoscope metal flaw detector equipped with the Polaroid camera and the mechanism to synchronize the transducer movement with the camera (Stouffer J.R. Author's personal collection).

Over several years, Stouffer and his team have developed various equipment to improve image quality and achieve high repeatability in the images and measurements obtained[38]. After success with the Sperry Reflectoscope in obtaining cross-sectional images, other equipment was developed. An example of this

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[35] Hopkins, D. L. "The use of ultrasound to predict fatness in lambs." *Meat Science* 27 (1990): 275-281.
[36] Amin, V. "An introduction to principles of ultrasound." *Iowa State University. Study Guide* (1995): 1-34.
[37] Stouffer, J. R., et al. "Development and application of ultrasonic methods for measuring fat thickness and rib-eye area in cattle and hogs." *Journal of Animal Science* 20 (1961): 759-767.
[38] Stouffer, J. R. 1963.

is the prototype mechanical B-scan unit on a Branson model 6 metal flaw detector (Branson Instruments Company, Danbury, CT) that was used for evaluation of beef cattle at the International Livestock Exposition (Chicago, IL), November 1960. Some months later, the Prototype of Branson 510 scanner was introduced, and in 1964, the Branson model 12 introduced intensity-modulated A-mode with a curved guide for plotting fat and area[39]. In the late '60s, as a result of all the accumulated experience was introduced the Scanogram (Figure 5) produced by Ithaco Inc (Ithaca, NY). This commercial unit was the primary system used for the next two decades for most of live animal evaluations[40]. In this instrument, the transducer is motor-driven along a track, shaped to fit the back of different animal species while; the movement of the probe was captured by a camera photographing successive echoes that are displayed on an oscilloscope. A two-dimensional scan is built up by holding the shutter of the camera open as the probe travels the length of the track[41]. Because sound waves would not progress through the air to a coupling agent such as mineral or vegetable oil is first applied to the skin in the area to be observed to ensure the transmission of the sound waves into the subject.

Figure 5. Scanogram, commercial mechanical B-scanner, model 721 produced by Ithaco Inc. being used for examination of a pig (Stouffer J.R. Author's personal collection).

This equipment was operational until the early 1990s, and the latest work was published in 1992 in a cattle paper[42]. This high longevity is explained by the quality of the images (Figure 6), which allows high

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[39] Stouffer, J. R. 2004.
[40] Ibid
[41] Andersen, B. B., et al. "Comparison of ultrasonic equipment for describing beef carcass characteristics in live cattle (report on a joint ultrasonic trial carried out in the UK and Denmark)." *Livestock Production Science* 10 (1983): 133-147.
[42] Fiss, C. F., & J. W. Wilton. "Contribution of breed, cow weight, and milk yield to the preweaning, feedlot, and carcass traits of calves in three beef breeding systems." *Journal of Animal Science* 71 (1993): 2874-2884.

repeatability of the mediated and a good estimation capacity, which compares in several works with the RTU equipment[43,44].

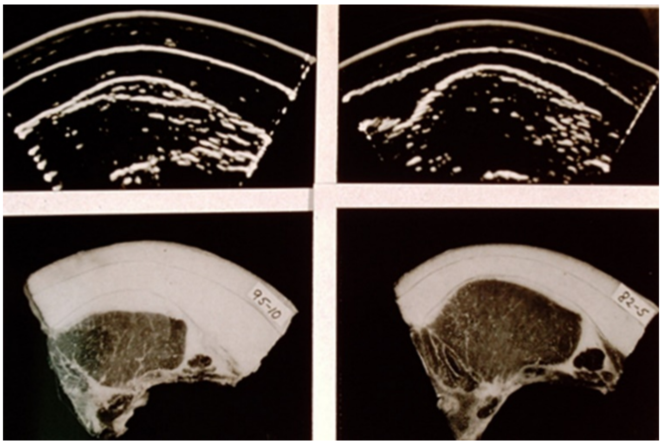

Figure 6. Examples of cross-sectional Scanogram images (top) and the equivalent cut (bottom) (Stouffer J.R. Author's personal collection).

In an exhaustive search in the Scopus animal science journals, it was possible to find works using the Scanogram in several species (Table 1).

Table 1. Number of articles by country and species on Scopus database using Scanogram equipment (models 721 and 722).

Country	Cattle	Horse	Pig	Sheep	Turkey
Australia	3		1	3	
Canada	6				
Denmark	2				
Italy	1				
Japan	1				
New Zealand	1			1	
United Kingdom	17		2	5	
United States of America	8	1	8	2	1

The emergence of real-time ultrasound machines

Real-time ultrasound (RTU), as the name implies, is a technique that uses repeated scanning to form an almost instantaneous image, hence real-time designation[45]. The entire image must be displayed within 33 ms or less in order to update the information at real-time frame rate[46]. The probes used in the RTU can produce images of a section of an anatomical region under study (e.g. *Longissimus thoracis et lumborum*), and a single scan enhances its potential, providing an image in grayscale. The technique was

[43] Silva, S. R., & V. P. Cadavez.
[44] Silva, S. R.
[45] Simm, G.
[46] Insana, M. F. "Ultrasonic imaging," in *Encyclopedia of Biomedical Engineering*, eds. M. Akay & N. Hoboken (New York, John Wiley and Sons, 2006): 1-9.

primarily developed for human medicine to visualize rapidly moving organs such as the heart and its valves[47]. Siemens Medical Systems launched the first real-time ultrasound scanner in 1965[48]. This equipment (Vidoson) consisted of a display oscilloscope and a transmitter-receiver in which two 2.5 MHz transducers rotate in the focus of a parabolic acoustic mirror, so the ultrasound beam directed to the mirror is reflected to the patient. As the transducers rotate, a continuous linear scan is produced, which is repeated approximately 16 times per second[49]. Later in 1973, the company Advanced Diagnostic Research Corporation introduced the linear array transducer technology that contained 64 inline crystals, which allowed for real-time imaging with higher quality and speed[50]. The launch of real-time ultrasound (RTU) equipment led to the end of B-mode scanners, such as the Scanogram, which had been phased out in the late 1980s[51]. The first RTU equipment employed in animal science was the Danscanner[52]. This equipment, which was built for use with animals, had a probe with 80 piezoelectric elements arranged in a row on a fluid-filled head, shaped like the dorsal-lumbar of the species in which it is used[53]. In the late 1970s and early 1980s, some comparisons of Danscanner with other equipment such as A-mode and Scanogram were performed. These studies were performed on sheep[54], cattle[55] and swine[56,57]. In general, the results proved to be favorable to Danscanner in estimating carcass equivalent measurements and repeatability with results very close to those obtained with the Scanogram. In the early 1980s, RTU machines developed for human medicine became the most widely used in predicting carcass traits of meat species. The first works were performed with Aloka 210 (Figure 7A) and Toshiba Sonolayer SL32 equipment[58]. These equipment were portable, robust enough to be used in animal science and their images were of good quality, which allowed for better accuracy and precision in predicting carcass and

47 Szabo, T. L. Diagnostic ultrasound imaging: inside out (Academic Press, Connecticut, USA, 2004).
48 Woo, J. "A short history of the development of ultrasound in obstetrics and gynecology." *History of Ultrasound in Obstetrics and Gynecology* 3 (2002): 1-25.
49 Winsberg, F., et al. "Continuous ultrasound B scanning of abdominal aortic aneurysms." *American Journal of Roentgenology* 121 (1974): 626-633.
50 Otto, C. M. "Principles of echocardiographic image acquisition and Doppler analysis." in *Textbook of Clinical Echocardiography*. ed. C. M. Otto (WB Saunders, Philadelphia, 2000): 1-3.
51 Szabo, T. L.
52 Busk, H. "Improved Danscanner for cattle, pigs and sheep." In *In vivo Measurement of Body Composition in Meat Animals*, ed D. Lister (London, Elsevier, 1984): 158-162.
53 Thwaites, C. J.
54 Kempster, A. J., et al. "An evaluation of two ultrasonic machines (Scanogram and Danscanner) for predicting the body composition of live sheep." *Animal Science* 34 (1982): 249-255.
55 Andersen, B. B.
56 Kempster, A. J., et al. "A comparison of four ultrasonic machines (Sonatest, Scanogram, Ilis Observer and Danscanner) for predicting the body composition of live pigs." *Animal Science* 29 (1979): 175-181.
57 Alliston, J. C., et al. "An evaluation of three ultrasonic machines for predicting the body composition of live pigs of the same breed, sex and live weight." *Animal Science* 35 (1982): 165-169.
58 Silva, S. R., & V. P. Cadavez.

meat traits[59]. Also, various types of probes could be used, which made these types of equipment very flexible and adjusted to different species and work purpose. Besides, it was possible to connect a video, a camera or even a thermal printer, which allow image recording for later analysis. Throughout the 1990s, various RTU types of equipment were used in research on estimating animal composition and meat characteristics[60], but the most notable equipment was the Aloka 500 (Figure 7B).

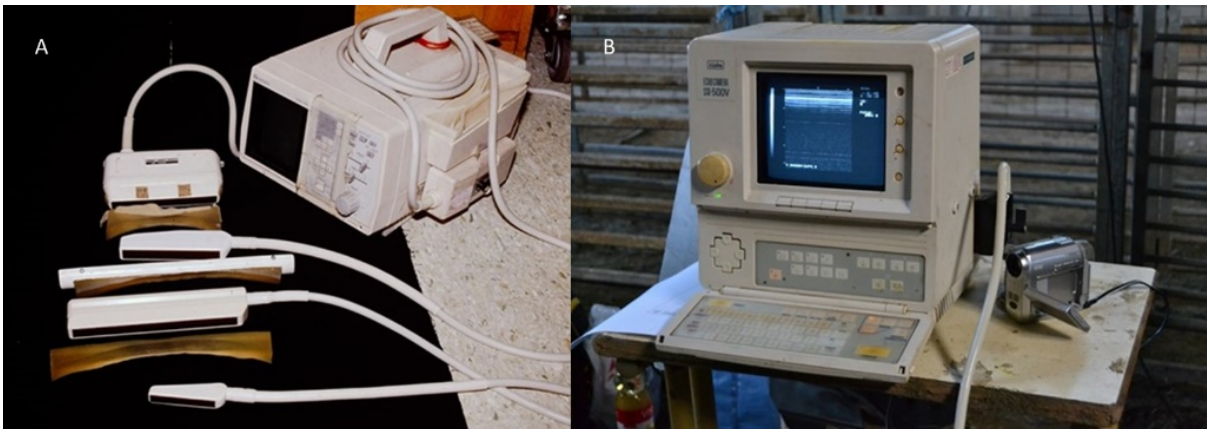

Figure 7. Aloka 210 scanner with several linear ultrasound probes and specially shaped standoff guides for each species (A) (Stouffer J.R. Author's personal collection) and Aloka SSD 500V equipped with a video camera to image capture (B) (Silva S.R. Author's personal collection).

This equipment presented technological evolution as monitor bigger than the SSD-210, alphanumeric keyboard, video output and also the possibility of being equipped with different linear probes of different frequency. Among them a large one at 17 cm, 3.5 MHz which have sufficient length to allow all *Longissimus thoracis et lumborum* muscle area in an RTU image. It is undoubtedly for these attributes that the first works in which this equipment was used are in the early 1990s, shortly after its launch in 1990[61] and the last are of the present year[62]. Over this period, there are hundreds of works that have been published related to carcass or meat characteristics prediction that used this equipment. Over the years, technologies have been sought to improve the RTU. Over the years, technologies have been sought to improve the RTU. One such example is related to the development of a system for pork carcass evaluation with an automated and computerized ultrasonic system[63]. This system called carcass value

[59] Stouffer, J. R. 2004.
[60] Silva, S. R., & V. P. Cadavez.
[61] Stouffer, J. R. "Using ultrasound to objectively evaluate composition and quality of livestock. 21st Century Concepts Important to Meat-Animal Evaluation." *University of Wisconsin, Madison, WI* (1991): 49-54.
[62] Detweiler, R. A., et al. "The impact of selection using residual average daily gain and marbling EPDs on growth, performance, and carcass traits in Angus steers." *Journal of Animal Science* 97 (2019): 2450-2459.
[63] Liu, Y., & J. R. Stouffer. "Pork carcass evaluation with an automated and computerized ultrasonic system." *Journal of Animal Science* 73 (1995): 29-38.

technology (CVT) is based on an Aloka 500V scanner, a 3.5-MHz linear array transducer, a computer and Auskey Software image analyzer (Figure 8A). The Auskey Software determines carcass composition, fat depth, muscle depth and per cent lean, from a longitudinal scan RTU image, as shown in Figure (8B).

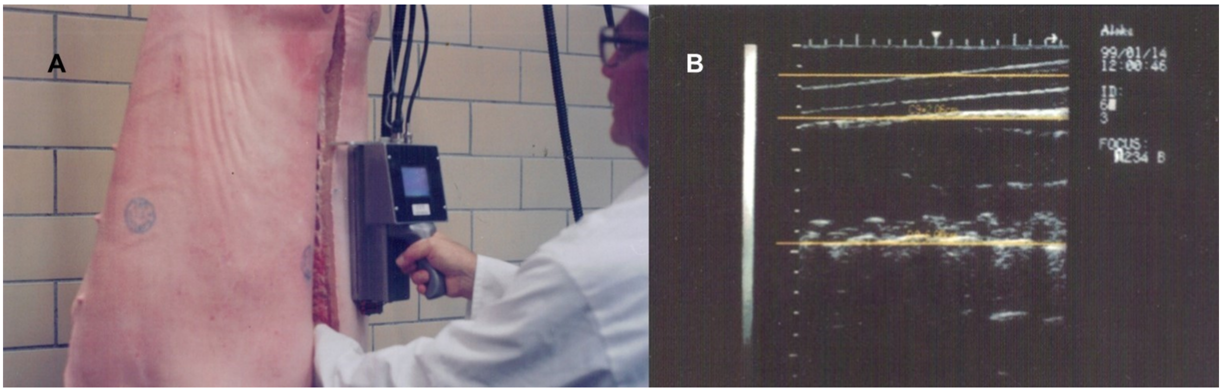

Figure 8. Carcass value technology (CVT) scanning a carcass (A) and longitudinal scan RTU image (B) (Stouffer J.R. Author's personal collection)

The average fat and muscle depths are determined from 5 sub-region measurements and displayed on the screen of the handheld scanner. One side of the pork carcass is scanned longitudinally from the last rib to the tenth rib five centimeters from the backline at a chain speed of 1,000 carcasses per hour. IBP/Tyson Meatpacking Company has been using this technology since 1998 to the present for predicting lean percentage as a basis for paying producers for 19 million hogs per year. This evaluation procedure has also been used by many Swine Breeder Companies throughout the world as shown in Figure (9). Similar Auskey Software has been developed and used by Beef Cattle Breeders for determining fat depth, muscle depth and marbling between the 12th and 13th ribs of live cattle.

Figure 9. Evaluation procedure of a swine using the AUSkey system (Stouffer J.R. Author's personal collection)

FUTURE

Throughout the history of the development and use of the ultrasound technique to animal science, it becomes clear that this technique plays an essential role in the objective evaluations of live animals for carcass-related traits and meat quality. There is now a need for accurate and objective body composition and carcass information that is required for performance testing in animal breeding programs, for precision feeding and the development of value-based payment and marketing systems. Technological development will allow RTU and software equipment with higher, more automated and more accurate image processing capabilities. Links to other fields, such as genomics, which require very accurate phenotypic information, will benefit significantly from the evolution of RTU. Based on current knowledge, a stronger connection between RTU and computed tomography will also be expected in the animal study of body composition in longitudinal experiments and also in two-step selection programs.

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