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Ultrasonic scanning of live cattle.
Introduction C.A.Miles, R.W.Pomeroy & J.M.H. arries.

Recently an ultrasonic scanner, the Scanogram, designed specifically for use on animals has become available commercially. Its inventor, Professor J.R. Stouffer, Cornell University, visited the Meat Research Institute in April, 1970 and under his guidance numerous ultrasonic scans of cattle, pigs and lambs were made. This paper presents the results of an experiment on cattle.

There is a wide range of correlations quoted in the literature for the relationship between back fat thickness of cattle (usually the mean of three measurements at different lateral positions over M. longissimus thoracis at the last rib) measured on the carcass and that measured ultrasonically. Correlation coefficients range from the non-significant to 0.96 (1, 2, 3, 4). A similar diversity (ranging from 0.22 to 0.93) in correlation is also evident in the measurement of M. longissimus thoracis area, again generally measured over the last rib (see for example 5 and 6). Some possible reasons for this divergence of experimental data have been identified in the present investigation.

This study involved the use of a different type of experimental design to that generally reported. Instead of taking ultrasonic measurements of a large number of animals at a single anatomical location, each animal was measured in a number of anatomical locations and relatively few animals employed. In this way it was possible to investigate the relative precision of the ultrasonic technique at different anatomical locations. In addition by measuring a number of anatomical parameters at each location the study provided information concerning the inter-relationship between the errors involved in measuring them.

Experimental

Animals. Six steers, three Shorthorn and three Hereford crosses, aged between 18 and 24 months were used as experimental animals. They were selected to reveal a good range of fatness. Judged by eye two were very lean, two of average fatness and two very fat. Carcass weights ranged from 286 to 334 kg.

Equipment. Two dimensional ultrasonic scans were made using a "Scanogram" ultrasonic animal scanner. This equipment is the subject of a recent patent, (7) from which constructional details may be obtained. A $\frac{1}{2}$ " diameter 2MHz transducer was used, scans being made at linear magnifications of $\frac{1}{3}$ or $\frac{1}{2}$ and recorded photographically. Calibration for the velocity of sound in tissue was made using a lead calibration block supplied with the instrument, the calibration being checked periodically.

Procedure. Each animal was scanned in eight or nine planes perpendicular to the spine at various positions along the back. These positions were: at the head of the last rib and working anteriorly at the head of every rib to the 8th or 9th; in a posterior direction from the last rib between the spinous processes of each vertebra up to between the second and third and fourth lumbar vertebrae.

The cattle were shorn of hair at those positions where scans were to be made and constrained in a cattle crush while they were ultrasonically tested. Three of the steers were tranquillised by intramuscular injection of promazine hydrochloride, two at a dose of 1.32 mg/kg live weight and the other at 1.92 mg/kg live weight.

Immediately following completion of the scan the animals were slaughtered and hung in the conventional way. The positions at which scans had been made were marked on the carcass by the injection of a vegetable dye, through the hide prior to flaying.

The hot carcasses of three of the steers were scanned within two hours of slaughter at the same sites at which scans had been made on the live animals.

Following chilling the sides were frozen in a -40°C room and, using a band saw, sectioned through the planes at which scans had been made. The sections were then measured and photographed.

Measurements. Two sets of measurements were made from the transverse scans. For the first set (termed analysis 1) all the scans of all the animals, live and carcass, were interpreted independently by two judges. A third judge only completed interpretations of the scans of four of the animals. In addition a second set of measurements were taken (termed analysis 2). Five scans were selected for independent analysis by nine judges. Each judge performed 5 interpretations of each scan.

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All interpretations were made by tracing the outline of the anatomical features from the ultrasonic scan. A thin perspex sheet was placed between photograph and tracing paper to avoid indentation of the outlines drawn by the judges on the photograph. The estimated position of the backbone, top and bottom of the hide and bottom of fat and the Mm. longissimi thoracis et lumborum boundary were marked on each tracing.

Measurements were taken from all the tracings and carcass sections as follows: $\frac{2}{3}$ cm intervals were marked off on the surface boundary from the backbone. At these points lines were drawn perpendicular to the surface and measurements taken from the surface to the ventral boundaries of hide, fat and Mm. longissimi thoracis et lumborum. A line was drawn across the widest part of the Mm. longissimi thoracis et lumborum and the measurement recorded (called the A measurement). Then the widest part of the Mm. longissimi thoracis et lumborum perpendicular to the 'A' line was measured (called the B measurement). The area of Mm. longissimi thoracis et lumborum was measured with a planimeter. All linear measurements were made to the nearest 0.5 mm (i.e. 1 mm or 1.5 mm life size respectively for the $\frac{1}{2}N$ and $\frac{1}{2}J$ scans). The corresponding uncertainties in area measurements were 0.4 cm^2 and 0.9 cm^2 respectively.

The carcass depth measurements were made directly from the carcass sections whilst the 'A', 'B' and area measurements were made from carcass photographs (of approximately $\frac{1}{2}$ life size). In the case of carcass measurements an allowance was made for hide thickness of 6 mm, to allow direct comparison between estimates made on the live animal and the corresponding measurements on its skinned carcass.

Numerical analysis and Results

1. Analysis 1. For each animal there were 5 sets of data, each set separately comprising measurements of fat thickness, Mm. longissimi thoracis et lumborum depth, Mm. longissimi thoracis et lumborum 'A', 'B' and area. The first two sets were matrices, the six columns being distances from the midline of the back and the rows being locations along the spine, either eight or nine. The 'A', 'B' and area measurements were arranged as single column matrices each figure representing a different anatomical location along the back. There were at least three matrices of each type associated with each animal: ultrasonic measurements taken from the scans of the live animal by at least two judges and the corresponding carcass measurements. In addition, measurements taken by each judge from the ultrasonic scans of three of the carcasses were available for comparison purposes.

Although it is not valid to assume that the carcass measurements have the same values as those of the living animal (due to hanging and post mortem conformational changes) these values provide a physically meaningful base line. Accordingly the matrices of each anatomical parameter were converted to $(n-1)$ matrices of carcass measurements minus scan measurement at the same point on the same animal. This difference will subsequently be called bias. The bias surfaces may be constructed for each animal and each judge by plotting bias as a perpendicular displacement from the anatomical location coordinate system. All the surfaces (all animals and all judges) should be coincident planes of zero bias for perfect agreement between ultrasonic and carcass measurements. A similar procedure may be adopted for 'A', 'B' and area measurements except that the surfaces become lines (the matrices become vectors) since anatomical position is defined solely by the position along the spine.

The results of this method, which reveal the deviations from the ideal of zero bias lines and surfaces may be expressed in a convenient manner numerically in terms of mean bias and standard deviation about this mean, the smaller the standard deviation the better the agreement between different estimates of the same parameter; the smaller the mean bias the better the absolute agreement with carcass measurements. For practical use a bias would not matter if it were constant and known since it could be allowed for. Table 1 records these mean bias and standard deviation values calculated from two judges' interpretations of the scans of the four steers scanned at $\frac{1}{2}$ magnification.

In order to compare the accuracy of the technique at the different anatomical locations, the Mm. longissimi thoracis et lumborum 'A', 'B' and area bias values were subjected to an analysis of variance. The different animals provided the replicates and anatomical position and judge were assigned as two possible factors influencing bias values. Table 2 presents the results of these analyses of 'A',

'B' and area bias measurements of three judges' interpretations of the scans of 4 animals.

Table 1

Pos. along spine	Distance from spine cm	Fat depth bias mm					Km. longissimi thoracis et lumborum depth bias in mm				
		2.5	5	7.5	10	12.5	2.5	5	7.5	10	12.5
3/4	No	4	4	4	4	4	2	4	4	4	4
	Mean	-3.0	-2.5	6.8	4.0	3.8	2.0	-5.5	1.5	4.3	8.3
	S.D.	2.6	2.9	2.6	6.2	5.6	-	14.5	2.5	7.9	8.7
2/3	No	8	8	8	8	8	5	8	8	8	8
	Mean	-5.3	-1.3	0.3	0.3	1.5	-23.4	-3.5	-6.6	-3.8	6.8
	S.D.	4.6	3.2	5.2	5.0	5.5	17.6	9.3	10.0	3.5	6.8
1/2	No	8	8	8	8	8	4	8	8	8	8
	Mean	-0.4	-0.1	3.0	3.0	4.8	-8.8	6.4	5.0	2.3	6.5
	S.D.	4.7	2.6	2.7	4.1	4.6	7.8	9.3	5.6	7.8	6.3
13/1	No	8	8	8	8	8	5	8	8	8	8
	Mean	0.0	0.3	1.0	1.6	2.4	-2.4	12.4	8.9	1.3	2.5
	S.D.	4.7	2.7	2.1	2.0	1.4	17.4	6.6	7.9	7.7	10.4
12/13	No	8	8	8	8	8	6	8	8	8	8
	Mean	5.9	4.5	4.3	2.3	2.9	10.7	18.5	12.1	7.6	13.0
	S.D.	5.4	5.6	7.5	5.6	3.7	27.9	8.6	6.8	5.2	10.34
11/12	No	8	8	8	8	8	1	8	8	8	8
	Mean	2.9	6.9	-1.5	-2.0	-0.8	-	17.1	5.9	0.1	-0.6
	S.D.	5.9	4.8	8.0	5.5	5.8	-	9.6	5.7	10.8	12.3
10/11	No	8	8	8	8	8	2	7	8	8	8
	Mean	3.4	0.1	0.5	3.4	1.1	43.0	18.0	3.6	1.5	-02.6
	S.D.	5.1	4.5	7.0	9.7	6.7	-	17.2	9.6	16.2	17.0
9/10	No	5	8	8	8	8	1	8	8	8	8
	Mean	0.4	-2.8	-3.8	-5.8	-3.6	-	24.6	11.9	7.9	6.3
	S.D.	8.9	3.4	3.4	5.1	6.3	-	9.4	9.8	11.2	13.7
8/9	No	1	4	4	4	4	-	4	4	4	4
	Mean	-	-2.5	-4.5	-5.3	-3.5	-	28.5	21.5	5.0	-6.5
	S.D.	-	4.7	7.7	7.7	4.8	-	13.3	15.7	20.9	12.1

Table 2 Mean bias values

Parameter	R.S.D.	Judge	2/3	1/2	13/1	12/13	11/12	10/11	9/10
A (1) in mm	12.7	X	19.0	10.0	6.3	6.8	9.8	5.8	1.5
		Y	24.8	7.3	-1.0	-2.3	7.5	3.3	-1.5
		Z	21.8	1.8	-9.0	-2.8	1.5	5.3	-8.3
B (2) in mm	8.2	X	-7.3	-0.3	7.3	5.0	6.0	1.5	3.8
		Y	-6.5	-3.0	2.5	-2.8	2.8	-4.3	1.3
		Z	-7.5	-3.5	3.0	-0.3	1.5	0.5	1.0
Area (3) in cm ²	10.4	X	2.3	3.7	5.3	6.5	10.8	12.0	7.1
		Y	3.2	-0.4	-11.8	-8.6	3.1	-2.8	5.3
		Z	2.1	-0.7	-5.1	-4.4	-1.2	3.2	-2.6

(1) No interactions significant ($P > 0.05$)

Differences between judges not significant ($P > 0.05$)

(2) Differences between positions significant ($P < 0.001$)

Differences between judges not significant ($P > 0.05$)

(3) Differences between positions significant ($P < 0.05$)

Differences between judges significant ($P < 0.01$)

Differences between positions not significant ($P > 0.05$)

2. Analysis 2. The results of the repeated interpretations of a selected number of scans by nine judges were converted to bias values as in analysis 1. Analyses of variance were performed on the 'A', 'B' and area bias values separately in order to compare the "between-and within-judge" variances. In addition, the fat thickness bias and Mm. longissimi thoracis et lumborum depth bias values were also subjected to analyses of variance with lateral distance from the spine and judge assigned as the two possible factors influencing the data. The results of these analyses are discussed below.

Discussion

Carcass deformation. The direct comparison of measurements of anatomical parameters measured on a live animal and the corresponding measurements taken from sections of its carcass is necessarily associated with errors independent of particular measurement technique. These errors are introduced by carcass deformation resulting from post-slaughter treatment (e.g. hanging and splitting) and rigor mortis.

Figure 1

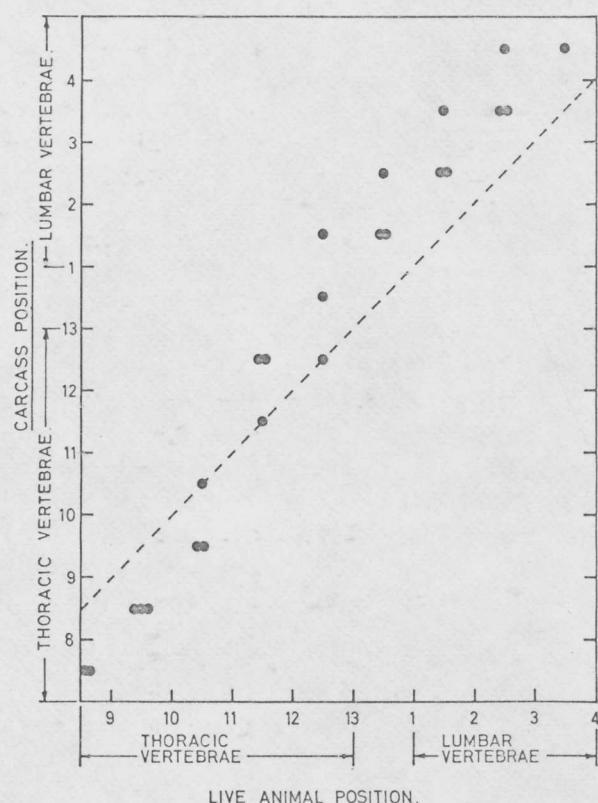


Figure 1 records the relationship between the position of the soft tissue relative to the skeleton as obtained by palpation on the live animal and the corresponding position on the carcass obtained by direct measurement. It can be seen that in the extreme thoracic regions the soft tissue, in which the scan position had been marked, moved cranially relative to the skeleton. In addition a caudal movement was recorded in the lumbar region.

The relevance of these shifts will be discussed at appropriate points in the following discussion in which it is convenient to consider the measurement of each anatomical parameter separately.

(a) Measurement of fat thickness

Analysis 1. An examination of the standard deviations of Table 1 reveals that the bias surfaces were bunched closely together in central positions (7.5 cm, 10 cm and 12.5 cm distances from the backbone) over the Mm. longissimi thoracis et lumborum in the 13th thoracic/1st lumbar plane. In these positions the thickness of the second layer of fat was very small, and therefore differences between live

and carcass measurements due to a confusion between the first and second layers would also be small. The small positive mean bias and small standard deviations recorded at these positions result from a confusion between the first and second layers of fat. Bias values become more positive and standard deviations increase towards the lumbar positions as the thickness of the second layer of fat increases. The negative bias and large standard deviations in the extreme anterior position were due to confusion between the fat boundary and the ventral surface of M. trapezius. The negative mean bias values in the lumbar regions on the 2.5 cm and 5 cm lines were due to the presence of a layer of gristle, the dorsal surface of which was defined in this experiment for fat thickness measurements as the lower boundary of fat. In many of the tracings of the ultrasonic scans however, this layer was not identified.

Analysis 2. In all cases there were highly significant differences ($P < 0.001$) in the bias values between judges and between lateral distances from the backbone. No interactions were significant ($P > 0.05$). Possible reasons for these differences are discussed above. Although all the mean bias lines of each scan cut the bias = 0 axis at least at one point, thus indicating a lateral distance at which the estimated fat thickness agreed best with the carcass measurement, this distance from the vertebral column differed between scans.

Although there are positions in the ultrasonic scans of cattle at which fat thickness measurements agree with the carcass measurements within the limits of within-and between-judge variations^a, these positions depend on the conformation of the anatomy under investigation and in general will not only depend on the location at which an animal is scanned but also on anatomical variation between animals. Gross differences between ultrasonically estimated fat thickness and carcass measurements occur as a result of mis-identifying discontinuities in acoustic impedance with anatomical boundaries. Clear identifications of anatomical boundaries is at times confused by the presence of multiple reflection artifacts which are not always obviously identifiable as such.

(b) Measurement of M. longissimi thoracis et lumborum depth

Analysis 1. With reference to Table 1 it can be seen that in general mean bias values of M. longissimi thoracis et lumborum depth were positive, indicating an under-estimation of the depth. Standard deviations were smaller in the lumbar regions than at other positions, due to the transverse processes of the lumbar vertebrae providing good reflecting surfaces and thus giving rise to clear echoes. In the thorax the identification of the ventral boundary of M. longissimi thoracis et lumborum was more uncertain. The positive bias values may in part be due to the fact that the velocity of sound in muscle is greater than that in fat. Another effect may be seen by examining the bias values along the 5 cm and 7.5 cm lateral lines. Here very large positive bias values were recorded in the extreme thoracic regions scanned in this study and there is a tendency for the bias values to be slightly negative in the extreme lumbar positions. In view of the rapid anterior increase in M. longissimus thoracis depth, the under-estimation of M. longissimus thoracis depth in the extreme anterior positions may be due to the cranial movement of the surface soft tissues relative to the skeleton as recorded in Figure 1. In the lumbar regions of the animal mis-interpretation errors are of importance in the medial positions. These result from a confusion between the ventral boundaries of the M. longissimus lumborum and M. multifidus dorsi. Consequently there is a tendency to over-estimate M. longissimus lumborum depth at this location.

Analysis 2. There were highly significant ($P < 0.001$) differences between the bias values at different distances from the spine in all scans except one. No interactions were significant ($P > 0.05$). Significant differences between judges at least to the $P < 0.01$ level, were recorded for all scans except two, where the reflections from the transverse processes of the lumbar vertebrae were particularly clear.

(c) Measurement of 'A'

Analysis 1. The highly significant difference ($P < 0.001$) in the bias values of 'A' between positions, recorded in Table 2, was largely due to the gross under-estimation of 'A' in the lumbar regions. Agreement with carcass measurements was better at position 13/1, 12/13 and at 9/10 than at other positions. No significant interaction or differences between judges was apparent ($P > 0.05$).

In view of the rapid increase in carcass 'A' measurement towards the extreme lumbar regions, the caudal movement of the lumbar surface tissues relative to the skeleton (see Figure 1) may be responsible for the large bias values in 'A' recorded at position 3/4 and 2/3.

The large residual standard deviation about the mean bias values of 'A' at all positions (Table 2) is due to the inability to define precisely the lateral and medial boundaries of Mm. longissimi thoracis et lumborum on the ultrasonic scans.

Analysis 2. Significant differences ($P < 0.01$) between judges' estimates of 'A' were resolved by an analysis of variance of the results of repeated interpretations of five individual steer scans. This showed that whilst judges were relatively consistent within themselves, they differed significantly from one to the other in their mean assessments.

(d) Measurement of 'B'

Analysis 1. Table 2 records the results of the analysis of variance of bias values of 'B' as a function of position and judge. No significant interaction or differences between judges ($P > 0.05$) were evident but there was a significant difference between the 'B' bias at different anatomical locations ($P < 0.05$). The 'B' measurement was over-estimated by all judges at position 2/3, better agreement with carcass measurements occurring at 1/2, 12/13, 10/11 and 9/10 than at other positions. The over-estimation of 'B' at positions 3/4 and 2/3 was due to the gross under-estimation of the depth of the dorsal surface of M. longissimus lumborum in this region.

Analysis 2. The repetition study yielded significant differences between judges in all the scans examined at least at the $P < 0.05$ significance level. It is interesting to note that the differences between judges in their measurement of 'B' in the lumbar scans 3/4 and 2/3 were due to differences in the interpretation of the dorsal boundary of the M. longissimus lumborum only.

(e) Measurement of Mm. longissimus thoracis et lumborum area

A significant difference between the judges' estimates of area at any position was recorded (Table 2). However, differences between bias values at different positions were not significant ($P > 0.05$). This is due to the fact that if 'A' was under-estimated 'B' tended to be over-estimated.

Conclusions

The ventral boundary of Mm. longissimi thoracis et lumborum was more clearly defined in the ultrasonic scans of the lumbar regions than in those of the thorax. Ultrasonic scans of the extreme anterior positions were particularly difficult to interpret due to the possible presence of M. trapezius and M. spinalis et semi spinalis overlying M. longissimus thoracis.

Ultrasonic measurements of fat thickness compared most favourably with carcass measurement in the 13th thoracic/1st lumbar plane in central positions (7.5 cm, 10 cm and 12.5 cm distance from the mid-line). While the variation between animals may be substantial at these locations the absolute fat thickness is frequently small so that they may not necessarily be the best suitable sites for detecting differences between animals.

Significant differences between anatomical locations were recorded for the agreement between ultrasonic and carcass measurements of Mm. longissimi thoracis et lumborum 'A' and 'B' measurements. 'A' tended to be under-estimated and 'B' over-estimated in the lumbar regions.

In general interpretation of the scans tended to under-estimate Mm. longissimi thoracis et lumborum area at all positions. Differences between the agreement of carcass and ultrasonic measurements were not significantly ($P > 0.05$) related to location.

The results of the experiment to determine the "within-and between-operator" variations in interpretation of selected scans have shown that whilst operators may be relatively consistent within themselves in general they differ significantly from each other. It would therefore be advisable, in studies involving interpretations of ultrasonic scans by more than one judge, to allow for the extent to which each judge tends to over-or under-estimate. Equally in applying the technique in

livestock improvement schemes, e.g. performance testing, it would be desirable to arrange for all the scans to be interpreted by the same operator.

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