New equipment for estimating carcass composition by measurement of the speed of ultrasound in the living animal

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Introduction

Previous papers have described and examined the accuracy of a method for estimating carcass fatness based upon measurement of the speed with which ultrasound is transmitted through the soft tissues of the live animal (1-3). The method was developed to overcome some of the problems of the ultrasonic pulse-echo technique used hitherto. The method:

(a) is quick, painless, safe and capable of being used by non-scientific staff under farm conditions

(b) gives a digital reading which may be used to yield a fatness prediction on the spot, requiring neither subjective interpretation by experienced judges nor lengthy analysis of photographs and

(c) responds equally to subcutaneous, inter- and intra-muscular fat.

This paper describes equipment for measuring the speed of ultrasound in farm livestock. Part of the equipment was built to our specification by Wells-Krautkramer Ltd. and the rest was built at the MRI. The whole system has been undergoing field trials since April 1982 and this paper includes some of the findings of those trials.

Principle of the method

The principle of the method has been described in detail elsewhere (1). The method relies on the fact that, in general, the speed (V) of ultrasound in muscle or fatty tissue at body temperature is correlated with the volume fraction of fat (Y) which the tissue contains, via the equation:

$$Y = (b/V) + a \qquad \text{(equation (1))}$$

where a and b are constants (4)

Consequently if muscles and fatty tissues are arranged in an arbitrary number of parallel layers, the mean volume fraction of fat in the mixture is given by:

$$\overline{Y} = b\,(\overline{1/V}) + a \qquad \text{(equation (2))}$$

where $(\overline{1/V})$ is the transmission time that a pulse of ultrasound takes to travel through the tissues, divided by the tissue thickness, characteristics that can be measured directly (1-3, 5-7).

If, in a live animal, $(\overline{1/V})$ is determined through a region comprising adipose tissue and muscle only (such as the soft tissues of the limbs), the mean volume fraction of fat in the tissues through which the beam passed may be estimated via equation (2). However, it is important that the measurement of $(\overline{1/V})$ be made precisely since at body temperature $(\overline{1/V})$ for lipids is only about 14% higher than that for fat-free tissues. By defining measurement sites on the animal so that different animals may be measured at one or more corresponding sites, it is possible to rank animals in order of predicted fatness at these sites (1,6) and to correlate the data with tissue proportions in the carcass (2,3,6).

Measurement equipment

The determination of $(\overline{1/V})$ requires a measurement of the time of flight of an ultrasonic pulse across the animal and a measurement of the tissue thickness. These are measured on an animal using a specially designed frame as shown in Figure 1.

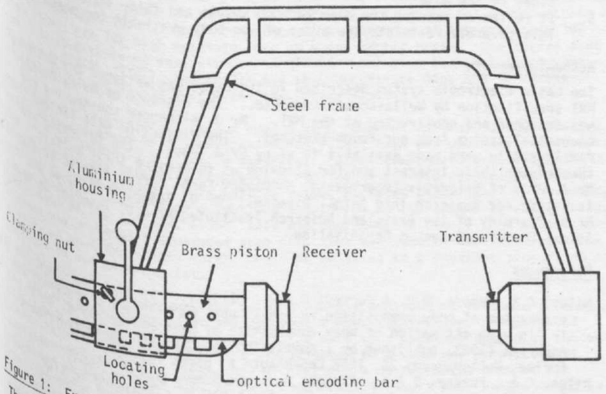

Figure 1: Frame used to hold transducers in line and facing one another on opposite sides of the animal

The frame holds two transducers, one a transmitter and the other a receiver, in line and opposite one another at pre-determined points on opposite sides of the animal. The distance between the faces of the transducers can be adjusted in discrete steps to accommodate various sizes of animal.

An electronic system automatically carries out a standard sequence of operations to obtain a valid measurement of $(\overline{1/V})$. It measures the time of flight (τ) of an ultrasonic pulse from one side of the animal to the other, records the distance (d) separating the transducer faces and computes $(\overline{1/V})=\tau/d$. These three parameters are displayed by the unit and are available on an RS232 line for external logging and printing.

Measurement of the time of flight (τ)

The whole system is microprocessor controlled but the basic acoustic system for measuring the time of flight consists essentially of a pulse generator, pre-amplifier, amplifier with automatic gain control, comparator threshold detector and timer.

At a rate, determined by a front panel control, the timer is started and simultaneously a pulse generator produces a high voltage pulse of short duration which is applied to the transducer acting as transmitter. This emits a pulse of ultrasound which travels through the tissue of the animal. After a delay, dependent upon the thickness of the tissue and the speed of sound, the pulse is received on the other side of the animal by the receiving transducer which reconverts it to an electrical pulse. This pulse passes through a pre-amplifier and is rectified, shaped and its amplitude adjusted by an amplifier with automatic gain control to between 8 and 9 volts. This is fed to a threshold detector which, at a predetermined level on the rising edge of the pulse, generates a new sharp pulse to stop the timer. The threshold level, which may be adjusted, was set at 1V for work described in this paper.

The time recorded by this measurement (τ_m) does not equal the required time of flight because it includes a system delay (τ_o) which has to be predetermined and subtracted from the reading:

$$\tau = \tau_m - \tau_o$$

The system delay depends on such factors as the choice of trigger level threshold and the transducers employed. For measurements of mature cattle, 1 MHz transducers, 25.4 mm in diameter were found to be suitable and at a trigger threshold of 1 volt, τ_o happened to be 1.50 ± 0.05 µs for our system. This was determined at intervals during the trial and showed no discernable drift away from the adopted value over a six month period. τ_o was determined in preliminary measurements of the pulse transit time across various lengths (d) of water, τ_o being the intercept of the regression of τ_m against d (Table 1) since

$$\tau_m = (d/V_w) + \tau_o$$

where V_w = the speed of ultrasound in water.

Tap water was used routinely for this work but glass-distilled water was used to obtain the data given in Table 1. The residual standard deviation of the regression, 0.025 µs, is comparable with the resolution of the timer (.02 µs, since it is based on a 50 MHz oscillator). Errors in the distance measurement also contributed to the scatter of the data about the regression line.

Table 1 Linear regression analysis of pulse transit time (τ_m) recorded by the equipment against path length (d) in glass-distilled water at 25.2°C. The equation $\tau_m = \frac{d}{V_w} + \tau_o$ applies

	This work	Previous work
Slope $1/V_w$ ± SE µs/cm	6.6820 ± 0.0007	6.6834 (1) 6.6776 (2) 6.6808 (3)
Intercept (τ_o) ± SE µs	1.49 ± 0.04	
Residual standard deviation µs	0.025	

Measurements (this work) at 1 MHz, and a mean path length of 37.3 cm.
(1) Kaye and Laby, 1973. (2) Greenspan and Tschiegg, 1957 (3) American Institute of Physics Handbook, 1963.

Measurement of distance

The ultrasonic transducers were held in line and facing one another using the frame sketched in Figure 1. One transducer was fixed to one side of a steel frame while the other transducer was attached to the end of a brass piston which slid within an aluminium housing fixed to the other end of the frame. A spring-loaded tapered pin mounted in the aluminium housing, could be located in any one of a number of holes drilled at equal intervals along the length of the brass piston. Once the transducers were at the desired separation, with the pin located in the appropriate hole, the piston was clamped with a wing nut, the frame was carefully positioned around the animal and a switch operated to initiate the measurements.

An optical coding bar is used to record the transducer separation. The encoding bar is divided into 64 sections, each section being of equal width. A section is either left open or blanked off to provide a unique coding pattern. A metal block, attached to the aluminium housing, houses 6 photo emitters and receivers which produce a 6 bit code that is used to identify the position of a particular hole. This 6 bit code is then interpreted by circuitry within the unit to give a direct reading of the inter-transducer distance with a resolution of 0.01 cm.

The maximum error in the distance measurement was considered to be approximately 0.03 cm at a spacing of 50 cm. This was calculated on the extreme basis of the frame being subjected to a tensile force of 10N along the axis of the transducers, a temperature change of 30°C and that these and all other errors, including the repeatability of relocation at a particular hole, were cumulative.

Determination of $\overline{1/V}$

A microprocessor incorporated in the equipment is used to check the stability of the amplitude of the received signal and, if this is acceptable, to take the time of flight and distance readings, compute $\overline{1/V}$, display the results and send the data to an RS232 line for external logging and printing. If the received signal is not sufficiently stable, or too high or too low, the display and output are suppressed and new data are requested.

The standard error of the slope of the regression ($1/V_w$) reported in Table 1, represents an error of approximately 0.01% and indicates the order of magnitude of the ultimate limit of the precision of the equipment for speed measurements through samples of about 40 cm in thickness, since it appears to be determined largely by the finite resolutions of the time interval and distance recordings (0.02 µs and 0.01 cm respectively). This precision was obtained under laboratory conditions and it is emphasised that for measurements on animals much larger errors arise, as we shall see below.

Measurement on animals

In order to rank animals on the basis of the transmission measurements, it is necessary to define positions on the animal that can be located reproducibly from animal to animal and from one occasion to another. Sites on the hind limbs were defined relative to the position and size of skeletal features as shown in Figure 2 and the short-term repeatability of the ultrasonic measurements determined by measuring the animals twice, the two measurement sessions being separated by a period ranging from 4 hours to 14 days. At each session at least four measurements were made at each of the two sites and the site-means used to compute an overall mean which was used for all subsequent analysis. The within-animal standard deviation of the data (Table 2), a measure of the repeatability, represents about 0.06% to 0.11% of the measured values, or expressed in terms of predicted lipid content averaged over the two sites, 4.3 to 7.8 ml lipid/litre tissue.

Comparison of the data in Tables 1 and 2 will show the uncertainty of the speed measurements of cattle was about 6 to 11 times larger than the error quoted for water. Several factors contribute to the loss in precision:

(a) the limited precision with which the measurement sites could be located on animals;

(b) small additional errors in the measurement of distance due to the effect of stress on the frame and its finite coefficient of thermal expansion;

Table 2 Repeatability† of the measurement of the reciprocal of the speed of ultrasound* in groups of living cattle. Data are residual standard deviations, expressed in μs/cm.

	Number	Residual standard deviation μs/cm
Dairy cows (from Herd A)	10	.0056
Dairy cows (from Herd B)	10	.0042
Hereford bulls	68	.0069

†short term, measurements repeated within a period of 4 hrs to 14 days.

*measured by transmission through the hind limbs and averaged over two sites (B and B_1), defined in Figure 2.

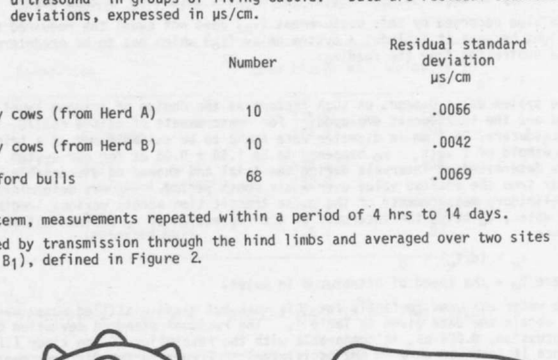

Figure 2 Sites where transmission measurements were made. A: lateral ridge of the trochlea of the distal end of the femur. T: caudal extremity of the ischiatic tuber. AT follows contour of buttock. OT = AO, AP = 2PT. PC' and OC perpendicular to AT. C and C': caudal points of the buttock. PB = BC' and $OB_1 = B_1C$ (these are medial plane projections).

(c) additional errors in the measurement of transmission time due to phase cancellation effects caused by tissue inhomogeneities, perturbing the shape of the leading edge of the received pulse.

Uncertainties due to (a) might be reduced by averaging measurements over more sites and those due to (c) might be reduced by increasing the frequency (f) of the sound since these errors should fall as 1/f.

During the course of the field trials some cattle were measured immediately prior to slaughter and dissection at the MRI. There had been a particular interest in measuring the body composition of female cattle during the period of the trials and we were able to accumulate enough data to examine correlations. A report of these experiments will be given elsewhere, and it is necessary to note here only some of the results.

(a) there was a strong positive correlation between measurements of 1/V made with the equipment on 51 live female cattle and adipose tissue proportions in their carcasses determined by physical dissection (Fig.3)

(b) the slope and form of the regression of carcass fatness against reciprocal speed was similar to that observed previously with other equipment on steers (6) and bulls (2). However, there appeared to be a slight shift of the calibration curve, such that in these data, carcasses were slightly fatter at the same speed of sound.

(c) the precision of the correlation was acceptable for some practical applications and about the same as that observed previously on steers and bulls (2,3,6). 1/V significantly ($P<.001$) improved the precision of the prediction made on the basis of live mass (M) alone, and the residual standard deviation, after regression on 1/V and M, was 19.2 g adipose tissue/kg carcass. This compared with 40.9 g/kg after regression on live mass alone.

Practical aspects

The equipment allows the above measurements to be made at a rate of about 10-20 animals per hour and the major consumable is acoustic couplant: we used liquid paraffin at a rate of about 25 ml/animal. Data may be logged automatically using an external microcomputer. We used an Epson HX-20, which printed the data on-site and retained the data in its memory after it was switched off at the end of measurement sessions. The data was recalled on return to the laboratory and loaded automatically via an RS232 line to another computer for further processing.

Potential and limitation of the method

The equipment described in this paper has considerable potential for practical application in live animal evaluation and it is perhaps useful to end by listing some of the advantages and disadvantages of ultrasound transmission.

Advantages

1. It employs portable equipment, suitable for making measurements on farms. The method is quick, safe and painless.
2. It is suitable for measurement of large farm animals.
3. The method can be used by non-scientific staff, since it gives a direct digital reading, requiring no subjective assessments.
4. The method yields an 'on-the-spot' fatness prediction, requiring no subsequent lengthy analysis of photographs.
5. It responds equally to subcutaneous, inter- and intra-muscular fat.
6. It is probably more sensitive at low fat levels than measurements of subcutaneous fat thickness.
7. The regression equations appear to be less sensitive to breed differen
than ultrasonic pulse-echo techniques.
8. It has low running costs.

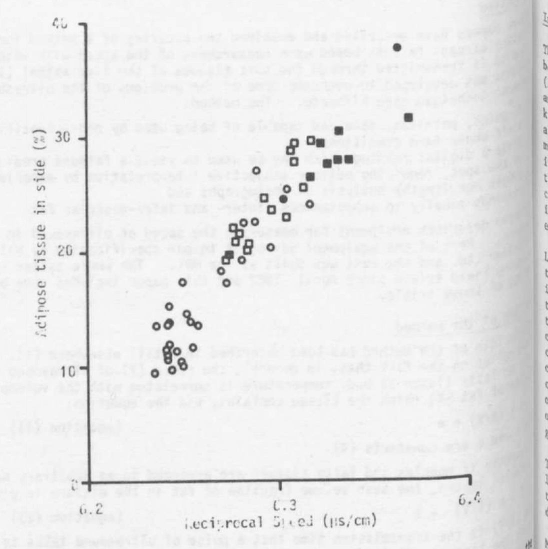

Fig. 3 % Adipose tissue in the side against 1/V. Correlation between the reciprocal of the speed of ultrasound in the hind limbs of live female cattle and the proportion of adipose tissue in the carcass determined by dissection. Circles represent heifers, squares represent cows. Open symbols represent British Friesian; closed Hereford.

Disadvantages

1. Perhaps the most serious limitation is that it depends on the accuracy of the relation between a small section of the body and overall carcass composition.
2. It gives no information on the way the fat is distributed among the different depots.
3. The relationship between ultrasound speed and fatness is indirect.
4. The transducer assembly is cumbersome, because the method requires that the transducers are held in line and facing one another on opposite sides of the animal.
5. It relies on passing the beam through muscle and fatty tissue only. This severely restricts the areas of the body available for measurement.

Acknowledgements

The basic electronic system described in the paper was designed and built to MRI specification by Wells-Krautkramer Ltd. The distance encoding device was designed and constructed at the MRI. Mr J. Alexander constructed the mechanical system from our rough sketches. The dissection data for the female cattle were made available to us by Dr J. Wood. The following are thanked for their interest and for allowing us to measure their animals: Mr J. Wray of Bridget's Experimental Husbandry Farm: Dr J. Roberts of the Institute for Research into Animal Diseases; Mr R. Baker, Mr M. Gibb and Mr E. Charmley of the Grassland Research Institute, Mr J.S. Tavernor of the Animal Breeding Research Organisation.

References

Miles, C.A., Woods, M.O. & Fursey, G.A.J. (1982). In vivo technique for estimation of body composition in beef: note on ultrasound transmission. In 'In vivo estimation of body composition of beef' edited by B. Bech Andersen (1982) published by 1 Kommission los Landhusholdningsselskabets forlag, Rolighedsvej 26, 1958 Copenhagen V, pages 139-147.

Miles, C.A., Fursey, G.A.J., Fisher, A.V. and Brown, A.J. (1983). Predicting carcass composition from the speed of ultrasound in live Hereford Bulls. (Abstract). Anim. Prod. 36, 526.

Miles, C.A., Fursey, G.A.J. & Pomeroy, R.W. (1983). Ultrasonic evaluation of cattle. Anim. Prod. 36, 363-370.

Miles, C.A. & Fursey, G.A.J. (1977). Measurement of the fat content of meat using ultrasonic waves. Fd. Chem. 2, 107-118.

Miles, C.A. & Fursey, G.A.J. (1974). A note on the velocity of ultrasound in living tissue. Anim. Prod. 18, 93-96.

Woods, M.O. (1984). Ph.D. Thesis. University of Bristol

Ludwig, C.D. (1950). The velocity of sound through tissues and the acoustic impedance of tissues. J. Acoust. Soc. Am. 22, 862-866.

Kaye, G.W.C. & Laby, T.H. Tables of Physical and Chemcial constants and some Mathematical Functions. Longman, London and New York.

Greenspan, M. & Tschiegg, C.E. (1957). Speed of sound in water by a direct method. J. Res. NBS 59 (4), 249-254.

American Institute of Physics Handbook. (1957). 2nd edition, pages 3-
McGraw-Hill Book Co. Inc., New York.