Evolution and use of ultrasonic technology in the swine industry

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ABSTRACT: The use of ultrasound to measure biological tissue dates back to at least 1950, and early ultrasonic work focused primarily on applications to human medicine. The application in livestock species was somewhat slow due to the cumbersome, fragile machines and high investment costs. Historically, the application of ultrasound to swine has focused on composition and reproductive status assessment, with most of the research carried out through land-grant institutions. Early researchers evaluated the relationship among ultrasound measurements and carcass measures. However, the accuracy of the early amplitude-depth (A-mode), single-crystal devices was often quite variable. The introduction of B-mode (brightness modality) ultrasound, using multiple-crystal transducers and displayed in real-time, greatly enhanced the accuracy of live animal composition and provided an understanding of extraneous effects on accuracy of measurements. In 1993, the U.S. swine industry implemented a national ultrasound training and certification program for composition assessment. Application of ultrasound principles has expanded to include on-line carcass composition estimation in packing facilities as well as on-farm applications for the measurement of lean growth rate and subsequent nutrition modeling. Early research in the reproduction area used Doppler ultrasound systems that measured fluid flow within the uterus. A-mode systems were evaluated in the mid 1970s. Doppler and A-mode devices, while relatively inexpensive and accurate within specified time frames during gestation, are less accurate than real-time ultrasound. Research indicates real-time ultrasound is an accurate system of pregnancy detection as early as 22 d after first mating. Enhanced technology, increased portability, and reduced cost have allowed ultrasound to be a common tool used in swine units, packing plants, and research institutes. Future research in the areas of composition, muscle quality, and reproductive biology, along with enhanced imaging capabilities, will lead the way to new, innovative applications.

Key Words: Composition, Detection, Pregnancy, Swine, Ultrasound

J. Anim. Sci. 80(E. Suppl. 2):E19–E27

Introduction

The application of ultrasound technology in the swine industry dates to the late 1950s when Claus (1957) reported research results evaluating the feasibility of using ultrasound to evaluate carcass composition on the live pig. This paper was quickly followed by additional research reports (Hazel and Kline, 1959; Price et al., 1960ab; Stouffer et al., 1961) that described the accuracy of live animal measurements obtained with ultrasound compared with metal probe measures on live pigs and traditional carcass measures. These initial findings corresponded closely with a change in focus by the swine industry to reduce fat and increase muscle in existing swine populations and the establishment of swine testing centers throughout North America and Europe. Since the early application of ultrasound, geneticists, nutritionists, meat scientists, and engineers have actively pursued advances in methodology and developed additional applications for ultrasound technology to improve the swine industry.

Enhancing reproductive efficiency within the swine industry has been a second focal point for ultrasonic research and application. Fraser and Robertson (1968) reported encouraging results for research conducted using Doppler ultrasound instrumentation to detect pregnancy status of breeding females. As with composition estimation, these early results led to expanded research initiatives to improve the accuracy and early detection capabilities of ultrasound for determining pregnancy status. Advanced ultrasound image capabilities continue to expand the applications of ultrasound for reproductive purposes.

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[1] Salaries and research support from state and federal funds appropriated to the Ohio Agric. Res. and Dev. Center, The Ohio State University. Manuscript 37-01AS.

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Received July 27, 2001.

Accepted December 7, 2001.

Table 1. Partial listing of research reports evaluating the accuracy of ultrasound devices

Research publication	Ultrasound device	Ultrasound type
Hazel and Kline, 1959	Kelvin and Hughes Mark V	A – mode
Price et al., 1960a	Sperry Reflectoscope	A – mode
Price et al., 1960b	Sperry Reflectoscope	A – mode
Stouffer et al, 1961	Sperry Reflectoscope	A – mode
Anderson and Wahlstrom, 1969	Branson Model 212	A – mode
Adams et al., 1972	Lean Meater	A – mode
Alliston et al., 1982	Sonatest	A – mode
	Scanogram	Linear
	Danscanner	B – mode
Sather et al., 1982	Krautkramer USM2	A – mode
	Scanoprobe 731A	A – mode
Mersmann, 1982	Scanogram Model 722	A – mode
Busk, 1986	Renco Lean Meater LM7	A – mode
	Krautkramer USK-6	A – mode
	Aloka SSD 210DX	B – mode
	Scanmatic SM-1	A – mode
	Danscanner	B – mode
Forrest et al., 1986	Technicare 210DX	B – mode
Kanis et al., 1986	Krautkramer USK6	A – mode
	Renco Lean Meater	A – mode
Sather et al., 1986	Krautkramer USM2	A – mode
	Scanoprodbe 731A	A – mode
Lopes et al., 1987	Technicare 210DX	B – mode
McLaren et al., 1989	Johnson and Johnson 210DX	B – mode
Turlington et al., 1990	Technicare 210DX	B – mode
Christian and Moeller, 1990	Aloka 500	B – mode
Moeller et al., 1998	Aloka 500	B – mode

The objective of this review article is to highlight the early applications and the evolution of ultrasound technology within the swine industry with a focus in the areas of composition assessment and improvement in reproductive efficiency.

Ultrasound as a Tool to Measure Composition

Instrumentation and Accuracy

Response to market signals in the 1950s increased interest in producing leaner pigs, resulting in the development of genetic selection programs to meet this goal. Improving the rate of genetic improvement and the accuracy of selection required methods to evaluate composition in the live pig. Hazel and Kline (1952) developed the metal backfat probe, an invasive method to measure backfat depth, and reported correlations above 0.80 between live and carcass measures of backfat. Although accuracy of the metal probe was reasonable, the potential for infection at the points of incision and the need for animal restraint made this technique difficult and undesirable. The first reported use of ultrasound for measuring backfat (Claus, 1957) was quickly followed by additional research evaluating this new, noninvasive technology. Numerous manufacturers supplied ultrasound instrumentation to the swine industry throughout the years and many research projects focused on evaluating accuracy as well as comparisons among machines. Table 1 lists several research articles published since the late 1950s and the types of machines tested.

Early ultrasound devices utilized amplitude-depth (A-mode) ultrasound technology involving a sound emitted from a single quartz crystal located within the ultrasound transducer. Sound waves emitted from the transducers entered the animal and traveled through the biological tissues (skin, fat, fascia, and muscle), and differences in acoustic density resulted in sound being reflected back through the transducer to receiver. Using time/distance relationships, the reflected waves were converted into signals that were interpreted by using either an oscilloscope, a series of lights or, in later years, LED readout.

The A-mode, single-point estimates of fat and muscle depth were generally compared with carcass measurements at multiple locations along the loin, just off the midline, to determine accuracy relative to the carcass measurement. Multiple A-mode measures, taken at various angles of incidence, were recorded on Polaroid film and used to obtain the first crude, two-dimensional, cross-sectional view of the loin for estimation of loin muscle area (Price et al., 1960b; Stouffer et al., 1961). Many trials reported that early ultrasound instrumentation was not as effective for measurement when backfat depths were large (Claus, 1957; Price et al., 1960b) and when taken over the shoulder region due to the presence of the trapezius muscle. Stouffer et al. (1961), an early pioneer in ultrasound, noted the need for further refinement of instrumentation due to the large variation found between operators interpreting images, a concern that was later expressed in research reported by Sather et al. (1982), who indicated operator ability was more critical than machine when measuring composition with ultrasound. Meyer et al. (1966) published a research bulletin summarizing research findings and results describing the application of ultrasonic techniques for estimation of live animal and carcass measurements.

Accuracy of A-mode ultrasonic devices was quite variable within and across research reports. Hazel and Kline (1959) reported relatively high correlations (r = –0.76 to –0.90) between live ultrasound fat depth and percentage lean cuts. Price et al. (1960a) reported correlations of 0.89, 0.91, and 0.89 between live ultrasound, live ruler, and carcass ultrasound backfat in relation to carcass backfat, respectively, when fat was measured at the center of pigs' backs. Correlations were significantly smaller for off-midline backfat measured near the shoulder (Anderson and Wahlstrom, 1969; Adams et al., 1972; Mersmann, 1982). Sather et al. (1986) compared the effect of operator, machine, and probe site and reported fat measures were more accurate when only two fat layers were measured and noted machine × operator interactions demonstrated that interpretation ability was not the same for either operators or machines. Summarized across trials, A-mode ultrasound was consistently less accurate at locations and on pigs where fat depth was large and A-mode frequently underestimated corresponding measurements on carcasses. Sather et al. (1986) hypothesized that with some A-mode machines, the underestimation may have been a function of the inability to consistently define the third layer of fat that covers the loin muscle of the pig.

Early attempts to measure loin muscle area with A-mode revealed only moderate correlations with carcass loin muscle area measurements (Price et al., 1960b, r = 0.74; Stouffer et al., 1961, r = 0.70). The primary problems with multiple A-mode measures to outline the loin were 1) lack of highly trained technicians, 2) animal movement and restraint, and 3) the time involved in obtaining images. Attempts to predict carcass loin muscle area from ultrasonic loin depth were not predictable or reliable due to differences in muscle shape and the inability to consistently differentiate the third layer of fat over the loin from the muscle. Busk (1986) reported correlations between loin depth and area of 0.51 and 0.60 at the 10th and last rib locations, respectively.

Although the accuracy of A-mode devices was often less than ideal, the relatively low investment cost and perceived ease of operation made them widely used for seedstock selection, central testing programs, university and industry research, and on-farm applications. Still today, many swine producers and researchers continue to utilize A-mode technology for measuring fat depth due to the low investment cost.

The introduction of B-mode (brightness mode), real-time ultrasound represented a significant advance in our ability to measure composition of the live animal and hanging carcass. B-mode ultrasound utilized multiple sound-emitting quartz crystals arranged in a linear array within the transducer and produced a two-dimensional image of the tissue being investigated on a video screen. The image appeared in real-time as a result of continuous transmission and reception of sound waves that were converted to images at a frame-refreshing rate between 8 and 16 frames per second. Images used to estimate composition were created using ultrasound frequencies between 3.0 and 5.0 MHz emitted from transducers containing 64 to 120 quartz crystals along a length of 12 and 17 cm. This allowed the entire loin and individual fat layers covering the loin to be viewed and allowed technicians to refine anatomical location of the probe based on the shape of the loin muscle and presence or absence of other muscle systems. A new wave of experimentation started in the late 1970s and through the 1990s as university researchers attempted to evaluate the efficacy of real-time ultrasound.

Resolution capabilities of the first real-time machines, generally 256 × 256 lines of resolution, provided a significant challenge for researchers. An early report comparing real-time ultrasound (Danscanner) with A-mode devices (Alliston et al., 1982) found A-mode devices were superior to the real-time device and the addition of real-time loin muscle area did not improve the ability to predict carcass lean. Forrest et al. (1986), using a Technicare 210DX fitted with a 3.5-MHz linear probe, compared carcass and live real-time measures with split carcass measurements and reported carcass real-time measurements were more highly correlated than live real-time with the measured carcass value for backfat (r = 0.75 vs 0.71) and loin muscle area (r = 0.70 vs 0.68) at the 10th rib location. Busk (1986) compared off-midline fat at three locations (10th rib, last rib, and last lumbar vertebrae) using real-time (Aloka SSD-210DX fitted with a 3.5-MHz, 12.5-cm linear transducer) and A-mode machines. The results showed no differences among machine, but for all machines fat was more highly correlated at the 10th rib (r = 0.87 to 0.91) than at the last rib (r = 0.78 to 0.90) and last lumbar locations (r = 0.67 to 0.73) across machines. Lopes et al. (1987) reported correlations between real-time 10th rib backfat and split carcass measurements ranging from 0.80 to 0.89 with mean absolute deviations between real-time and carcass fat depth ranging from 2.2 to 6.2 mm. They also reported loin muscle area correlations at the 10th rib ranged from 0.27 to 0.71 with mean absolute deviations from 2.5 to 6.5 cm^2. Proposed reasons for large variability in real-time accuracy, as measured by the correlation coefficient, across research trials was attributed to resolution capabilities of the machine, experience of the operator (McLaren et al., 1991), and potential shifts in fat and muscle when comparing a hanging carcass with a standing live measure (Turlington, 1990).

Houghton and Turlington (1992) reviewed the accuracy of ultrasonic measurements as predictors of carcass measurements across species and noted differences due to species, technician, and instrumentation. They noted correlations were the most common method of accuracy assessment but that correlation coefficients were not a good measure of accuracy because 1) correlations are influenced by variability within the population studied, 2) correlations do not reflect a consistent over or underestimation bias, and 3) correlations are not easily understood by the industry. They suggested frequency distributions of the absolute deviation between ultrasound and carcass measure as a better method of evaluating accuracy. Smith et al. (1992) reported real-time 10th rib backfat averaged 4.4 mm less than corresponding carcass measures and the absolute difference between real-time and carcass measures was 4.78 mm. Moeller (1990), using an Aloka 500 fitted with a 3.5-MHz, 12.5-cm linear probe, reported an average underestimation bias of 2.0 mm and 2.3 cm^2 for backfat and loin muscle area, respectively, at the 10th rib location. Turlington (1990) reported underestimation bias of 1.0 mm when comparing real-time backfat with a hanging carcass and an overestimation of 1.0 mm when comparing real-time backfat with a carcass frozen in standing position, which supported a theory that fat and muscle may shift when a carcass is hung by its rear leg. Bates et al. (1994) reported the influence of muscle quality on the accuracy of real-time measurements taken with an Aloka 500 fitted with and a 3.5-MHz, 12.5-cm linear transducer and demonstrated that real-time measures of loin muscle area on normal-quality loin showed smaller underestimation bias (0.19 cm^2 vs 2.9 cm^2) and smaller absolute deviation (1.9 cm^2 vs 4.83 cm^2) compared with pale, soft, exudative (PSE) loins.

Robinson et al. (1992) described a statistical measure of variation termed the standard error of prediction (**SEP**) as the best measure of accuracy of ultrasonic accuracy compared with the carcass. The standard error of prediction statistic is calculated using the following formula:

$$\text{Standard error of prediction}=\sqrt{\frac{\Sigma(\mathit{Carcass}_i-\mathit{Ultrasound}_i-\mathit{Bias})^2}{N_i-1}}$$

for $i = 1$ to n. *Bias* = the average difference between carcass and ultrasound measurements within the subset being analyzed, and N_i = the number of animals within the subset being analyzed.

Using this formula, accuracy is assessed after adjustment for bias and a few larger errors (deviations between carcass and ultrasound measures) are considered more serious than numerous small errors due to the deviations being squared. Moeller and Christian (1998) reported average underestimation bias of 1.15 mm, average absolute deviation of 2.77 mm, and average SEP for backfat of 3.21 mm in a study involving 1,095 animals from eight purebred breeds of swine when comparing real-time to carcass measures. An Aloka 500 machine with 512 × 512 lines of resolution was used in this study. Loin muscle area measurements in the same test showed an underestimation bias by real-time of 0.16 cm^2, average absolute deviation of 3.29 cm^2, and SEP of 3.99 cm^2. When the data were analyzed within standardized measurement levels for carcass backfat and loin muscle area, real-time was found to slightly overestimate (0.5 mm) fat thickness on lean pigs (< 24.1 mm) and underestimate (1.0 to 3.1 mm) fat thickness in fat pigs (> 24.1 mm), with SEP values significantly better for pigs having less than 30.3 mm carcass backfat (SEP = 3.1 mm vs 3.8 mm). Real-time ultrasound instrumentation overestimated carcass loin muscle area by 2.32 cm^2 when the carcass measured < 32.3 cm^2 and underestimated carcass loin muscle area by 2.26 cm^2 for carcasses with loin muscle area > 39.1 cm^2. The SEP values were smaller for loin muscle area when carcass measurements were < 39.1 cm^2. This study verified earlier reports that magnitude of the carcass measurement affects the accuracy of ultrasonic estimates.

Cisneros et al. (1996) compared transverse and longitudinal real-time techniques on live pigs as predictors of lean cut yield and fat-free lean content in the carcass. Their results showed little difference in prediction ability (R^2) when comparing a transverse scan to a longitudinal scan but did note that longitudinal placement of the probe was more accurate when taken anterior to the last rib location compared with a posterior last rib location. Improved image resolution, expanded resolution (512 × 512 lines) capabilities, and enhanced image contrast (64 to 256 shades of gray) have improved the utility of ultrasound for measuring loin muscle area. Improved image quality allowed the lateral and bottom boundaries of the ultrasound image to be more readily defined and easier to interpret, resulting in improved ccuracy and repeatability of the technique.

Serial Measurements of Composition and Lean Growth Modeling

Another important focus of ultrasonic research was the serial measurement of pigs to predict composition at various stages of life. The implications of accurate knowledge of composition affect nutritional formulation, studies of growth and development, adjustment factors for breeding animal evaluation, and practical on-farm management decisions that affect efficiency of production. Noffsinger et al. (1959), Cox (1963), and Quijandria and Robison (1971) conducted serial ultrasound studies to evaluate fat deposition differences in breeds and sexes and found fat deposition was linear in the weight ranges studied. Cooksley and Cunningham (1977) reported that 98% of variation in backfat thickness could be explained by a linear relationship with weight. Ahlschwede et al. (1978) in one of the largest studies reported (n = 54,085 boars) determined that the relationship between backfat and weight was essentially linear with only a small deviation accounted for by nonlinear effects. Mersmann (1984) reported results suggesting that curvilinear deposition of backfat occurred for off-midline fat at one-fifth and three-quarter body length locations and linear deposition occurred at the one-half body length location.

Mersman (1984) reported nonlinear deposition of loin muscle area at the one-half body length location between d 56 of age and 90 kg, and McLaren et al. (1989) reported significant linear and quadratic regression coefficients for serial measures taken from 8.9 to 98.5 kg live weights. In contrast, Tess et al. (1986) reported fat, lean, and protein accretion was linear between 10 and 24 wk of age, and Moeller (1990) reported linear deposition for fat and loin muscle area between 70 and 105 kg live weight. Moeller et al. (1998) reported linear deposition of backfat and loin muscle area at the 10th rib location and a quadratic component that accounted for less than 1% of the variation in the best-fitting regression equation over a weight range from 70 to 105 kg.

Improved genetics, capable of maintaining high levels of lean to heavier live weights, and a better understanding of nutritional needs of the pig have expanded the interest in using ultrasound to predict composition at various live weights and matching nutritional programs to more accurately reflect the nutrient needs for lean growth. Accurate lean growth models rely heavily on the ability to accurately assess both backfat and loin muscle on the live pig via ultrasound. The portability and improved accuracy of real-time machines as well as more highly trained technicians now allow independent swine producers to collect serial scan information at a relatively low cost and develop farm-specific nutritional programs to meet their genetics and environment.

Implications for the Packing Industry

The packing industry is constantly searching for accurate, noninvasive technology to estimate value of the carcass for merit based purchasing. Ultrasound technology is currently being used in some U.S. swine packing plants to determine carcass lean content and payment schedules. Ultrasound systems used in packing facilities includes relatively simple A-mode technology, more complex B-mode instrumentation, and very complex, multi-transducer A-mode systems utilizing computer imaging to differentiate fat and muscle. An initial, and sometimes ongoing, problem with ultrasound in packing plants was the ability to consistently establish appropriate contact between the transducer and the carcass at line speeds that can exceed 1,000 carcasses per hour. Poor contact between the probe and the carcass results in either no measurement or a measurement with the potential for large errors. A second problem experienced has been related to durability of ultrasound devices in an environment that is often less than ideal for complex circuitry. In addition, the consistency of the angle and location of the transducer with respect to anatomical references on the carcass are critical factors that affect accuracy in packing plant situations.

The UltraFom (SFK Technology A/S, Denmark) ultrasonic system represents an A-mode device used to measure fat and muscle depth on the hot carcass. The UltraFom can incorporate either single or multiple transducers to allow for measurement at one or multiple anatomical locations. As with all A-mode devices, the accuracy of the device is a function of transducer angle, consistency of anatomical location, and experience of the operator. A newer, more advanced UltraFom 300 uses 64 ultrasound-emitting crystals to measure fat and muscle depth. The UltraFom is capable of measure carcasses at line speeds of 1,200 per hour.

The AutoFom (SFK Technology A/S, Denmark) is a complex A-mode ultrasonic instrument, utilizing 16 individual transducers positioned in a U-shaped trough. The hot, wet swine carcass is moved across these transducers from tail-head through the shoulder with the reflected ultrasonic signals recorded and analyzed using mathematical algorithms to predict composition of the total carcass as well as primal proportions. Carcass measurements are taken every 5 mm along the length of the carcass and every 25 mm along the width of the carcass, with a total of approximately 3,000 measurements per carcass. This technology offers significant advantages due to the ability to measure whole-body composition and the absence of a human operator, but at this time algorithms to estimate lean are still being developed.

Animal Ultrasound System (**AUS**) (Animal Ultrasound Services, Ithaca, NY) utilizes B-mode instrumentation to assess backfat and loin muscle depth from a longitudinal image obtained approximately 5 to 6 cm off the midline from the last rib forward approximately 17 cm. The AUS system utilizes a 17-cm, 3.0-MHz, linear array transducer. Fat depth and loin depth to the bottom of the intercostals spaces is measured at various locations along the length of the transducer and used to estimate percentage lean in the carcass. Liu and Stouffer (1995) reported R^2 values of 0.88 and a residual standard deviation of 0.54 kg when predicting defatted, deboned weight of lean in the four lean cuts and an R^2 of 0.92 with an residual standard deviation of 0.49 kg when predicting weight of grade lean. The accuracy of the AUS system appears to be influenced by transducer location and angle, operator experience, and clarity of the images obtained at line speeds.

Technician Education and Certification

In an effort to improve the accuracy and consistency of ultrasonic data collected in the swine industry, the National Swine Improvement Federation has conducted ultrasound education and certification clinics every year since 1993. The focus of these clinics has been to provide a forum for ultrasound technicians to interact and discuss the critical factors that affect the accuracy of ultrasound procedures. The educational program focuses on 1) understanding the anatomy of the animal, 2) applying ultrasound technology to the anatomy, 3) factors affecting image quality and consistency, 4) image interpretation, and 5) an explanation of why and how accuracy is assessed.

Technician certification consists of hands-on scanning, during which technicians are required to scan and interpret ultrasonic backfat and loin muscle area at the 10th rib on 50 market hogs with varying levels of fat depth and loin size. Market hogs are renumbered and scanned a second time to assess the repeatability of backfat and loin muscle area by each technician. Ultrasound measurements are compared with split carcass measurements obtained by two experienced meat scientists with the requirement that the maximum deviation between the two carcass measurements be no more than 1.3 mm for backfat and 1.29 cm^2 for loin muscle area. Certification criteria for backfat depth are as follows: standard error of prediction = 3.8 mm, repeatability 3.8 mm and bias = ± 3.8 mm. Criteria for loin muscle area are the following: standard error of prediction = 3.22 cm^2, repeatability = 3.22 cm^2, and bias = ± 3.22 cm^2. Technicians must meet all criteria (standard error of prediction, repeatability, and bias) to certify for backfat and (or) loin muscle area. Certification is extended for a period of 2 yr.

Applications of Ultrasound for Reproduction

Efficiency and cost of production for a swine enterprise are directly associated with reproductive efficiency of the breeding herd. The impact of poor conception and farrowing rates as well as the extra feed and housing costs for females that not reproductively active has long been an area of interest for researchers and swine producers. Almond and Dial (1987) summarized the pregnancy diagnosis techniques available to producers, including the use of various ultrasound techniques. The ideal pregnancy test as described by Almond and Dial (1987) has high accuracy (> 95%), low prevalence (< 5%) of false positive and false negative results, is safe, simple, and inexpensive and provides results within a few minutes. Researchers and clinicians (Almond et al., 1985) defined accuracy of pregnancy detection in terms of sensitivity (the ability to detect pregnant animals and reported as the proportion of pregnant animals that test positive) and specificity (the ability to detect non-pregnant animals, measured as the proportion of non-pregnant animals that test negative). Because ultrasound offered the opportunity to meet many of these targets a significant number of research projects in the past 30 yr have been conducted to study the efficacy of ultrasonic instrumentation.

Doppler Ultrasound

Fraser and Robertson (1968) and Fraser et al. (1971) reported on the use of a fetal pulse detector or “Doppler” device that consisted of an amplifier and transducer. The amplifier converted the ultrasonic reflections into audible signals, which in turn were used to detect pregnancy in swine and sheep. Doppler ultrasound devices detect changes in frequency of the sound waves as the sounds are reflected off moving objects such as blood flow, fetal movement, and gastrointestinal movement. Through analysis of the various sounds within the pregnant uterus, researchers were able to determine the distinct audible characteristics of the fetal heart, maternal pulsations, and fetal circulation from which a pregnancy status was diagnosed. The Doppler devices were commonly placed on either side of the rear flank, just above the teat line near the second and third last teats and angled toward the uterus or inserted rectally to detect pregnancy.

Fraser and Robertson (1968) reported 33 of 37 swine correctly diagnosed as pregnant when tested between 6 and 13 wk postbreeding; three animals were wrongly diagnosed pregnant and one animal was incorrectly diagnosed nonpregnant. McCaughey (1979) compared Doppler ultrasound with vaginal biopsy at scheduled intervals between d 20 and 39 of pregnancy and concluded that the Doppler instrument studied was unlikely to be satisfactory before d 27 of gestation, although the majority of sows were diagnosed by d 35. McCaughey (1979) also noted the average time required to diagnose a pregnancy was 3.0 min. Almond et al. (1985), in a report comparing Doppler with amplitude-depth ultrasound, reported both instruments were not reliable between d 15 and d 22 of gestation, the A-mode machine was more sensitive between d 23 and d 45 than the Doppler device, but the Doppler device had higher specificity of detecting nonpregnant females. Almond and Dial (1987) summarized that Doppler instrumentation was subject to extraneous sounds such as fans and measurements taken near feeding time and they noted a large variation in accuracy due to stage of gestation as well as significant differences in quality of instrumentation.

Amplitude-Depth (A-Mode) Ultrasound

A-mode (pulse echo) ultrasound is designed to detect and diagnose pregnancy based on the presence or absence of a fluid-filled uterus. The fluid-filled sacs surrounding the developing embryo and fetus create a fluid-filled void that is detected by the ultrasound waves and reported either on an oscilloscope, as an auditory signal, or as a light turned on when the fluid-filled voids are detected. The transducer is positioned in the rear flank area just above the teat line near the second to third last teat and angled anterior and dorsal toward the opposite loin. Errors in transducer placement, including posterior angle, can result in false-positive results due to detection of a full urinary bladder. Mycotoxins, such as zearalenone, and uterine infections can also create fluid accumulation and false-positive results (Almond and Dial, 1987).

Lindahl et al. (1975) reported results of a study utilizing A-mode technology using oscilloscope readouts. The results in laboratory and on-farm settings showed that of 612 sows diagnosed pregnant, 608 farrowed and only 2% of sows diagnosed nonpregnant farrowed a litter when measured between 30 and 90 d of gestation. They indicated the optimal range for determination of pregnancy with A-mode is from 30 to 90 d of gestation, below which not enough fluid is present in the uterus and beyond which fetal growth and reduced volume of uterine fluids reduces accuracy. Almond and Dial (1986) reported A-mode devices fitted with a diode ruler was less accurate than an A-mode device with an oscilloscope for both sensitivity and specificity. Almond and Dial (1987) reported that, across studies they had summarized, A-mode devices tended to have higher sensitivity but poorer specificity than Doppler devices, but they cautioned that variation in instrumentation was also a significant concern with A-mode ultrasound.

B-Mode Ultrasound

The development of B-mode, real-time ultrasound instrumentation had a significant impact on the ability to accurately detect pregnancy at early stages of gestation. By visualizing the internal anatomy in two dimensions on a video monitor, researchers and producers have the ability to correctly position the transducer and allows for assurance of the nature of the fluid-filled uterus. Transducers used for reproductive purposes generally range in frequency from 3.5 to 7.0 MHz, depending on the penetration capabilities desired. Lower frequency probes allow for deeper penetration and reduced image resolution and are often used when probing externally. Higher-frequency probes provide high-resolution capabilities and are often used for transrectal examination. Both linear and sector probes are commonly used in the reproductive assessment, with linear most commonly used in transrectal and sector probes used for transabdominal scanning.

Inaba et al. (1983) evaluated the use of a linear real-time ultrasound to detect pregnancy from d 18 through 32 of gestation. Results indicated 13, 30, 73, 91, and 100% of animals evaluated were correctly diagnosed as pregnant or nonpregnant at d 18, 19, 20, 21, and 22+, respectively. Jackson (1986) evaluated 308 sows between d 24 and 37 following mating using real-time and indicated 100% (n = 23) of animals diagnosed as nonpregnant were correctly identified and 99% (282 of 285) of sows diagnosed pregnant farrowed or aborted, confirming pregnancy. Woodard et al. (1994) reported success with real-time ultrasound as early as 22 d following mating. In a second report using field data, Woodard et al. (1995) reported 74.5% accuracy for correct pregnancy diagnosis between d 17 and 20 and an increase to 97% on d 21 through d 58 of gestation.

Armstrong et al. (1997) compared the influence of technician and probe type/frequency on the sensitivity, specificity, and accuracy of real-time ultrasound at d 21 after mating. One technician was found to be superior to the second technician regardless of probe frequency; the superior technician expressed a higher sensitivity (84.6 vs 68%), specificity (95.7 vs 88%), and higher overall accuracy (89.9 vs 78%) when using a 3.5-MHz sector probe, with overall accuracy increasing to 94.4% compared with 88.2% when using a 5.0-MHz linear probe. Both technicians were found to have better success when using a 5.0-MHz linear probe compared with a 3.5-MHz sector probe.

Almond (1998), in a summary article, reported on additional uses of ultrasound, including detection of retained piglets at farrowing, assessment of fetal vitality, and counting the number of live and dead pigs within the uterus. Belstra (2000) reported the use of real-time to diagnose reproductive problems such as cystic follicles or metritis within the uterus as well as opportunities to study follicular growth and ovulation, uterine involution, and embryonic development/mortality.

A number of factors have traditionally prevented widespread adoption of real-time ultrasound on swine farms, including, cost, reliability, and portability. Historically, technological advances in ultrasonic instrumentation occur first in human medicine and are gradually passed down to the animal industries, resulting in high initial cost and equipment that is not designed for the environment in swine facilities. In recent years, as operation size has significantly increased, new real-time machines are being manufactured specifically for animal use. This has resulted in more competition, lower investment costs, increased durability, and enhanced design features. Of all the improvements, increased portability may be the most important feature of current real-time models. Battery-operated, lightweight ultrasound machines are now readily available and with the addition of wrist-held monitors and vision goggles, technicians are able to routinely pregnancy-check females at a very quick, yet accurate, pace. Further improvement in ultrasound resolution, current models are now have 1,024 × 1,024 lines of resolution, will provide even more opportunities to improve reproductive efficiency in the future.

Implications

Ultrasound technology has had a profound impact on the efficiency of production across the swine industry.

Ultrasound applications continue to expand as the swine industry modifies management practices that affect productivity and profitability. Large swine farms routinely utilize ultrasound for pregnancy detection, condition scoring, and lean estimation, and seedstock producers rely on ultrasound to improve genetic merit for composition traits. Cost is the main factor limiting widespread, on-farm application of ultrasound. However, purchase price continues to decline and ultrasound services are now common. Technology advances will expand both research and commercial applications. The advances will initiate at the human medicine level and be passed down to the swine industry. Improved resolution, refined probes, and color imaging capabilities promise to improve the functionality of ultrasound in the swine industry.

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