524. Beretning fra Statens Husdyrbrugs forsøg

Red. B. Bech Andersen
National Institute of Animal Science
Department of Cattle and Sheep Experiments

In Vivo Estimation of Body Composition in Beef

(Report on a CEC Workshop held in Copenhagen 15–16th December, 1981)

Engelsk med dansk sammendrag

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FORORD

Inden for husdyrbrugsforskningen anvendes der hvert år mange ressourcer på at udvikle, anskaffe og afprøve nye tekniske hjælpemidler.

Et vigtigt og højt prioriteret område er udviklingen af hjælpemidler til at udvælge de mest værdifulde avlsdyr så sikkert og tidligt som overhovedet muligt. Avlsarbejdets fremtidige effektivitet afhænger i vid udstrækning af forskningsresultaterne inden for dette område. Også fodringsforsøgene er afhængige af tekniske landvindinger, der kan bidrage til en yderligere belysning af de fysiologiske processer, der foregår i vore husdyr.

EF-kommissionen har været opmærksom på betydningen af at fremme forskningsaktiviteterne inden for dette område. Derfor blev der i Edinburgh i september 1981 afholdt en EF-konference om emnet "Anvendelse af biokemiske og endokrinologiske parametre som indirekte mål for mælke- og kødproduktionsegenskaberne". Og for at følge og koordinere den hastige udvikling vedrørende ultralydmåling, røntgenscanning m.v. blev der i København i december 1981 afholdt en EF-konference med titlen "In vivo bestemmelse af kroppens kemiske og anatomiske sammensætning hos Kvæg".

I denne konference deltog 32 forskere repræsenterende diciplinerne genetik, fysiologi, slagtekvalitet og elektronik. Mange af de afholdte foredrag skønnes at have international interesse, hvorfor de i beretningen publiceres på engelsk. Endvidere findes der i beretningen et udførligt sammendrag på dansk.

Statens Husdyrbrugsforsøg medvirker i in vivo projekter i Tyskland, Frankrig, England, Sverige og Norge og har dermed bidraget til fremskaffelsen af en stor del af de fremlagte resultater.

Konferencen blev tilrettelagt af A. Cuthbertson fra England samt B. Bech Andersen, Statens Husdyrbrugsforsøg.

Ud over de i beretningen anførte danske foredragsholdere har T. Liboriussen, H. Knudt Krag, Just Jensen og F. Lauritzen deltaget i konferencens praktiske gennemførelse.

København, februar 1982.

A. Neimann-Sørensen

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DANSK SAMMENDRAG

Den 15. og 16. december 1981 blev der i København afholdt en international konference over emnet: "In vivo bestemmelse af kroppens sammensætning hos kvæg". Konferencen var arrangeret af Statens Husdyrbrugsforsøgs afdeling for forsøg med kvæg og får efter opfordring fra EF Kommissionens ekspertgruppe vedrørende koordinering af medlemslandenes forskningsaktiviteter inden for oksekødsproduktionens område. Ialt 32 forskere fra 9 forskellige lande deltog i konferencen. Rejse- og opholdsudgifter blev betalt fra EF.

I det følgende gives et kortfattet dansk sammendrag over de foredrag, der blev afholdt ved konferencen.

1. Rapport vedrørende et EF ultralydprojekt gennemført i Danmark og England.

Undersøgelsen gennemførtes i 1980/81, og resultaterne er detaljeret omtalt i en officiel EF publikation.

Rapporten indledes med en gennemgang af ultralydprincippet og de vigtigste typer af ultralydudstyr.

Forsøget omfattede en sammenligning af følgende fem udstyr: "Scanogram", "Danscanner", "Ohio Nuclear", "Brüel og Kjær" og "Philips Diagnost R". Dyrematerialet bestod af 30 ungtyre/stude fra MLC forsøgsstationen i England og 20 ungtyre fra H-F forsøget på Egtved Avlsstation. Efter scanningen blev dyrene slagtet og dissekeret i kød, talg og knogler.

Blandt de personer, som anvendte udstyrene, var der generelt størst tilfredshed med "Danscanner" og "Scanogram", som begge er specielt konstruerede til brug på husdyr.

De statistiske analyser viste, at de bedste resultater blev opnået ved måling over 1. lændehvirvel. Ultralydmålingerne på de levende dyr gav samme beskrivelse af slagtekvaliteten som billeder af et tværsnit af den overskårne slagtekrop. Muskelarealet gav den bedste beskrivelse af slagteprocent og kød/knogle forhold, mens fedtarealet var det bedste indirekte mål for fedningsgrad og kødprocent. Der var

ikke signifikante forskelle mellem udstyrene, men en tendens til at "Scanogram" var bedst til fedtmålinger og "Danscanner" bedst til muskelmålinger.

2. Anvendelse af in vivo teknik i de forskellige EF-lande.

a. Belgien har ikke for øjeblikket projekter med objektive in vivo målinger, men der anvendes i vid udstrækning ydre kropsmål og subjektiv pointgivning for muskelfylde. Forventer senere at iværksætte projekter med ultralyd eller lignende teknik.

b. Danmark. Ultralydmålinger med "Danscanner" anvendes rutinemæssigt ved individprøver, avlsforsøg og enkelte fodringsforsøg. På eksperimentel basis omfattende projekter med henblik på en yderligere forbedring af ultralydteknikken og dens anvendelsesmuligheder. Endvidere er der sammen med Norges Landbrukshøgskole og hospitalssektoren indledt et projekt med røntgenscanning.

c. Frankrig anvender en subjektiv pointgivning for muskelfylde ved individprøver og forsøgsstationer. I Theix er der opnået lovende resultater med indsprøjtning af D_2O til bestemmelse af kroppens fedtindhold. D_2O står for Deuterium Oxid eller "tungt vand", og det er en ikke radioaktiv forbindelse, som kan anvendes uden risiko for dyr og mennesker. Andre in vivo forsøg i Frankrig omfatter en direkte sammenligning mellem subjektiv pointgivning, kropsmålinger, D_2O teknik og forskellige ultralydudstyr incl. "Danscanner". Foreløbige resultater viste, at såvel "Danscanner"-målinger som en kombination af 16 forskellige kropsbedømmelser gav en tilfredsstillende sikker beskrivelse af dyrenes slagteværdi.

d + e. Tyskland. I Vesttyskland anvendes stadig en subjektiv bedømmelse af slagteværdien på de levende dyr, selv om det erkendes, at det har en meget begrænset værdi på et relativt ensartet dyremateriale, som det der findes på individprøvestationer og forsøgsstationer. På eksperimentelt plan arbejdes derfor med isotopmærket vand, K^{42} og Na^{24}, photogrammetri og forskellige ultralydudstyr. "Danscanner"-udstyret anvendes i Kulmbach, München og Kiel.

f. Grækenland har endnu ikke en organiseret afregning efter slagtekvalitet, og de forsøgs- og avlsmæssige aktiviteter på dette område er derfor meget begrænsede.

g. Irland forventer at indføre ultralydmålinger ved individprøverne i efteråret 1982.

h. Holland anvender subjektiv bedømmelse af muskelfylde og fedningsgrad. Objektive in vivo målinger af kroppens sammensætning er ikke planlagt.

i. England har over en længere årrække gennemført ultralydmålinger med "Scanogram" og "Danscanner". Målingerne koncentreres om det subcutane fedtlag, og de anvendes rutinemæssigt ved individprøverne samt forskellige former for avls- og fodringsforsøg.

3. Potentielle muligheder for in vivo teknikkens anvendelse.

a + b. Avlsforanstaltninger. In vivo teknikkens avlsmæssige muligheder koncentreres især om individprøverne, hvor det tilstræbes at måle avlsværdien for mange aktuelle produktionsøkonomisk vigtige egenskaber. Disse egenskaber skal måles så sikkert som muligt og på det tidligst mulige tidspunkt under dyrets opvækst.

For nærværende koncentreres målingerne om kroppens anatomiske sammensætning, og ultralydteknikken er det mest anvendte hjælpemiddel. Målinger af det subcutane fedtlag giver den bedste bestemmelse af kroppens fedningsgrad og kødindhold, mens en måling af rygmuskulaturens tværsnitsareal især fortæller om slagteprocent og muskelfylde. Selektion for reduceret fedttykkelse kan på langt sigt have en uheldig effekt på egenskaber som appetit, energideponeringsevne og hunlig frugtbarhed. Selektion for stort muskelareal kan modvirke den negative effekt af avlsarbejdet for højere mælkeydelse og Holstein-Frisian importen.

Hvis en mere avanceret in vivo teknik gør det muligt på individprøvetyrene at følge udviklingen i de vitale organer, i energideponeringen eller i reaktionen på forskellige sultbehandlinger, vil det også blive muligt at inddrage konstitutionsegenskaber og indirekte mælkeproduktionsegenskaber i individprøver. En sådan udvikling vil fuldstændig kunne revolutionere avlsarbejdet med kombinationsracerne.

c + d + e. Fodringsforsøg. Inden for fodringsforsøgene er der et stort behov for at kunne følge de løbende ændringer i kroppens anatomiske og kemiske sammensætning, som finder sted gennem forsøgsperioden. En fuldt udviklet in vivo teknik kan muligvis supplere eller helt erstatte de meget omkostningskrævende klimakammerforsøg og slagteundersøgelser.

4. Den forventede tekniske udvikling inden for alternative in vivo muligheder.

a + b + c. Ultralyd. Den tekniske udvikling inden for ultralydteknikken fortsætter med uformindsket styrke. Vedrørende den type udstyr, der er specielt designet til måling af fedt- og muskelarealer på husdyr, vil der sandsynligvis ske en fortsat forbedring af målesikkerheden og udstyrenes robusthed. Endvidere søges udstyrene automatiseret så stærkt som muligt, ligesom de vil blive mere fleksible, så de kan anvendes til måling på flere forskellige steder af kroppen.

En anden type udstyr vil blive specielt udviklet til at måle dybere liggende organer m.v. Ekko-signaler fra denne type vil kunne opsamles i mikrocomputere og behandles over EDB for en mere nuanceret udnyttelse af resultaterne.

d. Computer styrede røntgenmålinger er en teknik, som der stilles store forventninger til også inden for husdyrbrugsforskningen. Ved Norges Landbrukshøgskole installeres i foråret 1982 et sådant udstyr til en samlet pris på 5-6 mill. kr. Statens Husdyrbrugsforsøg har indgået en samarbejdsaftale med Norges Landbohøjskole og får dermed lejlighed til i et vist omfang at benytte dette udstyr.

f. Dilution teknik anvendes indtil videre kun til forsøgsformål. Metoden gennemføres ved, at der indsprøjtes en kendt mængde tungt vand (D_2O) i dyret. På bestemte tidspunkter efter injektionen udtages der blodprøver, og fortyndingsgraden måles. Derved fås et mål for dyrets relative væskeindhold og dermed indirekte for fedningsgraden. Metoden har givet ret lovende resultater, men den er indtil videre arbejdskrævende og kostbar at gennemføre.

5. Afsluttende diskussion.

Der var blandt deltagerne enighed om, at in vivo teknikken har store potentielle muligheder inden for såvel avlsarbejdet som forsøgsvirksomheden. Derfor burde udviklingsarbejdet inden for dette område have en relativ høj prioritering i den nærmeste fremtid.

Da der er tale om en ret kostbar teknik, ligesom de opnåede resultater er af generel værdi, bør koordineringen mellem de forskellige landes udviklingsarbejde fremmes mest muligt. Det vil ligeledes være betydningsfuldt med en snæver kontakt til human medicinens udnyttelse af in vivo teknikken.

OPENING AND INTRODUCTION

A. Neimann-Sørensen
National Institute of Animal Science
Rolighedsvej 25, 1958 Copenhagen V.
Denmark

It is a pleasure to me first of all to welcome you all. I welcome you to Denmark, to Copenhagen, and to the Royal Veterinarian and Agricultural University. As announced in the programme the workshop is organized by the National Institute of Animal Science, and you may wonder, why then it is held at the University. To those, who are not acquainted with our organization in this country, I want to point out that the two institutions, the Royal Veterinarian and Agricultural University and the National Institute of Animal Science, are closely interrelated. Although the University has the Ministry of Education as its ressort and the National Institute has the Ministry of Agriculture as ressort, the two institutions work together both in research and teaching as far as animal science is concerned. This is possible, because they are placed close to each other.

I may add that this situation will change in the future, as the National Institute during the next years will be moved to Jutland (Aarhus), where a new institution will be built up. We look forward to have a new and modern institution, and many efforts have been made to maintain a close and fruitful collaboration with the University.

Opening now the CEC workshop on "In vivo estimation of body composition in beef" I want to thank the Commission for sponsoring and making the workshop possible. I address this thank to dr. Connell, who is present here. The workshop is part of the activities within the so-called beef programme - which has the aim to coordinate research on improvement of beef production in the community.

One of the major aims for research is to seek new tools. Tools, which in the breeding work can act as aids to selection and in this way help us in identifying the valuable genotypes, and maybe do this at an earlier stage than otherwise possible. Thereby, the rate of genetic progress can be increased.

Tools also, which in connection with nutritional work can be helpful in our undertanding of the physiolcgical processes. Such tolls, if we can find them, may be important in the future to monitoring the feeding of the animals, so as to obtain maximum yield and maintain the health of the animal.

In the CEC beef programme efforts of this kind have often been in our minds. One line of efforts in this direction can be exemplified by the results, which were presented at the workshop this September in Edinburgh on "The use of Biochemical and endocrinological parameters as predictors of dairy and beef performance". I regard these results to be promising.

Another line of efforts have taken advantage of the potential possibilities, which arise as the result of the rapid developments, which take place in the so-called "in vivo technique: ultrasonics, dilution or røntgen scanning".

The mentioned efforts and potential possibilities are the background, on which the EEC expert groups on genetics, on nutrition and on carcass and meat quality did recommend that the present workshop should be held.

Dr. A. Cuthbertson from U.K. and dr. B. Bech Andersen from this country have worked out the programme for our workshop, and in this emphasis has been placed on the interdisciplinary nature of our subject. Thus, there are experts here from several disciplines of research: physiological, genetics, carcass-experts and experts in electronic engineering.

Hopefully, this should guarantee a vivid discussion and a fruitful exchange of ideas.

CEC SUPPORTED ULTRASONIC TRIAL IN UK AND DK

B. Bech Andersen[1], H. Busk[1], J.P. Chadwick[2], A. Cuthbertson[2], G.A.J. Fursey[3], D.W. Jones[2], P. Lewin[4], C.A. Miles[3] and M.G. Owen[2].

1) National Institue of Animal Science, Copenhagen, Denmark.
2) Meat and Livestock Commission, Bletchley, Milton Keynes, England.
3) Meat Research Institute, Langford, Bristol, England.
4) The Danish Institute of Biomedical Engineering, Glostrup, Denmark.

The purpose of the experiment was to obtain information on the potential of different ultrasonic machines to describe carcass characteristics, and to asses their ease of handling and operation under practical conditions.

A report of the work was given at the workshop. This report is published under EUR 7640 (1981) Luxembourg. In the following a part of the report is presented, namely:
section 1) Introduction, section 5) Design, statistical methods and results, section 6) Discussion and conclusions and section 8) References.

1. INTRODUCTION

This publication follows a request from the CEC Beef Production Research Committee for a report on the application of ultrasonic techniques for predicting beef carcass characteristics from measurements of live cattle.

One of a range of non-destructive evaluation techniques, that could be used for assessing body composition of living animals, ultrasonic techniques appear to have the greatest potential for practical application at the present time.

The application of ultrasonics to the measurement of cattle was first reported by Temple, Stonaker, Howry, Posakony and Hazaleus (1956) and Stouffer, Wallentine and Wellington (1959). Since then ultrasonic techniques have improved considerably and several reports have examined the correlation between ultrasonic measurements of cattle and carcass compositions (e.g. Andersen, 1975; Kempster, Cuthbertson, Jones and Owen, 1981).

Several ultrasonic instruments are available commercially, but the potential user may have insufficient background information upon which to select the most suitable equipment and/or the best way of using it. This report aims to fill the gap.

5. DESIGN, STATISTICAL METHODS AND RESULTS OF THE TRIALS CARRIED OUT IN U.K. AND DENMARK

To obtain information on the potential of different machines to describe carcass characteristics accurately, and to assess their ease of handling and operation under practical conditions, trials covering a range of genotypes were conducted in Britain and Denmark. It was recognised that most ultrasonic machines require considerable skill both in operation and interpretation, and the comparison was effectively of machine/operator combinations.

The British work was based at the Meat and Livestock Commission's Carcass Evaluation Unit, Blisworth, Northants, and the Danish at Egtved Testing Station, Jutland.

a. MACHINES

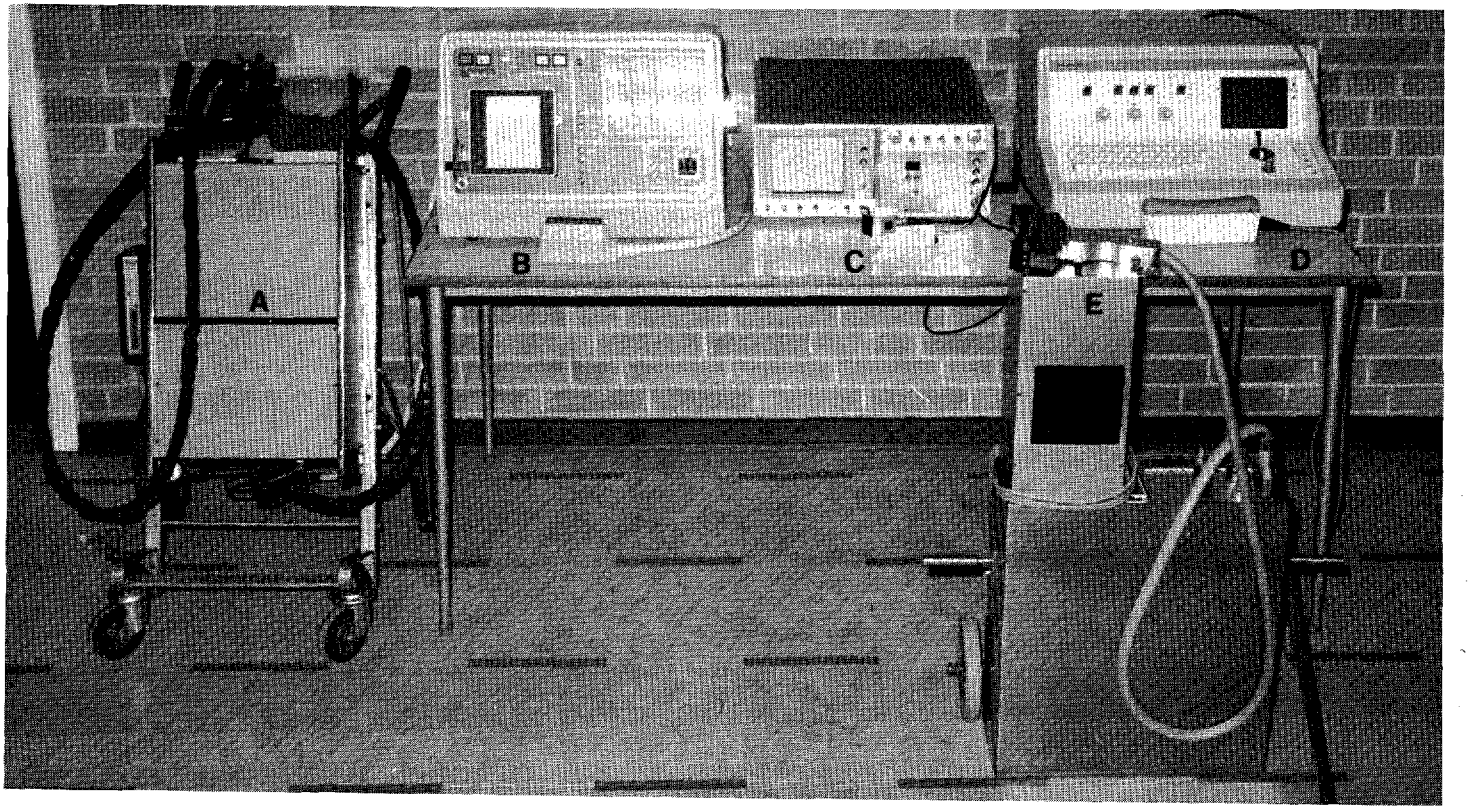
Selection of equipment for test was a considerable problem. Apart from equipment built specifically for use on live animals, it was considered important to include representatives of scanners built for diagnostic work on humans. Marked advances have been made in recent years in the development of scanners for human use and their potential value for use on live cattle warranted assessment. Because no more than five pieces of equipment could be conveniently tested, and evidence that measurements of area of fat in beef animals are more useful indicators of carcass fatness than a few simple fat depths (e.g. Cuthbertson, 1976), an example of an A-scope instrument was excluded. The medical scanners chosen for the test were those which appeared, from medical experience, to have a reasonable potential for use on animals and where the manufacturers were prepared to lend their expensive equipment for evaluation under working conditions far removed from the hospital environment.

The five machines eventually selected for the trial (Plate 1) comprised two built specially for use on animals: the "Scanogram" and the "Danscanner", and three made for use on humans : the Ohio Nuclear "Sonofluoroscope", the Philips "Diagnost R", and the Bruel and Kjaer "Spinner".

A. "Scanogram": This instrument is described briefly in section 1. The frequency of the single transducer was 2MHz and scans were recorded with a Polaroid camera.

B. Ohio Nuclear "Sonofluoroscope" : Scanning was performed with a linear 2.25 MHz (nominal) array. Its active area was 96 x 15 mm and it housed switches operating a frame-freeze and the camera shutter. Other transducers were available. The image was displayed on a video monitor measuring 95 x 127 mm on which an alpha-numeric identification could be displayed via a keyboard. The image had 16 levels of grey-scale with an adjustable threshold. Photography was accomplished with a multi-purpose Polaroid camera with viewer.

C. Bruel and Kjaer revolving transducer system : type 3402 : This system, referred to subsequently as the "Bruel and Kjaer spinner", produced a real-time image by use of a revolving transducer. This contained four identical elements which were mounted in a rotating drum. The instrument produced a grey-scale image which covered a sector of 65° and was displayed on a screen measuring 100 x 125 mm. In the trial, photography was accomplished with a hand-held Polaroid camera.



The five ultrasonic scanners: A. "Scanogram" - B. "Ohio Nuclear Sonoflouroscope" - C. "Bruel and Kjaer revolving transducer system (type 3402)" - D. "Philips Diagnost R" and E. "Danscanner".

D. Philips "Diagnost R" : Scanning was performed with a linear 2 MHz (nominal) array. Its active area was approximately 160 x 10 mm and it was supplied with a flexible membrane for coupling to a curved surface. Other transducers were available. The image was displayed on a 15 cm video monitor on which an alpha-numeric identification could be displayed via a keyboard. No provision was made on the console for a camera and in hospital photographs would be taken from an adjacent monitor. We however used a hand-held polaroid camera. A frame-freeze was operated from the console and the image had 16 levels of grey-scale.

E. "Danscanner"

This instrument is described briefly in section 1 (Fig.5). The frequency of the multi-element probe was 2.2 MHz and photographic records were made with a 35 mm camera, the shutter of which was operated by a switch on the transducer head.

b. OPERATORS

Each operator was allocated a machine which he operated throughout the trial. An assistant operator was needed for the Bruel and Kjaer to take the picture. In the case of both the "Scanogram" and "Danscanner", the operators had experience extending over several years, but with the medical equipment experience was limited to several days of preliminary test work before the start of the trial.

Each operator worked independently on the allocated machine, taking as many scans as he liked, but selected only one per measurement site for subsequent analysis. After scanning a batch of cattle, it was scanned a second time in a different order to obtain a measure of repeatability for each machine/operator combination.

c. ANIMALS, MEASUREMENT SITES AND CARCASS EVALUATION

In Britain, thirty cattle were scanned by each machine operating transversely across M.longissimus dorsi (eye muscle), at the tenth rib, first lumbar and third lumbar vertebrae. Hair was removed from these sites by clipping before scanning commenced. Twenty of the cattle were steers of mixed breeds selected to cover a range of fatness and conformation and ten were young Hereford bulls. After slaughter, measurements corresponding to those taken on the live animal were taken on the carcass, which involved cutting one side of each carcass at the three positions scanned. Thereafter, each side was separated completely into lean meat, fat and bone, following the procedure of Cuthbertson, Harrington and Smith (1972).

In Denmark, twenty three young bulls were measured of which twenty were Danish Black and White and three Red Danish. They were scanned after clipping the hair at the same sites as in Britain and carcass measurements taken at corresponding sites, omitting the third lumbar vertebra. One side of each of the twenty Danish Black and White carcasses was fully dissected by the Danish Meat Research Institute using the procedure described by Berg, Andersen and Liboriussen (1978). The results for the three Red Danish bulls are not included in the present analysis reported below.

d. SCAN PHOTOGRAPH MEASUREMENT AND INTERPRETATION

The photographic prints of the scans obtained from each machine on each measurement occasion were interpreted independently by two operators, one from Britain and one from Denmark. All prints were coded before interpretation and measurement so that interpreters did not know the identity of the animal or whether it was a repeat scan. All scan prints were enlarged to half life size for interpretation by the UK interpreter. After interpretation, depths were measured by ruler and areas by automatic measuring equipment. All Danish interpretations were made on scan photographs at the scale produced by the equipment, and measured as for the UK interpretations. From each scan, the interpreters obtained measurements of fat and muscle depths and areas, except for the Bruel and Kjaer which could only be used to provide fat and muscle depths. None of the medical equipment was able to produce a scan covering the whole cross-sectional width of the eye muscle and so the area for measurement was reduced for these machines. To allow comparison of the machines on a similar basis, scans produced by the "Scanogram" and "Danscanner" at the first lumbar vertebra were also interpreted to provide muscle areas equivalent to those obtained with the medical scanners.

Following normal practice, the Danish interpreter included the hide when measuring fat depths and fat areas in both the Danish and British sample of cattle. All data were corrected to a constant velocity of ultrasound of 1.54 km/s.

e. STATISTICAL METHODS

1. Ultrasonic measurements

For the UK and Danish data, separate models were fitted as follows for each interpreter/machine/measurement position subgroup:

$$x_{ij} = \mu + R_i + A_j + (E)_{ij}$$

where

x_{ij} = the ijth measurement

μ = the overall mean

R = replicate effect (first or repeat) i = 1,2

A = animal effect j = 1, 2.....30 (UK)

j = 1, 2.....20 (DK)

E = residual, or error term $(R \times A)_{ij}$

The analysis of variance table derived from this model is:-

Source of variation	Degrees of freedom	Expected value of mean square
Replicates	1	$\sigma_E^2 + N\sigma_R^2$
Animals	29 (19 DK)	$\sigma_E^2 + 2\sigma_A^2$
Residual (R x A)	29 (19 DK)	σ_E^2

where σ_E^2 σ_R^2 and σ_A^2 represent the variances due to error, replicate and animals, respectively and N = 30 UK; N = 20 DK.

2. Carcass measurements

Since only one carcass measurement was taken on each animal, for each characteristic, a simplified model was fitted to the UK and DK data separately as follows:

$$Y_j = \mu + a_j$$

where Y_j = the jth measurement

μ = the overall mean

a = animal effect j = 1, 2 ..... 30 (UK)

1, 2 ..... 20 (DK)

The analysis of variance table derived from this model is:

Source of Variation	Degrees of freedom	Expected value of mean square
Animals	29 (19 DK)	σ_a^2

3. Estimates of correlation coefficients

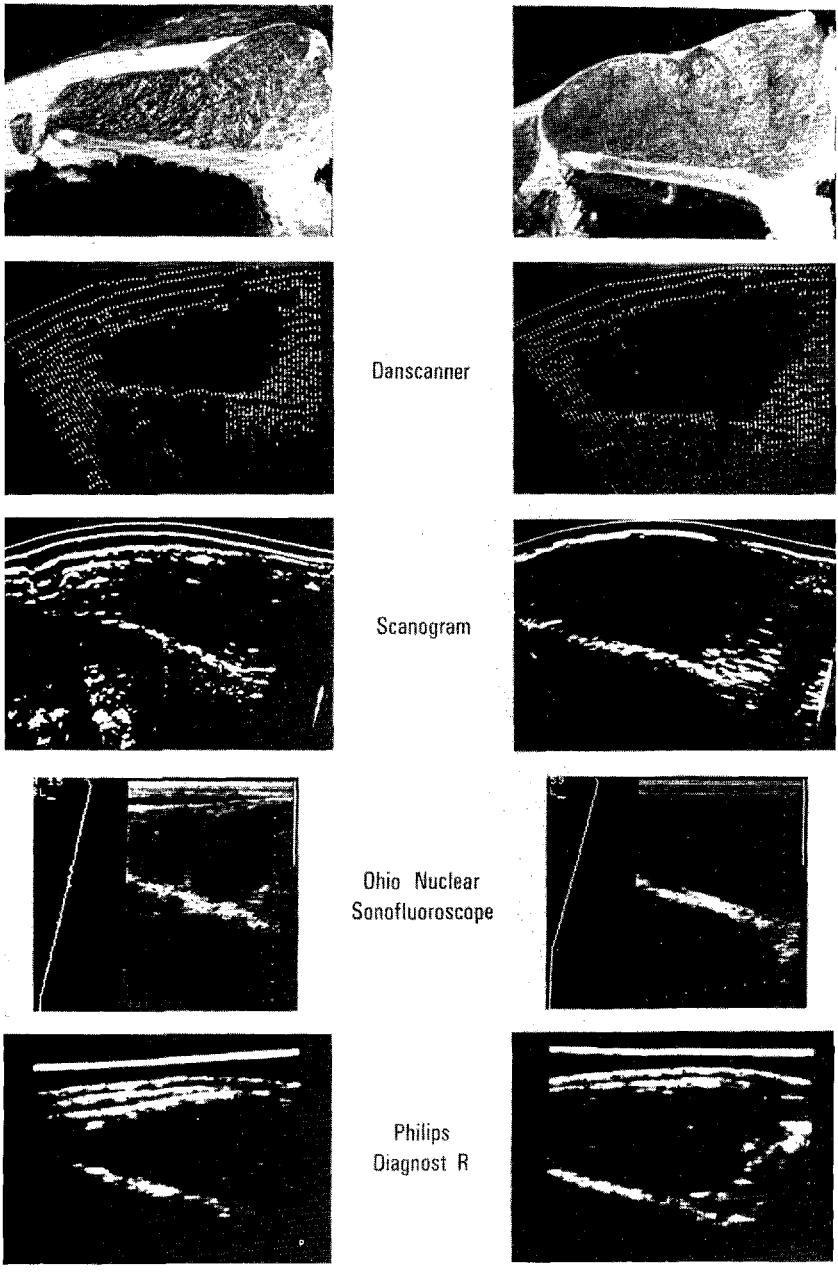
The most important derived correlations are:

a) The correlation between an ultrasonic measurement recorded on an animal, and a carcass measurement:

$$\frac{\sigma_{Aa}}{\sigma_a^2\left(\sigma_A^2 + \sigma_R^2 + \sigma_E^2\right)}$$

b) The correlation between an ultrasonic measurement recorded on an animal

ULTRASONIC SCANS - produced by different instruments



Ultrasonic scans of two contrasting cattle with corresponding sections of their carcasses. Recordings were made at the level of the 3rd lumbar vertebrae.

and a replicate taken on the same animal:

$$\frac{\sigma_A^2}{\sigma_A^2 + \sigma_R^2 + \sigma_E^2}$$

c) The correlation between an ultrasonic and carcass measurement, corrected to constant liveweight:

$$\frac{\sigma_{Aa} - \left(\frac{\sigma_{Ab} \cdot \sigma_{ab}}{\sigma_b^2}\right)}{\sqrt{\left(\sigma_A^2 + \sigma_R^2 + \sigma_E^2 - \frac{\sigma_{Ab}^2}{\sigma_b^2}\right)\left(\sigma_a^2 - \frac{\sigma_{ab}^2}{\sigma_b^2}\right)}}$$

σ_{Aa} = the between animal covariance of the ultrasonic and carcass measurement

σ_{Ab} = the between animal covariance of the ultrasonic measurement and liveweight

$\sigma_{a\,b}$ = the covariance of the carcass measurement and liveweight

σ_b^2 = the variance of liveweight.

f. RESULTS

1. Each instrument produced ultrasonic scans which compared recognisably with anatomical sections and distinguished between the fat, small-muscled animal on the left of Plate 2 and the lean, large-muscled animal on the right. All instruments recorded strong echoes from the transverse process of the lumbar vertebra (Plate 2), but the appearance of the scans differed markedly. The "Danscanner" and "Scanogram" pictures displayed the entire cross section of the eye muscle while the Ohio and Philips instruments showed a part of the muscle only and the Bruel and Kjaer only a 65° sector.

2. Means and standard deviations of liveweight at evaluation, dressing or killing out percentage, carcass composition and cut face measurements are given for UK and DK cattle in Tables 1a and 1b respectively. The residual deviations at constant liveweight are also given.

The Tables show that the UK sample of cattle were 87 kg heavier than those in DK, but dressing percentage was the same for both groups. The percentage of total fat in the carcass was greater in the UK cattle. This is unlikely to be due simply to the difference in dissection

procedure because fat depths and areas were also relatively greater in UK cattle.

Variation in liveweight was similar in both sets of data with the coefficient of variation being 11.6 per cent for UK and 12.2 per cent for DK cattle. For all the carcass characteristics, however, the variability was relatively greater for the UK cattle reflecting the greater range in breed types and their fatness.

3. Table 2 gives the repeatability (correlation between repeated measurements) of fat depths, fat areas and muscle areas at the tenth rib and first lumbar vertebra. The residual standard deviation of the measurement is also given. This represents the variation left after accounting for animal and repeat measurement effects. In general, correlations were higher at the first lumbar vertebra than at the tenth rib, and higher for fat depths and areas than muscle areas. There was a tendency for the repeatability of fat measurements to be highest for the "Scanogram" and for muscle areas the "Danscanner" tended to be highest. However, the differences between equipment were rather small with the exception of Bruel and Kjaer which showed poor repeatability.

4. Correlations between ultrasonic measurements and the corresponding cut face depths and areas are given in Table 3. Again these tended to be higher at the first lumbar vertebra but were of similar magnitude for fat depth, fat area and muscle area. No one machine stood out as being superior.

5. Table 4 presents the relationships between cut face carcass measurements on the one hand and dressing percentage, lean percentage and lean/bone ratio on the other, adjusted to constant live weight. Fat areas and depths were negatively correlated with lean percentage and lean/bone ratio, while the relationships involving muscle area were positive. In both sets of data, fat areas were more highly correlated with lean percentage than were fat depths. With the exception of muscle area, measurements at the tenth rib and first lumbar vertebra gave correlations of similar magnitude with the percentage of lean in the carcass.

6. Correlations between ultrasonically measured muscle area (adjusted to constant liveweight) and dressing percentage were, with one exception, positive (Table 5). However, correlations between fat measurements and dressing percentage were positive in UK data and negative in the DK data, perhaps reflecting differences in genotype in the two countries. With

all machines correlations were low to moderate.

7. At constant liveweight, percentage lean was negatively correlated with ultrasonic fat depths and areas, and positively correlated with muscle area (Table 6). For both fat depths and fat areas, correlations were higher at the first lumbar vertebra, compared with the tenth rib but, rather surprisingly, fat areas showed little advantage over fat depths generally in their relationship with lean percentage. Between the four machines capable of measuring areas, there was very little difference in the magnitude of the correlations, averaged over interpreter, location and origin of cattle.

8. Correlations between ultrasonic measurements and carcass lean/bone ratio tended to be low and negative for fat depths and areas (Table 7). Muscle areas were positively associated with lean/bone ratio. There was some evidence of machine differences.

9. More detailed results of the test work are given in Appendices 1 to 5.

g. PRACTICAL OBSERVATIONS ON THE TEST EQUIPMENT

At the end of the test work, each ultrasonic machine was scored on a five point scale, where 1 = poor and 5 = good. The score for each machine was agreed during a discussion involving the five operators participating in the trial. The results are not intended for statistical analysis.

The following characteristics were assessed:

Ease of operation

Operator comfort - An assessment of the physical effort required by the operator to produce a scan.

Adjustment possibility - Number of types of adjustment available to cater for animal variations.

Scan production efficiency - How quickly an acceptable picture is visualised including the time required to adjust the equipment.

Number of operators required - To obtain an acceptable scan, taking account of the fact that some machines needed an extra person to enable photographs to be taken.

Picture stability - Effect of animal movement.

Transducer shape size - Ability of each machine to measure animals of varying conformation and shape of the eye muscle.

Ease of site location - East of identification of desired measuring position by use of pre-scanning.

Coupling economy - Amount of liquid paraffin required to obtain a good picture.

Quality of results

Photographic reproduction - Quality of final "Scan" in relation to the complete transfer of all information from screen to film.

Thickness of echo - Clarity of the picture for interpretation.

Display size - Amount of information displayed on final scan.

Depth of signal penetration - Ability of the equipment to locate and identify bottom of the eye muscle even on large animals, particularly relevant at the tenth rib.

Picture distortion - Effect that rotation of the transducer has on the shape and size of eye muscle.

Comparison of scores given for each machine

	Scanogram	Danscanner	Philips	Ohio	B & K
Ease of operation					
1) Operator comfort	5	4	2	3	3
2) Adjustment possibilities	5	5	3	5	5
3) Scan production efficiency	2	5	5	5	4
4) No. of operators required	5	5	3	5	1
5) Picture stability	5	4	2	2	2
6) Transducer shape and size	4	5	3	2	1
7) Ease of site location	1	5	5	5	3
8) Coupling economy	5	5	3A	3A	2

	Scanogram	Danscanner	Philips	Ohio	B & K
Quality of results					
1) Photographic reproduction	4A	5	2	4	1
2) Thickness of echo lines	4	4	2	5	1
3) Display size	5	5	3	2	1
4) Depth of signal penetration	4	4	2	3	1
5) Picture distortion	5	5	3	4	1

A = Assumption - insufficient information available.

In addition to the above, the following advantages and disadvantages of each machine under practical conditions were described by the group of operators.

Scanogram

Advantages:

1) Large track enabling all sizes of eye muscle to be measured.
2) Minimal amount of physical effort required to hold track in position.
3) Robust, with very little damage likely to occur under farm conditions.

Disadvantages:

1) The design of the Scanogram is such that the cathode ray tube (screen) is not visible. Resulting scans can only be seen after being reproduced on Polaroid film. Thus optimum machine settings and site location are only obtained by trial and error. Taking account of the cost of labour and Polaroid film, this makes the Scanogram expensive to operate.
2) The rigid, fixed shaped track means that poor conformation (angular shaped) cattle are difficult to scan.

Danscanner

Advantages:

1) Immediate - real time - eye muscle visualisation.
2) Inexpensive standard camera film (24 x 36 mm) is used for scan registration.
3) Rubber membrane under transducer housing enables scans to be obtained successfully from most shapes of animal.
4) Easy site location.
5) Easy to clean.
6) Robust, although transducer head needs to be handled with more care than that of the Scanogram.

Disadvantages:

1) Transducer is not long enough to identify both the midline of the body and the lateral edge of eye muscle, but this spread of scan is seldom required and used in practice.
2) A trained operator is required to obtain a good scan. This is due to the fact that the transducer is held in position by downward pressure with one hand. When the operator takes his eye off the transducer to look at the screen there is a tendency for the transducer to slide out of position. However, this comment is valid for the rest of the equipment assessed, although it is not as critical in the case of the "Scanogram".

Philips

Advantages:

1) Storage facilities for two pictures, enabling a quick check on repeatability, and also to help to ensure that the best scan is photographed
2) Simple to operate, because there are few possible adjustments.

Disadvantages:

1) Needs two operators, as all the controls including the store switch are situated on the console.
2) Small transducer head allows only a sector of eye muscle to be scanned.
3) No camera facility.
4) In its present form the transducer head would not withstand on-farm use.
5) Tends to produce scans with very broad lines, making it difficult to measure fat thickness.
6) As (2) under Danscanner.

Ohio

Advantages:

1) Frame-freeze facility operated from transducer head.
2) Easy site location (transverse and longitudinal).
3) Produces scans with very thin lines, making it easy to measure fat thickness.

Disadvantages:

1) Very small transducer head, allows only one third of the eye muscle to be measured with each scan.

2) In its present form the transducer head would not withstand on farm use.

3) As (2) under Danscanner.

Bruel & Kjaer

Advantages:

1) None

Disadvantages:

1) Needs two operators, as all the controls are situated on the main unit.

2) No camera facility.

3) No storage facility.

4) Only depths of fat and muscle can be measured.

5) Produces very broad lines making it difficult to measure fat thickness, and also to distinguish between skin and subcutaneous fat. It may well be that this could be improved by the use of water bath coupling.

6. DISCUSSION AND CONCLUSIONS

1. The results presented in this report indicate that measurements obtained by ultrasonic scanning predict body composition with a similar degree of accuracy to that of corresponding cut face measurements on the carcass. The prediction using ultrasound seems better than might be expected from the relationship between the ultrasonic measurements and the corresponding cut face meaurements on the carcass. This is especially the case at the tenth rib, where there is more difficulty in identifying the appropriate anatomical features.

2. Apart from the Bruel and Kjaer scanner, which seemed poorer than the other equipment, no clear differences emerged between the machine/operator combinations in terms of predicting body composition. More distinct differences may be identified when further work has been undertaken involving multiple regression analyses of the best combination of measurements for each machine. Although the Philips and Ohio machines were only able to scan a section of the eye muscle and its overlying subcutaneous fat, they provided as good a description of carcass composition. Among the operators, however, there was a preference for the "Danscanner" and "Scanogram", which are specially constructed for use on farm animals.

3. An interesting general feature not referred to so far is that inclusion of the hide in the Danish interpreter's assessment of fat depths and fat areas did not seem to affect his precision in predicting carcass composition compared with the UK interpreter who excluded the hide from his assessment of fat.

4. In this trial work, the scanning and interpretation was carried out by experienced operators, and the results obtained may be better than would be achieved by those less experienced. It seems important that those starting scanning work should:

- understand the anatomy of the body;
- be trained in the use of the equipment, including its calibration;
- ensure a good back-up service;
- carry out periodic checks against carcass measurements or, when this is not always feasible, against similar machines.

5. In making the decision on which equipment to use, the other important factors to consider include: capital cost, ease of use, number of operators needed, operating costs, quality of service and robustness.

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Table 1a Means and standard deviations of liveweight, dressing percentage and carcass characteristics (30 UK cattle)

	Mean	S.D.	S.D. at constant liveweight
Liveweight (kg)	530.3	61.4	-
Dressing percentage	53.5	2.93	2.97
% lean	62.5	3.88	3.41
% subcutaneous fat	6.9	2.18	2.08
% total fat	20.8	4.57	4.15
% bone	15.3	1.69	1.72
Lean/bone ratio	4.1	0.51	0.50
Lean/fat ratio	3.2	1.04	0.98

Cut face carcass measurements:

	10th rib		1st lumbar vertebra		3rd lumbar vertebra	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Fat depth 7.5cm (mm)	8.4	4.8	6.6	4.6	9.3	4.5
Eye muscle depth 7.5cm (mm)	54.5	8.6	68.4	8.1	57.1	7.7
Fat area 0-15cm (cm^2)	12.5	5.4	10.8	5.0	10.2	5.2
Eye muscle area total (cm^2)	68.0	12.3	70.5	10.6	70.3	9.8
Fat area 5-12.5cm (cm^2)	6.0	3.3	4.8	3.0	6.4	3.4
Eye muscle area 5-12.5cm (cm^2)	39.9	6.2	44.7	6.1	38.6	5.2
Fat area over eye muscle (cm^2)	14.5	7.4	11.5	5.6	13.1	6.5

1st lumbar and 3rd lumbar cut face measurements only include 29 animals.

Table 1b Means and standard deviations of liveweight, dressing percentage and carcass characteristics (20 DK cattle)

	Mean	S.D.	S.D. at constant liveweight
Liveweight	443.3	53.9	-
Dressing percentage	53.3	1.55	1.42
% lean	67.9	2.60	2.66
% total fat	15.1	2.39	2.42
% bone	17.0	0.96	0.76
Lean/bone ratio	4.0	0.32	0.29
Lean/fat ratio	4.6	0.79	0.81

Cut face carcass measurements:

	10th rib		1st lumbar vertebra	
	Mean	S.D.	Mean	S.D.
Fat depth 7.5cm (mm)	7.0	3.2	4.5	2.8
Eye muscle depth 7.5cm (mm)	66.1	9.2	65.0	6.7
Fat area 0-15cm (cm^2)	11.6	3.8	9.2	3.7
Eye muscle area total (cm^2)	55.7	8.1	58.2	8.0
Fat area 5-12.5cm (cm^2)	5.3	2.2	3.6	2.0
Eye muscle area 5-12.5cm (cm^2)	40.7	6.0	43.0	6.5
Fat area over eye muscle (cm^2)	8.3	3.9	6.3	3.1

Table 2 Correlations and residual standard deviations (in parenthesis) between repeat ultrasonic measurements at 10th rib and 1st lumbar vertebra

Equipment	Interpreter	Animals	Fat depth, 7.5cm		Fat area		Eye muscle area	
			10th rib	1st lumbar vertebra	10th rib [1]	1st lumbar vertebra [2]	10th rib [3]	1st lumbar vertebra [4]
Scanogram	UK	UK	0.85(1.0)	0.74(1.0)	0.77(1.4)	0.82(1.3)	0.40(4.8)	0.45(5.4)
	DK	DK	0.71(1.0)	0.79(1.1)	0.83(1.0)	0.76(1.9)	0.49(3.7)	0.64(2.1)
Danscanner	UK	UK	0.26(2.4)	0.47(1.6)	0.34(2.6)	0.59(2.5)	0.67(3.8)	0.85(2.5)
	DK	DK	0.68(1.6)	0.57(1.3)	0.70(2.0)	0.51(1.9)	0.41(5.3)	0.82(2.7)
Philips	UK	UK	0.44(1.6)	0.71(1.2)	0.54(1.0)	0.69(1.3)	0.47(3.9)	0.45(3.7)
	DK	DK	0.54(2.0)	0.23(1.8)	0.60(1.3)	0.67(0.8)	0.45(3.0)	0.78(2.0)
Ohio	UK	UK	0.49(1.4)	0.75(0.8)	0.67(0.8)	0.81(0.6)	0.10(5.9)	0.77(2.9)
	DK	DK	0.54(1.7)	0.63(0.8)	0.55(1.4)	0.78(0.4)	0.09(4.2)	0.74(1.7)
B & K	UK	UK	0.36(2.4)	0.25(2.9)	--	--	--	--
	DK	DK	0.00(2.6)	0.35(1.4)	--	--	--	--

1) and 2) 0-15cm area for Scanogram and Danscanner and 5-12.5cm area for Philips and Ohio

3) total area for Scanogram and Danscanner and 5-12.5cm area for Philips and Ohio

4) 5-12.5cm area for all equipment

Table 3 Correlations between ultrasonic measurements and corresponding measurements on the cut face of the carcass

Equipment	Interpreter	Animals	Fat depth, 7.5cm		Fat area		Eye muscle area	
			10th rib	1st lumbar vertebra	10th rib [1]	1st lumbar [2] vertebra	10th rib [3]	1st lumbar [4] vertebra
Scanogram	UK	UK	0.38	0.49	0.47	0.81	0.50	0.53
	DK	DK	0.33	0.72	0.40	0.70	0.08	0.54
Danscanner	UK	UK	0.02	0.45	0.29	0.67	0.41	0.68
	DK	DK	0.44	0.65	0.53	0.71	0.56	0.68
Philips	UK	UK	0.50	0.28	0.38	0.52	0.48	0.61
	DK	DK	0.23	0.45	0.50	0.68	0.61	0.67
Ohio	UK	UK	0.44	0.42	0.32	0.61	0.30	0.68
	DK	DK	0.24	0.56	0.46	0.68	0.12	0.71
B & K	UK	UK	0.23	0.26	--	--	--	--
	DK	DK	-0.10	0.60	--	--	--	--

1) and 2) 0-15cm area for Scanogram and Danscanner and 5-12.5cm area for Philips and Ohio

3) total area for Scanogram and Danscanner and 5-12.5cm area for Philips and Ohio

4) 5-12.5cm area for all equipment

Table 4 Correlations between cut face measurements on the carcass and dressing percentage, % lean and lean/bone ratio (adjusted to constant liveweight)

Animals	Dressing percentage		% lean		lean/bone	
	UK	DK	UK	DK	UK	DK
Fat depth, 7.5cm						
10th rib	0.15	0.29	-0.37	-0.60	-0.04	-0.27
1st lumbar vertebra	0.53	0.11	-0.18	-0.71	0.40	-0.44
Fat area, 0-15cm						
10th rib	0.25	0.10	-0.58	-0.76	-0.06	-0.42
1st lumbar vertebra	0.52	0.11	-0.52	-0.77	0.13	-0.45
Eye muscle area						
10th rib	0.38	0.40	0.34	0.47	0.53	0.62
1st lumbar vertebra	0.54	0.21	0.60	0.73	0.72	0.68

Table 5 Correlations between ultrasonic measurements and dressing percentage (adjusted to constant liveweight)

Equipment	Interpreter	Animals	Fat depth, 7.5cm		Fat area		Eye muscle area	
			10th rib	1st lumbar vertebra	10th rib[1]	1st lumbar[2] vertebra	10th rib[3]	1st lumbar[4] vertebra
Scanogram	UK	UK	0.36	0.46	0.33	0.43	0.39	0.36
	DK	DK	-0.38	0.15	-0.48	0.07	-0.07	0.33
Danscanner	UK	UK	0.41	0.39	0.35	0.55	0.30	0.52
	DK	DK	-0.19	-0.07	-0.30	-0.05	0.35	0.52
Philips	UK	UK	0.32	0.26	0.16	0.31	0.11	0.44
	DK	DK	-0.27	0.07	-0.16	0.14	0.00	0.39
Ohio	UK	UK	0.22	0.36	0.29	0.29	0.11	0.54
	DK	DK	-0.24	-0.13	-0.23	-0.11	0.28	0.28
B & K	UK	UK	0.34	0.33	--	--	--	--
	DK	DK	0.18	0.30	--	--	--	--

1) and 2) 0-15cm area for Scanogram and Danscanner and 5-12.5cm area for Philips and Ohio

3) total area for Scanogram and Danscanner and 5-12.5cm area for Philips and Ohio

4) 5-12.5cm area for all equipment

Table 6 Correlations between ultrasonic measurements and % lean in the carcass (adjusted to constant liveweight)

Equipment	Interpreter	Animals	Fat depth, 7.5cm		Fat area		Eye muscle area	
			10th rib	1st lumbar vertebra	10th rib[1]	1st lumbar[2] vertebra	10th rib[3]	1st lumbar[4] vertebra
Scanogram	UK	UK	-0.29	-0.50	-0.49	-0.51	0.22	0.17
	DK	DK	-0.12	-0.59	-0.21	-0.61	0.25	0.26
Danscanner	UK	UK	-0.31	-0.36	-0.32	-0.41	0.31	0.40
	DK	DK	-0.33	-0.58	-0.28	-0.61	0.05	0.29
Philips	UK	UK	-0.44	-0.47	-0.60	-0.43	0.28	0.40
	DK	DK	-0.36	-0.52	-0.42	-0.54	0.17	-0.14
Ohio	UK	UK	-0.47	-0.61	-0.48	-0.66	-0.05	0.38
	DK	DK	-0.06	-0.65	-0.08	-0.69	0.12	0.24
B & K	UK	UK	0.22	0.13	--	--	--	--
	DK	DK	0.30	-0.37	--	--	--	--

1) and 2) 0-15cm area for Scanogram and Danscanner and 5-12.5cm area for Philips and Ohio

3) total area for Scanogram and Danscanner and 5-12.5cm area for Philips and Ohio

4) 5-12.5cm area for all equipment

Table 7 Correlations between ultrasonic measurements and lean/bone ratio in the carcass (adjusted to constant liveweight)

Equipment			Fat depth, 7.5cm		Fat area		Eye muscle area	
			10th rib	1st lumbar vertebra	10th rib[1]	1st lumbar[2] vertebra	10th rib[3]	1st lumbar[4] vertebra
Scanogram	UK	UK	0.11	0.09	0.08	0.12	0.54	0.35
	DK	DK	0.10	-0.37	-0.04	-0.34	0.25	0.48
Danscanner	UK	UK	0.11	-0.08	0.06	-0.03	0.61	0.74
	DK	DK	-0.14	-0.32	-0.14	-0.31	0.19	0.38
Philips	UK	UK	-0.06	-0.06	-0.13	0.01	0.39	0.53
	DK	DK	-0.44	-0.24	-0.25	-0.24	0.23	0.11
Ohio	UK	UK	0.02	0.01	0.07	-0.11	0.14	0.65
	DK	DK	0.03	-0.44	0.08	-0.44	0.07	0.56
B & K	UK	UK	0.19	0.14	--	--	--	--
	DK	DK	0.36	-0.16	--	--	--	--

1) and 2) 0-15cm area for Scanogram and Danscanner and 5-12.5cm area for Philips and Ohio

3) total area for Scanogram and Danscanner and 5-12.5cm area for Philips and Ohio

4) 5-12.5cm area for all equipment

PRACTICAL USE AND EXPERIMENTAL RESULTS OF IN VIVO TECHNIQUES

a. BEEF PRODUCTION RESEARCH OUTLINE IN BELGIUM

R. Verbeke
Faculteit Landbouwwetenschappen, Melle, Belgium.

A disciplinary research in beef production started in our country in the year 1960. The research Centre for Meat Production studied first of all the experimental design for researching the progeny testing scheme fulfilling the most special requirements: number of replicates, age and weight, experimental period including feeding and environmental conditions, going through to the kind of measurements and sampling.

This study of the transmitting ability for meat production and meat quality of A.I. bulls covered four breeds: Red West Flanders, Red and White East Flanders, Red and White Campine, and the breed of the Mid and High Belgium.

The testing embraced a continued outline starting up with male calves of 10 days old and finishing, when the young bulls had a weight of 450 kg.

In order to give readily comparable results growth and feed intake were noted periodically: weights were recorded at intervals of 4 weeks, and the physical development was measured quarterly. Most important traits for development were:

- height at whiters
- height at pelvis
- width of thigh (at trochanter level)
- width of chest
- depth of chest
- chest girth

A subjective scoring of the conformation was done at the end of fattening for the shoulder, the back, the loin and the leg using a 15 class-scoring system. Evenso the degree of fatness was recorded. After fattening up to 450 kg the animals were slaughtered and quantitative carcass traits are described. The most relevant traits are:

- Hot and cold dressed weight
- Length of carcass
- Blockiness of carcass
- Length of leg
- Blockiness of leg
- Width of leg

The EAAP scoring system was furthermore applied to all experimental carcasses. Efforts have been done to relate som in vivo characteristics to slaughter data.

To some extent the conclusion is that single characteristics of the live animals are only poorly correlated with carcass composition. Subjective scoring in vivo is in a general way good related to the conformation of the carcass, although the scoring of the degree of fatness gives not always faultless estimation of dressing percentage and degree of fatness of the carcass.

Since 1973 are in Belgium two testing stations with a capacity of each 400 animals. At the outset only performance test was examined, but this was soonly completed by progeny testing.

Briefly the performance test is executed with 1 month old bull calves after BULL'S DAMS (selected cows) and BULL'S SIRES (best proven bulls).

After 10 months' judging peformances (growth rate, feed conversion, type) only 25% of the bulls are selected at the test bulls for A.I. The test bulls sent up to the insemination centres serve in some extent in the population and are called waiting bulls, untill results of their offspring (males and females) are known. If tests are presageful the best proven bulls may become PROVEN BULLS and 20% of them become the BULL's SIRES kept for breeding.

Females served at 12-18 months are judged by ease of calving controls, milking characters and type before results are added to the results of the progeny test for bulls.

In all controls for meat production ability anatomical dissections of the three-rib-cut 7-8-9 or the one-rib-cut of the 8th rib are executed by the Studycentre for Meat Production.

Finally, we may hope in the future that ultrasonic measurements may confirm the credibility of the selection method involved in Belgium.

b. PRACTICAL USE AND EXPERIMENTAL RESULTS OF IN VIVO TECHNIQUES IN DENMARK

Hans Busk and Just Jensen
National Institute of Animal Science
Rolighedsvej 25, 1958 Copenhagen V.
Denmark

Several experiments during the last decades have shown that a visual judgement or traditional body measurements will not give a sufficient description of the carcass composition. On the other hand several experiments have shown that it is possible to make a cross-sectional scanning of the animals with ultrasonic and thereby determine fat area and muscle area in the lumbar region as an indirect measurement of the body composition.

In Denmark we have made a series of experiments with ultrasonic, and in the last years concentrated on the so-called Danscanner. This equipment is a real-time scanner developed to measure on animals. In table 1 is shown the repeatability between the measurements.

Table 1. Repeatability between two ultrasonic measurements on live cattle (50 young bulls from the performance test).

Area of m. longissimus dorsi	0.97
Area of hide + fat	0.84

The results show that the equipment is able to give so good a cross sectional picture that we are able to estimate it in the same way from time to time.

In table 2 is shown the correlation between ultrasonic measurement on live cattle and the corresponding measurement on the carcass.

Table 2. Correlation between ultrasonic measurement on live animals and corresponding measurement on carcass (132 young bulls from experimental stations).

Area of m. longissimus dorsi	0.71
Area of fat*)	0.79

*) On live animals it is both hide + fat, on carcasses only fat.

The results show that we are able to measure meat and fat area with a sufficient accuracy.

In table 3 is shown results from an experiment, where the measured animals are 15 months old crossbreed, young bulls from the testing station "Egtved".

Table 3. Phaenotypic correlations between ultrasonic measurements and carcass quality.

	Per cent				
	pistol lean	lean	fat	bone	lean/ bone
Ultrasonic measurements:					
Muscle area	0.42	0.21	-0.09	-0.44	0.47
Muscle area/fat area	0.78	0.71	-0.64	-0.23	0.59
Carcass measurements:					
Muscle area/fat area	0.75	0.74	-0.77	0.08	0.39

The results show that if both meat area and fat area are measured on the live animal, it is possible to obtain a good correlation between meat/fat ratio and different expressions for carcass quality. The meat area alone describes especially the meat/bone ratio. It can further be seen that there are the same correlations between the meat/fat area ratio and the carcass composition, even if it is measured with ultrasonic on the live animal or measured directly on the cross-section of the carcass.

Practical use of ultrasonic

The Danscanner equipment is used by routine in various situations. It is used for both cattle, pigs and sheep.

All the animals are measured over the first lumbar vertebrae, and a photo of the cross-sectional picture on the screen is taken, so it is possible later to make the different measurements on the photos.

In the performance test we measure the animal at 9th and 10½ months of age. 2 pictures of each measurements are taken.

The working condition is as follows:

1st day: Measuring of animals.

2nd " : Development of the film.

3rd " : Interpretations of fat area and meat area and planimetring on an electronic planimeter.

4th " : The results are adjusted for the effect of measuring day and live weight.

5th " : The results are published.

To be sure of that the results are as good as possible, it is necessary to control both the technicians, who use the equipment and the equipment itself very often. The accuracity of the results depends both on the person, who uses the equipment, and the person, who measures on the photo. Therefore, we very often compare results from live animals with results from carcasses. Beside this control a visual judgement of the scanning pictures and the measurements are made to control that the equipment is used after the instructions given. Very often we have with us a technician from the Medicotechnical Institute, who makes the Danscanner, when we carry out this control.

We think that it is important to make such a control. Without any control the equipment can be used in a wrong way, and consequently give bad results.

Corrections and presentation

The ultrasonic techniques is used by routine in various situations. In cattle breeding it is used on 5 groups of animals. The distribution on the different groups can be seen from table 4.

Table 4. Experimental animals used for ultrasonic measurements.

Group	Number of animals per year	Number of measurements per year
Dual purpose bulls	530	1060
Beef bulls	90	180
Private herds	100	100
Selection experiment:		
Bulls	75	225
Heifers	75	225
Other experiments	140	140
Total	1010	1930

The performance tests of dual purpose bulls comprises appr. 530 bulls per year. They are measured as close to the age of 273 and 318 days as possible.

The second group is performance tests for beef bulls. This project comprises about 90 bulls per year, and they are also measured twice, but at the age of 335 and 361 days

Beside the performance tests we offer private-breeders a measurement on their animals, making it possible to do some selection within the herds. There are only measured about 100 private bulls per year.

Beside the routine activities described above ultrasonic is used in different experiments. A selection experiment has been going on since 1974, comprising about 150 cows (Hansen and Liboriussen, 1981). In this experiment both bulls and heifers are measured, giving a total of 150 animals per year. These animals are measured 3 times at an age of 255, 285 and 315 days, respectively.

The last group is bulls in different breeding and feeding experiments, about 140 animals per year. These animals are measured a week before, they are slaughtered. After slaughter, the muscle area is measured on the carcass and then dissected into lean, fat and bone. These results are then used for control of the equipment.

The performance tests and the other experiments are carried out on 6 test stations. The animals are grouped so that measuring is going on 1 or 2 days/months/station.

Before the ultrasonic measurements can be used, some corrections must be made for weight and day of measurement. The methods are discussed in detail by Jensen and Andersen, 1981. The corrections are based on a linear least square model, taking the following factors into consideration:

$$\begin{aligned} Y = {} & \text{Breed} + \text{Sire (Breed)} \\ & + \text{Station} + \text{M-day (Station)} \\ & + \text{Age-Group} + \text{Weight} \\ & + \text{Residual} + \text{Weight(Age Group)} \end{aligned} \qquad (1)$$

The resulting analysis of variance is shown in table 5. As can be seen, there is a strongly significant effect of "day of measurement".

Table 5. Analysis of variance of muscle area.

Effect	DF	Mean square corrected for other effects	F -value	P > F
Breed	2	132.06	1.67	0.1903
Sire(Breed)	249	79.06	3.97	0.0061
Station	2	48.71	0.38	0.6814
Day (Station)	271	126.79	6.37	0.0001
Age Group	1	49.13	2.47	0.1164
Weight	1	8007.70	402.01	0.0001
Weight(Age Group)	1	53.26	2.67	0.1021
Residual	3244	19.92		

Even though extensive technical investigations have been done, no single factors have been found as a cause of the variation, but it must be due to variations from day to day in adjustment of the equipment, the ability of same or in the evaluation of the photographies, when measuring the areas.

Correction for the effect of day of measurement is carried out by subtracting the least square constants for the day-effects calculated in model (1), from the relevant measurements.

The relation between muscle area and live weight is different in different age groups. A curve-linear function across age-group can describe this difference. The following function has been derived: (V is weight when measuring):

$$\text{Muscle area} = \text{constant} + 0.1844V - 1.529 \cdot 10^{-4} \cdot V^2.$$

This function is used, when correcting to constant weight, which is 400 kg for performance tests of dual purpose bulls.

The average of the corrected measurements is used in a selection index for muscle area. The breeding values are published as U-index with mean 100.

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c. IN VIVO ESTIMATION OF BODY COMPOSITION IN BEEF

Preliminary results from experiments conducted by the National Institute for Cattle Breeding in order to compare different techniques for predicting in vivo beef carcass characteristics

By E. Rehben
National Institute for Cattle Breeding
Beef-performance recording service
149, rue de Bercy
75595 Paris Cêdex 12
France

- A SHORT REVIEW of DIFFERENT TECHNIQUES USED ROUTINELY in FRANCE to ESTIMATE BEEF CARCASS CHARACTERISTICS

Different techniques for different purposes are used routinely to estimate in vivo beef carcass characteristics. The most common ones are mensurations and visual appreciations did by an expert.

For commercial transactions, only visual appreciations by experts are in current use. Most of them are based on a 18 levels schedule, whose each level is described by photographies. In that system an animal is characterised by one letter (E, U, R, O, P and A) and one sign (+, = or -), from E+ for the best beef conformation, to A- for the worst.

The beef performance records in current use for genetic improvement programs are visual appreciations by experts or/and mensurations. According to the breed or the animal type (calf, yearling, cow ...) different techniques are used.

The progeny-testing of dairy bulls involves an evaluation of the beef characteristics of their progeny. These measurements, did on farm, on young cows, consist of mensurations and visual appreciations. Different techniques or schedules are used according to the breeds. In 1980 data concerning about 40.000 cows were recorded for these programmes.

Concerning beef-cattle, techniques are also different. An appreciation of beef conformation at weaning is recorded for a large part of the 120.000 calves of the national on-farm beef performance recording system in order to calculate cow-index.

The appreciation of beef conformation has been done with other measurements, which concern skeletal development and some breeding qualities. The experts appreciate different anatomical sites, which receive a score from 1 for the worst to 10 for the best. These scores are recorded on a special form (table 1 - appendix). Some of the 10 scores are added in order to get three aggregate scores. The first one concerns beef conformation ("développement musculaire" - table 1 - appendix), the second one skeletal development ("développement squelettique" - table 1 -), and the third one some breeding qualities ("qualité de race" - table 1 -). Only the aggregate scores regarding beef conformation and skeletal development are used to calculate cow index. In 1980, 65.000 beef breed calves at weaning were measured according to this technique.

THE GENERAL CONTEXT of the EXPERIMENTS CONDUCTED by the NATIONAL INSTITUTE for CATTLE BREEDING

These works concern only the measurements of current use on farm or in station for genetic improvement programmes. In that context, for the institute the main problems regarding the techniques to estimate in vivo beef characteristics are the following:

- to have a standardized technique to evaluate in vivo in station by visual appreciations some carcass characteristics of young dairy bulls before progeny testing,
- to have techniques to evaluate in vivo on-farm, by visual appreciations, some beef characteristics of the young dairy cows recorded for progeny testing,
- to compare the efficiency of different techniques commercially available for predicting in vivo beef characteristics, either for on-farm beef performance records or in station.

Concerning the two first problems, the Institute is conducting a large experiment, which involves in vivo appreciations and carcass measurements of 600 animals of different dairy breeds (Hol-

stein Frisean and Normand) and of different types (calves, young bulls and cows). The measurements and the slaughtering of all these animals are not yet finished. The complete results will be available only in December 1982.

Concerning the third problem, in May/June 1981, the Institute conducted experiments in co-operation with the Danish National Institute of Animal Science. All the results from these experiments are not yet available, but complete works about these data will be published in April 1982. Consequently, the results presented in the following parts are only first and incomplete conclusions from these experiments.

ANIMALS, IN VIVO MEASUREMENTS and CARCASS EVALUATIONS

Choice of techniques to measure the animals "in vivo"

Different techniques were kept according to the following criterions:

- to be used routinely or commercially, available for on-farm and/or in station beef-performance records,
- to be used on a large scale in France.

This mainly in order to eliminate techniques only suitable for laboratory works.

The following technqiques were kept:

- visual appreciations according to the technique used for beef breeds,
- visual appreciations according to a new experimental technique for dairy breeds,
- mensurations,
- measurements by two different B mode ultrasonic machines ("Sonic" and "R90"). The table 2 presents the main characteristics of these equipments,
- measurements by a complete ultrasonic machine ("Danscanner").

Measured animals

The animals measured, chosen among four different breeds, represent different types, from a dairy type (Holstein Frisean) to a beef type (Charolais and Limousin) with a dual purpose breed (Normand). Young bulls were measured because their characteristics are very close to that of animals controled in station or on farm. The table 3 presents the main characteristics of these animals.

Measurement sites and carcass evaluation

For each animal were measured in vivo:
- 21 scores by visual appreciation,
- 7 mensurations,
- 4 Longissimus Dorsi depth at six and twelve centimeters from the third lumbar verterbrae by two different machines,
- different measurements of depth and area by Danscanner at the third lumbar vertebrae.

The carcass measurements were the following:
- Longissimus Dorsi area at the third lumbar vertebrae,
- Longissimus Dorsi depth at six and twelve centimeters from the third lumbar vertebrae,
- Dressing percentage,
- Bone in percentage of carcass weight,
- Saleable lean meat ratio,
- Fat in percentage of carcass weight,
- Quick cooking cuts in percentage of total saleable lean meat,
- Calculated retail value index of the fore quater.

The carcass measurements were done by the meat laboratory of the Institute according to a French commercial jointing of a half fore quater (all muscles are deboned, trimmed and cut ready for sale). The animals were slaughtered at the latest two weeks after the in vivo measurements. During this period, they were fed in order to keep a constant weight.

Main purposes and organization of "in vivo measurements"

The purpose of this experiment is double:
- to analyse different operator effect,
- to estimate relationships between different "in vivo" measurements and carcass characteristics.

Eight operators measured the animals. Except for Danscanner, all the operator measured twice the same animal:
- two operators appreciated the animals according to the techniques used for beef breeds,
- two operators appreciated the animals according to the experimental techniques for dairy breeds,
- two operators used the two ultrasonic machines,
- two operators measured the animals with Danscanner.

PRELIMINARY RESULTS

Correlations between repeat in vivo measurements

This relationship was estimated by a simple correlation coefficient. The tables 4, 5 and 6 present the different repeatability got by the different operators for the different measurements. Danscanner measurements are not concerned by these estimations.

According to the repeatability value and its variation, it is possible to classify the measurements in three groups:
- The first one (table 4 .) contains eight visual appreciations and one mensuration, whose repeatability is always above 0.66 for all the operators,
- The second one (table 5, .) contains eight visual appreciations, six mensurations and two ultrasonic measurements. The repeatability of these measurements depends on the operators, but at least one operator get a repeatability above 0.66.
- The third group demonstrates that these experts seem to be unable to appreciate five anatomical traits in current use for on-farm beef performance records.

Correlations between ultrasonic measurements, carcass measurements and beef characteristics

Measurements were done after slaughtering at the different anatomical sites measured by ultrasonic machines. The table 7 presents the correlation coefficients between the ultrasonic measurements, the carcass measurements at the same site, and different beef characteristics.

Our conclusions are the following:

- Except for quick cooking cuts percentage the correlations are significant.
- The correlations between carcass measurements and beef characteristics demonstrate that the best way to predict body composition in vivo is Longissimus Dorsi area.
- The correlations between areas measured by Danscanner, areas measured on carcass and beef characteristics, demonstrate that Danscanner measurements can be used for predicting body composition.
- The differences of accuracy between carcass measurements and Danscanner depend on the beef characteti-stics predicted (small difference for bone percentage, important difference for fat percentage).
- Except for bone ratio, a depth measurement at six centimeters from the third lumbar vertebrae seems to be more efficient for predicting beef characteristics than at twelve.
- The correlation variations between R90 and Sonic seems to indicate that the accuracy of these two machines is similar and does not depend on the frequency or on a scale choice.

Relationships between in vivo measurements and beef characteristics

Before these works, according mainly to their repeatability, some measurements and some operators were eliminated

in order to keep the best conditions for each technique. For Danscanner measurements one sery was also kept.

The in vivo measurements were gathered in six groups according to their current use:

- 12 visual appreciations were according to the method used for beef cattle,
- 16 visual appreciations were according to the experimental method used for dairy cattle,
- 6 mensurations,
- 2 ultrasonic measurements by R90,
- 2 ultrasonic measurements by Sonic,
- 4 ultrasonic measurements by Danscanner.

The relationship between each group of in vivo measurements and each beef characteristic were estimated by a multiple correlation coefficient. The table 8 presents the different reults obtained.

Our conclusions are the following:

- It seems not possible to predict quick cooking cuts percentage with these measurements,
- The two techniques of visual appreciation used by experienced experts seem to have the best efficiency for predicting beef characteristics.
- Danscanner measurements' accuracy seem to be at a good level, but lower than that of visual appreciation.
- Ultrasonic depth measurements and then mensurations seem to have the worst accuracy.

CONCLUSIONS

The work on these data are not yet finished, and these preliminary results are incomplete.

Other analysis will be conducted about these following problems:

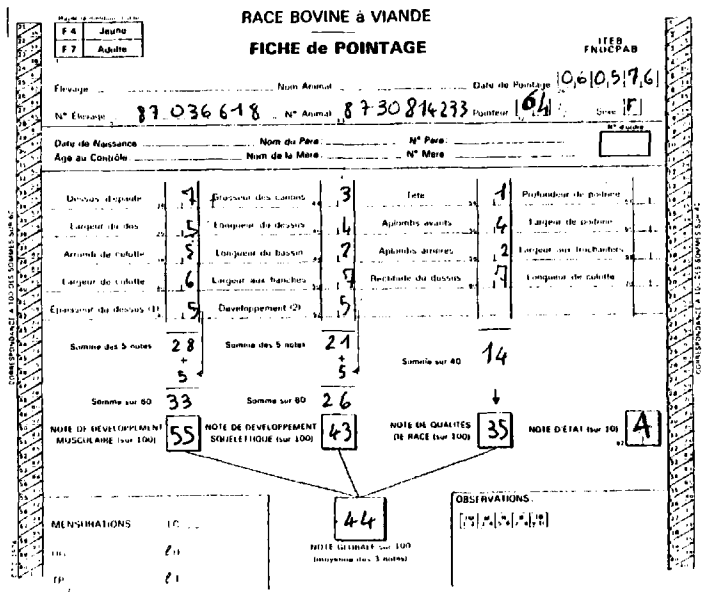
- Works based on analysis of variance will aim to determine different operators effect on in vivo measurements.

- Other detailed works will be conducted to verify, if the classification of the different techniques got on sixty very variable animals remains the same inside a genetic type (dairy type or beef type), and if visual appreciation remains the more efficient technique, which relation to be used for predicting different beef characteristics, and if this relation depends on the breeds.

The complete results of these works will be available in April, 1982.

TABLE 1

Form used to appreciate beef-cattle characteristics for on-farm beef performance records



- TABLE 2 -

Main characteristics of the two ultrasonic machines used for in vivo measurements

Name	R90	SONIC
Firm	Compagnie Générale de Radiologie - FRANCE	Merit, Lowson and French Ltd (U.K.)
Speed reference	1590 m/s	1500 m/s
Frequency	5 MHz	2,5 MHz
Scale	0 to 50 mm or 0 to 100 mm	0 to 25 mm or 0 to 100 mm

- TABLE 3 -

Main characteristics of the measured animals

Breed	Number	Weight
CHAROLAIS x NORMAND	15	545 Kg ± 10
NORMAND	15	575 Kg ± 30
HOLSTEIN x FRISEAN	15	476 Kg ± 28
LIMOUSIN	13	618 Kg ± 25

- TABLE 4 -

In vivo measurements repeatability

Measurement code	Operator			
	1	2	3	4
1 ⁂	0,96	0,97	0,94	0,90
2 ⁂	0,97	0,96	0,94	0,90
3 ⁂	0,95	0,92	0,93	0,90
4 ⁂	0,95	0,92	0,93	0,92
5 ⁂	-	0,91	0,85	-
6 ⁂	-	0,72	0,82	-
7 ⁂	0,96	-	-	0,89
8 ⁂	0,92	0,86	0,91	0,92
9 o	0,98	-	-	0,94

⁂ visual appreciation

o mensuration

\+ ultrasonic measurements

- TABLE 5 -

In vivo measurements repeatability

Measurement code	Operator					
	1	2	3	4	5	6
10 ⁂	-	0,64	0,70	-	-	-
11 ⁂	-	0,68	0,61	-	-	-
12 ⁂	-	0,81	0,65	-	-	-
13 ⁂	0,49	0,74	0,49	0,29	-	-
14 ⁂	-	0,66	0,47	-	-	-
15 ⁂	0,72	0,88	0,61	0,47	-	-
16 ⁂	0,65	0,90	0,60	0,37	-	-
17 ⁂	0,74	0,90	0,63	0,82	-	-
18 o	0,92	-	-	0,75	-	-
19 o	0,90	-	-	0,66	-	-
20 o	0,95	-	-	0,83	-	-
21 o	0,79	-	-	0,53	-	-
22 o	0,85	-	-	0,41	-	-
23 o	0,87	-	-	0,61	-	-
24 +	-	-	-	-	0,92	0,61
25 +	-	-	-	-	0,72	0,58

⁂ visual appreciation

o mensuration

\+ ultrasonic measurement

- TABLE 6 -

In vivo measurements repeatability

Measurement code	Operator			
	1	2	3	4
26 ⁂	-	0,55	0,30	-
27 ⁂	-	0,53	0,48	-
28 ⁂	-	0,42	0,42	-
29 ⁂	0,59	-	-	0,56
30 ⁂	0,32	-	-	0,38

⁂ visual appreciation

o mensuration

\+ ultrasonic measurement

- TABLE 7 -

Correlations between carcass measurements, ultrasonic measurements and beef characteristics

	2nd lumbar vertebra muscle area		3rd lumbar vertebra			
			muscle depth at 6cm		Muscle depth at 12cm	
	(1)	(2)	(1)	(2)	(1)	(2)
Dressing percentage	0,88	0,73	0,83	0,77 0,70	0,77	0,69 0,66
Bone in % of carcass weight	- 0,78	- 0,72	- 0,78	- 0,79 - 0,72	- 0,82	- 0,70 - 0,73
Saleable lean meat ratio	0,83	0,71	0,72	0,60 0,69	0,73	0,55 0,65
Fat in % of carcass weight	- 0,45	- 0,51	- 0,24	- 0,21 - 0,27	- 0,21	- 0,04 - 0,21 - 0,18
Quick cooking cuts in % of total saleable lean meat	- 0,05	- 0,05	0,09	- 0,03 - 0,07	- 0,16	- 0,19 - 0,16 - 0,17
Calculated retail value index of the fore quater	+ 0,82	0,69	0,70	0,56 0,67	0,70	0,51 0,70 0,61

(1) carcass measurements

(2) ultrasonic measurements

. above : R90

. under : Sonic

- TABLE 8 -

Prediction of beef characteristics for different in vivo measurements

	Visual appreciations according to dairy-cattle technique	Visual appreciations according to beef cattle technique	Mensurations	Ultrasonic measurements of depth (Sonic)	Ultrasonic measurements of depth (R90)	Measurements by Danscanner
Dressing percentage	0,70 2 % *	0,82 1,6 % *	0,56 2,5 % *	0,52 2,4 % *	0,59 2,2 % *	0,67 2 % *
Bone in % of carcass weight	0,85 1 % *	0,90 0,9 % *	0,73 1,4 % *	0,67 1,5 % *	0,69 1,4 % *	0,72 1,4 % *
Saleable lean meat ratio	0,73 2 % *	0,80 1,8 % *	0,28 3,1 % *	0,50 2,7 % *	0,37 3 % *	0,61 2,4 % *
Fat in % of carcass weight	0,47 2,4 % *	0,66 2,1 % *	NS	0,18 2,9 % *	NS	0,40 2,5 % *
Quick cooking cuts in % of total saleable lean meat	NS	NS	NS	NS	NS	NS
Calculated retail value index of the fore quater	0,70 0,4 F *	0,78 0,4 F *	0,25 0,7 F *	0,46 0,6 F *	0,32 0,7 F *	0,59 0,5 F *

___ value of the square of the multiple correlation coefficient

* residual standard deviation of the regression

d. REVIEW OF PRACTICAL USE AND EXPERIMENTAL RESULTS OF IN VIVO TECHNIQUES FOR THE ESTIMATION OF BODY COMPOSITION IN BEEF CATTLE IN THE FEDERAL REPUBLIC OF GERMANY

E. Kallweit
Institut für Tierzucht und Tierverhalten (FAL), Mariensee
3057 Neustadt 1
Federal Republic of Germany

Pure beef breeds are of little importance in the Federal Republic of Germany. Beef is mostly obtained from dual purpose cattle. For economic reasons the interest in high milk yields prevails over that for good beef carcasses. Since almost 50% of the beef produced is from young bulls, also little attention is paid to meat quality, since their carcasses are very lean.

The main objectives of progeny performance tests are daily weight gains, feed efficiency and carcass grades, focussing on conformation.

Live fattening bulls are in general evaluated by visual appraisal. This, however, provides little information for carcass values, when groups are quite uniform as in progeny testing, Other, more objective methods are still not routinely practized in Germany.

Research has been conducted on the feasibility of isotope dilution analysis, ultrasonic measurements and photogrammetry.

Isotope dilution analysis were performed on pigs and cattle in our institute by PFAU (1972). For the determination of body water, protein and fat, tritiated water (HTO), ^{42}K and ^{24}Na were used. SALEM (1970) calculated multiple correlation coefficients of $r = 0.8 - 0.9$ between ^{42}K and ^{24}Na for muscle, bone, water content, protein, fat-free body mass and fat-free dry matter. For the amount of total fat, a coefficient of $r = 0.4$ was obtained.

The method is for a variety of reasons not applicable to large numbers of animals, but must be restricted to research.

Ultrasonic measurements on cattle have been practized in Germany since some twenty years ago. J.R. Stouffer from Cornell University promoted these studies during his stay in Göttingen in the early sixties. Recently, a thesis was published by W. Appel (1980) of Kiel University, who used the "Danscanner"-device. He found rather poor correlations between ultrasonically determined cross sections and the corresponding carcass measurements: r = 0.40 - 0.63 for the first and r = 0.25 - 0.51 for the 5th lumbar vertebra.

More promissing results were recorded by directly correlating ultrasonic data with the weights of wholesale cuts. For hind quarter cuts, correlations range up to r = 0.65; they were with r = 0.55 lower for cuts from the front quarter. Vice versa, area measurements on the carcasses had opposite results.

The positive correlations between areas and cut weights may to some extent be due to differences in body weights. For ultrasonic measurements and carcass weights, positive correlations of r = 0.38 and r = 0.55 were calculated, however, before correcting for body weights.

The author considers the apparatus as useful for performance testing, although it is prone to environmental disturbances. Further research on ultrasonic measurements is in progress at Kulmbach and Grub (Munich), but results have not yet been published.

Photogrammetry was originally employed for obtaining linear measurements. Later, W. Leydolph of Göttingen pioneered in the development of techniques for assessing the animal volume or certain fractions of it. The present state of perfection is summarized in the thesis of Saage (1980). In this study, he used two pairs of synchronized, flash light equipped cameras. One pair was placed behind the animal at a distance of 500 cm and a hight of 210 cm. The second pair was located alongside the animal, 535 cm away and 250 cm high. The background wall was completely covered with equidistant dots. The photographs taken were measured, and the data analyzed by a special computation program, designed for correlating volume fractions with wholesale cuts of the carcass. The photogrammetrically determined wolumes of the rounds correlated with r = 0.79 to the round weights; similarly r = 0.66 was calculated for the loins. The lower loin can

be contributed to the high variability in loin muscle thickness, in addition, inaccurate cutting might also be a source of error.

The former could be taken care of by ultrasonic measurement. Although the reproducibility of photogrammetry still lacks perfection because, for one, the positioning of the animal awaits further optimization, the author renders the combination of photogrammetry with ultrasonic measurements as the most promissing approach. Lately, Kellner substituted inexpensive standard cameras for the high performance equipment used before. It should also be possible to scale down on the rather time-consuming evaluation, which at present lasts about 3.5 hours. Research activities aiming at a reliable and inexpensive adaptation for field purposes are in progress.

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e. THE DETERMINATION OF CARCASS-VALUE OF LIVE CATTLE WITH THE DANISH ULTRASONIC EQUIPMENT "DANSCANNER"

E. Ernst, W. Appel and J. Claus
Institut für Tierzucht und Tierhaltung
der Universität Kiel
Olshausenstrasse 40 - 60
2300 Kiel
W.-Germany

Introduction

In a trial with 799 bulls of dual purpose breeds ultrasonic measurements were done appr. 24 hours before slaughtering at the first and fifth lumbar vertebra. The structure is shown in table 1.

Table 1. Structure of data.

Breed	Black and White	Red and White	Angler
Bulls with pedigree	239	193	-
Bulls without pedigree	124	15	-
Auction-bulls	50	98	80
Total	799		

Method of investigation and model of calculation

To scan the animals, they were tied in a cattle crate or a weighing scale.

To get a good contact between "Danscanner" and animal, the measure-point (first and fifth lumbar vertebra) were oiled and after that supplied with a contact-gel.

At the above mentioned points the meat areas were taken.

Scanning of one animal took round about five minutes.

Only one person was scanning the total of animals.

After slaughter,measurements corresponding to those taken on the live animals were taken on the carcass. That involved cutting one side of each carcass at the two points scanned.

One side of 37 black and white carcasses were dissected, corresponding to the DLG-cut.

The analysis of systematic factors, influencing the results, was done using LSQ-program of Harvey (1976; Least-Squares and Maximum Likelihood General Purpose Program).

Results

Repeatability of measuring

The repeatability of ultrasonic measuring by "Danscanner" was excellent,as table 2 shows:

Table 2. Repeatability of ultrasonic measures

	Lumbar vertebra	
	1.	5.
US-measures n = 737	0.959	0.959

Correlation coefficients for values of muscle area - Danscanner - carcass

The correlation between meat areas, determined by ultrasonic equipment resp. at the carcass had a level of 0.46 up to 0.63 for the first and 0.25 up to 0.50 for the fifth lumbar vertebra, as table 3 shows.

The highest correlations (Echem 1979) correspond with the best conditions, when scanning.

Table 3. Correlation coefficients (r_p) for values of muscle area, measured by ultrasonics (mean of 3 measures), and muscle area, determined by carcass cut.

Material	n	Carcass cut			
		1. lumbar v.		5. lumbar v.	
		total[+)]	m.l.d.	total[+)]	m.l.d.
Progeny testing					
Echem 1979	126	0.63^{xxx}	0.61^{xxx}	0.50^{xxx}	0.49^{xxx}
Futterkamp 1979	115	0.47^{xxx}	0.46^{xxx}	0.40^{xxx}	0.41^{xxx}
Futterkamp 1978	98	0.49^{xxx}	0.48^{xxx}	0.35^{xxx}	0.34^{xxx}
Lindhof	73	0.55^{xx}	0.53^{xxx}	0.31^{xxx}	0.25^{x}
Fattening bulls					
Lindhof 1979	83	0.57^{xxx}	0.58^{xxx}	0.43^{xxx}	0.32^{xx}

+) M. long. d. + M. multifidus d.

x) = $p < 0.05$; xx = $p < 0.01$; xxx = $p < 0.001$.

Correlation coefficients between ultrasonic measurements and weight of carcass-parts

The correlation (r_p) between ultrasonic measurement and weight of carcass-cuts were in the range from 0.3 to 0.6, as table 4 shows:

Table 4. Correlations between ultrasonic measures and weights of carcass-parts.

Carcass-parts (weight)	ultrasonic values		
	$\bar{x}$ of 3 measures		Ø of $\bar{x}$
	1. LV	5. LV	1. and 5. LV
Weight left half	0.38^{x}	0.55^{xx}	0.53^{xxx}
Forequarter, Sa.	0.30	0.47^{xx}	0.44^{xx}
Rump and best ribs with bone	0.43^{xx}	0.59^{xxx}	0.58^{xxx}
Round with bone	0.35^{x}	0.49^{xx}	0.48^{xx}
Pistol with bone	0.37^{x}	0.53^{xxx}	0.51^{xx}
Rump and best ribs without bone	0.46^{xx}	0.63^{xxx}	0.62^{xxx}
Round without bone	0.37^{x}	0.54^{xxx}	0.52^{xxx}
Pistol without bone	0.40^{x}	0.57^{xxx}	0.55^{xxx}
Hindquarter, Sa.	0.41^{x}	0.59^{xxx}	9.58^{xxx}

x = $p < 0.05$; xx = $p < 0.01$; xxx = $p < 0.001$

The correlations between "rump and best ribs without bone" and ultrasonic measures are relatively high. Nearly the same height is given for "round without bone", "pistol without bone" and the parts of the round.

It should be said that a material correction on live-weight effected unrealistic values. Therefore, the material is not corrected on live-weight.

Estimation of heritability coefficients

The estimation of heritability coefficients is based only on a small number of animals. Therefore, the following coefficients (table 5) only show a tendency.

Table 5. Coefficients of heritability of ultrasonic measures

Ultrasonic measures	Echem[1] h^2	Futterkamp[2] h^2
$\bar{x}$ 1. Lumbar v.	.86 ± 0.40	.39 ± 0.25
1. Measure 1. Lumbar v.	.78 ± 0.39	.37 ± 0.25
$\bar{x}$ 5. Lumbar v.	.53 ± ÷.33	.52 ± 0.28
1. Measure 5. Lumbar v.	.54 ± 0.34	.32 ± 0.24

Final consideration

An "in vivo"-estimation of body composition in beef by the equipment described seems to be possible under the special condtions of performance-test-stations. When using the equipment on occasion of auctions the developmens of the pictures, the drawing of them, and the determination of the areas take too much time. Some technical ameliorations (Polaroid-camera, electronical determination of areas or straight lines) could help to use this ultrasonic equipment too on occasion of auctions, when field-material is sold.

f. A BRIEF REVIEW OF THE SITUATION IN GREECE

John Matsoukas
University of Thessaloniki
School of Agriculture and Forestry
Department of Animal Husbandry
Thessaloniki
Greece

First of all I would like to say that I am very glad to be here with you and participate in this workshop of "in vivo estimation of body composition in beef". So, I will have the chance to be informed about the recent progress on this very interesting subject and besides to take advantage of the relative discussions, which are going to be carried out among well known specialists on this field.

So far, unfortunately, in my country there has been no research project on the subject of "in vivo estimation of body composition in beef", neither a method has been applied in this field for practical purposes. So, I am sorry to say that there are no relative data to be presented on you.

As I feel the main reasons for this situation in my country are as follow:

In Greece despite of what happens in other European countries carcass quality does not contribute much to the price of carcasses. It should be mentioned that there has been no official grading system for beef carcasses as for other kind of carcasses, too. Sometimes and occasionally the beef carcasses are differentiated a little as to their prices. This is done usually by the cattle dealers, who offer the farme the same price for a group of carcasses produced by the same category of animals after an improper and subjective evaluation, which has been done on the living animals considered as a group. After what has been mentioned, obviously the beef producer's interest for applying methods for an improvement of carcass quality has been very limited. However, it should be mentioned that recently there is more and more preference of the consumers for lean meat.

There has not yet been any kind of Institution or Station with proper facilities and specialists in this field for relative research project to be conducted. Also, traditional effects and the unfavourable structure of our Animal Production for many years have as a result the delay of any progress on this subject as in other ones, too.

Future possibilities

Since 1979 a breeding program with dairy cattle has started in our country under the guidance of the Ministry of Agriculture and the co-operation of the Animal Husbandry Department of the School of Agriculture of the University of Thessaloniki. The main objectives for this period have been the control of milk production and the increase of genetic variation in this trait towards the better by using frozen semen of progeny tested Holstein bulls of high breeding value originated from U.S.A. and West Germany. The population, about 6000 controlled cows, in this program, which is carried out more systematically in Northern Greece, consists mainly of the Friesian breed (85%), and the data are recorded and processed by a computer.

At this, and before we go into a progeny testing af bulls, I think that a performance testing of young bulls to be organized and applied is necessary. There is no doubt that the performance testing in a station can improve efficiently basic qualities of the cattle population of our program such as daily gain, feed efficiency, capacity of consumption, appetite, soundness, reproductive efficiency and body composition in connection with carcass yield and quality.

Of course, for the moment the evaluation of carcass quality, as mentioned before, is not of the same importance in comparison with other European countries. But, progressively, there is more and more interest of the consumers for lean meat. Besides this trend there is a lot of discussions about the necessity of standardization of carcasses according to their qualities and a more suitable cutting of them for application of a modern and efficient marketing system on meat products in my country. On the other hand, for the

moment, there is a price differentiation between carcasses of the same weight according to their internal quantity of fat, because this is removed, and it is not paid by the cattle dealer. So, the more internal fat, there is in the cattle, the less money the producer receives.

With these perspectives, I feel that the method of "in vivo estimation of body composition of young bulls" is getting interest for my country. Therefore, we have to get ready with your help to look at the possibilities of starting to organize such a program in the frame of our cattle breeding program.

With this application a substantial step could be done towards the improvement of cattle carcass quality, and so we could be prepared to meet future market needs properly.

9. REVIEW OF PRACTICAL USE AND EXPERIMENTAL RESULTS OF IN VIVO TECHNIQUES FOR THE ESTIMATION OF BODY COMPOSITION IN BEEF CATTLE IN IRELAND

E. Ryan
Department of Agriculture
Agriculture House
Dublin 2
Ireland

The cattle and beef industry is of vital importance to the Irish economy. In 1980 it represented about 36% in monetary terms of total agricultural output, 50% in monetary terms of total agricultural exports and 19% of the total value of all exports. Over 80% of the output from the Irish beef industry is exported and up until the mid 1970^{s} the United Kingdom was the main market outlet. The Hereford is the main beef breed and together with the Angus breed they traditionally provided terminal crossing sires to produce beef from dairy herds. Since 1974 many of the main beef breeds on the Continent have been imported to play the same role. In 1980 beef breeds accounted for 51% of all inseminations carried out by the AI services.

Improvement in production and quality in the pedigree beef breeds is brought about through their participation in the National Programme for the Genetic Improvement of Beef Cattle. This programme has three main components:

(1) On-Farm Weight Recording
(2) Central Performance Testing
(3) Progeny testing of bulls in AI for beef merit.

Ireland's entry to the EEC in 1973 opened up European markets, which demanded leaner carcasses than were traditionally produced. This had led to an increase in emphasis on the production of leaner faster growing animals. Central performance testing in Ireland commenced in 1973, and young bulls are evaluated for growth rate, feed efficiency, body measurements and conformation. The deposition of excess fat continues to be a problem associated with the Hereford

and Angus breeds, and the scale of eye muscle area is of importance in all beef breeds. Future plans incorporate the assessment of depth of back fat and eye muscle area using Ultrasonic Techniques. Selection of bulls for the AI services from the Central Testing Station will take cognisance of the data available on these two characteristics. Ultrasonic measurements will commence, hopefully, on the 1982/83 group of performance test bulls.

h. IN VIVO ESTIMATION OF BODY COMPOSITION IN BEEF IN THE NETHERLANDS

Jan Jansen
Department of Animal Breeding
Landbouwhogeschool
P.O. Box 338, Wageningen
6700 AH Netherlands

Introduction

In breeding programs effort is made to improve the efficiency of lean meat-production. Especially bull performance testing offers good possibilities for testing and selection. Quantitative carcass characters like muscle-to-fat and muscle-to-bone are important traits in lean meat production. Predictive parameters measured on live animals should be used to estimate these traits. (See also Bech Andersen et al., 1981).

In the Netherlands morphological characteristics are used for prediction of body composition of live animals. Both fleshiness and fat covering are scored. The classification is related to photographic and descriptive standards and based on linear scale (1 = minimum, 18 = maximum). This is similar to EAAP-recommendations for assessment for carcass characteristics (De Boer et al., 1974).

Any subjective scoring sytem should fulfil the following conditions to be useful:

a. it should be repeatable. This means that repeated scorings under the same conditions correspond with one another (i.e. same classifier). Differences are due to measurement errors and time influences.

b. it should be reproducible. This means that repeated scorings under different conditions correspond with each other. This includes classifier influences.

Secondly in vivo estimates should be good predictors of carcass properties. Finally to be useful in breeding programs it is also required that the traits considered have an economic value,

show variation and are heritable. In this paper some properties of the Dutch scoring system will be discussed.

The value of subjective scoring

In a recent experiment 7 qualified classifiers scored 32 MRY bulls at fifteen months of age twice at 1-6 hours interval for fleshiness and fat covering. The bulls were in two feeding groups. The analysis of this experiment is described by Abrahamse and Oldebroek (1981). The results will be summarized here. The data were analysed with the following model:

$$\underline{y} = \mu + \underline{f}_i + \underline{s}_{j:i} + \underline{c}_k + t_{\_l} + (\underline{fc})_{ik} + (\underline{sc})_{jik} + \underline{e}$$

where: $\underline{y}$ = observation on j-th bull in feeding group i by classifier k at time l

μ = mean

$\underline{f}_i$ = effect of feeding group i (i = 1.2)

$\underline{s}_j$ = effect of j-th bull in group i (j = 1.16)

$\underline{c}_k$ = effect of k-th classifier (k = 1.7)

$\underline{t}_i$ = time of scoring (l = 1.2)

$\underline{fc}_{ik}$ = interaction of i-th feeding group with k-th classifier

$\underline{sc}_{jik}$ = interaction of j-th bull with k-th classifier

e = error.

All effects, except μ are considered to be random with variances: σ^2_f, $\sigma^2_{s/f}$, σ^2_c, σ^2_t, σ^2_{fc}, $\sigma^2_{sc/f}$, respectively

The analysis of variance is given in table 1. In general all main effect and interactions are significant. Especially, the classifier * bull interaction for fat covering causes problems. Fleshiness showed also significant differences in levels between repeated scorings. Estimates of variance components are given in table 2. It is clear from these results that differences in fat covering at this age are small and/or hard to detect.

Repeatability is calculated as r: $\frac{\sigma^2_{s/f}}{\sigma^2_{s/f} + \sigma^2_d + \sigma^2_e}$

and reproducibility as r': $\frac{\sigma^2_{s/f}}{\sigma^2_{s/f} + \sigma^2_c + \sigma^2_t + \sigma^2_{fe} + \sigma^2_{sc/f} + \sigma^2_e}$

Results are in table 3.

Repeatability of fleshiness is at an acceptable level. Figures for reproducibility are low. It is concluded that subjective scoring for fleshiness and fat covering is not yet consistent. For evaluation in performance test, bulls should be compared within classifier * station * season classes.

The relation between in vivo estimation and carcass characteristics

One week after the experiment described above animals were slaughtered, and subjective scoring of carcasses was done by two of the classifiers. The average score for carcasses is higher than on live animals (table 4). The correlations between scores averaged per classifier is .68 for fleshiness and .72 for fat covering.

Dommerholt and Bergström (1979) analysed data of 95 bulls of three breeds (HF, FH and MRY), which were slaughtered at three end weights: 420, 460 and 500 kg. Pooled correlations of fleshiness and fat covering with % lean were .28 and -.39. The two traits together explained 28.5% of the variation. % lean itself is a good predictor of lean meat quantity (r = .95). Further results are not yet known.

Discussion

The results presented here do not give a complete picture of the possibilities of the scoring system for estimation of the carcass characteristics in living animals and the application in breeding programs. Further research is currently underway to investigate

the relation between in vivo estimation and carcass characters in more detail. This involves both bulls and veal calves.

Also the relation between results of performance test of young bulls for AI and performance of progeny is investigated. Large numbers are required to get reliable estimates of genetic correlations. Results will not be known before 1986.

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Table 1. Analysis of variance for subjective scoring (*:P < .05)

Source	d.f.	ms (fleshiness)	ms (fat covering)
F	1	256.59*	278.22*
S/F	30	16.589*	3.54*
C	6	8.017*	44.754*
FC	6	5.905*	11.538*
SC/F	180	.657*	.498*
T	1	1.885*	.502*
error	223	.317	.278

Table 2. Estimates of variance components of subjective scoring

Source	fleshiness	fat covering
F	1.048	1.177
S/F	1.138	.217
C	.033	.519
GC	.164	.345
SC/F	.170	.110
T	.007	.001
error	.317	.278

Table 3. Repeatability and reproducibility of subjective scoring

	r	r'
fleshiness	.78	.62
fat covering	.62	.15

Table 4. Means of subjective score as live and slaughtered animals

	alive[1)]	carcass
fleshiness	9.88 ($\pm$1.46)	10.22 ($\pm$1.25)
fat covering	7.34 ($\pm$1.35)	8.06 ($\pm$1.70)

1) mean of two scorings.

I. PRACTICAL APPLICATIONS OF IN VIVO TECHNIQUES FOR THE ESTIMATION OF BODY COMPOSITION IN BEEF IN BRITAIN

A. J. Kempster

Meat and Livestock Commission, P. O. Box 44, Queensway
Bletchley, Milton Keynes, MK2 2EF

Testing and practical application of in vivo techniques has centred mainly on ultrasonic techniques although there has been more interest recently in visual assessment methods for determining conformation.

Comparison of ultrasonic machines for predicting carcase lean content

Four trials carried out by the Meat and Livestock Commission (MLC) to evaluate the Scanogram (manufactured by Ithaco in the USA) and the Sonatest (a simple A-mode machine manufactured by Balteau-Sonatest, Wolverton, UK) were reported by Kempster et al (1981). Cattle in the four trials differed in breed, sex and origin so the data provided an opportunity to determine the consistency of results in different circumstances. A total of 210 cattle were involved.

Fat thickness measurements (Sonatest and Scanogram) and fat and M. longissimus areas (Scanogram only) were taken at the 10th and 13th ribs and at the position of the 3rd lumbar vertebra. Their precision as predictors of carcass tissue percentages was examined when they were used in addition to live weight at evaluation.

There was little consistency between trials in the positions and measurements which gave the most precise prediction. Residual standard deviations to the prediction of carcass lean percentage from fat thickness measurements taken by Sonatest were in the range 2.5 - 2.7 and there was little advantage in using additional measurements in multiple regression. Fat areas taken by Scanogram were more precise predictors (within-breed residual standard deviations were close to 2.0). Precision was improved marginally to about 1.8 by using combinations of fat areas but M. longissimus areas were of little additional value (Table 1).

Trials have also been carried out at the ARC Animal Breeding Research Organisation, Edinburgh in collaboration with MLC and the ARC Meat Research Institute, Langford. The work has concentrated mainly on the Danscanner which has performed with acceptable precision. The full results of these trials have not yet been published. The Danscanner is being used in a major beef selection experiment to select two lines of Hereford cattle, one for lean tissue growth rate and the other for the efficiency of lean tissue gain (ABRO project number 01019, Genetic improvement of meat production in beef cattle).

Use of the Scanogram to select cattle of different breeds and crosses for slaughter at the same level of fatness

Following on from the trials evaluating the Scanogram, fat areas over the M. longissimus (0 to 15 cm from the dorsal mid-line) at the 10th and 13th rib positions have been used to select cattle for slaughter in the MLC beef breed evaluation programme. The sum of the two areas was used for prediction. Cattle were scanned at intervals through the growth period and weekly as they approached the required level of fatness (6 to 10% of subcutaneous fat in carcase). The identification of slaughter point was not based on predetermined prediction equations : instead, prediction relationships based on previous experience were given as guidelines at the beginning of each run and these modified as the trial progressed, each new animal slaughtered contributing to the pool of information. In general, a within-breed regression coefficient of approximately 0.25 percentage units of subcutaneous fat per cm^2 fat area, with intercepts depending on breed was found most appropriate. Intercepts varied from 3.0 to 5.0.

The accuracy of the slaughter procedure was examined using data for 1367 cattle from the first 3 years of the programme by Kempster and Owen (1981). Subcutaneous fat percentage predicted from the ultrasonic measurements was compared with the percentage estimated by visual assessment of carcass fat cover (SFe). The s.d. of the difference between the two was 1.65.

Data for a subset of 313 cattle were used to examine the relationships between the ultrasonically measured fat areas and actual subcutaneous fat percentage obtained by dissection. The residual s.d. for the prediction of subcutaneous fat within breed and production system was 1.18. The level of accuracy achieved was considered to be satisfactory within the context of the beef breed evaluation programme.

The residual standard deviation for predicting SFe from the ultrasonic measurements in the larger sample was 1.27. The difference between this and the standard deviation of the difference referred to above (1.65) is an indication of the difficulties which exist in developing and refining prediction equations to pin-point levels of fatness, and emphasises that one must be cautious about assuming that equations developed in one set of circumstances will apply accurately to other circumstances.

In vivo techniques in bull performance testing

In Great Britain, bull performance tests are operated by the MLC at five stations accommodating in total about 400 bulls each year. Growth rate and feed intake of individual bulls are measured using age-constant testing for a period from about 150 to 400 days of age. At the end of the MLC test, the bulls are visually assessed for conformation and a withers height measurement is taken in addition to ultrasonic fat areas over the M. longissimus. The Scanogram is used for this purpose, fat areas being measured over the M. longissimus from 0 to 15 cm from the dorsal mid line at the 10th and 13th ribs and at the level of the 3rd/4th lumbar vertebrae.

The information is not used in a selection index; breeders are provided with the information for each characteristic independently and have the opportunity to give the weighting to each which they see fit in their breeding programmes.

Details of the testing programme have been given by Lewis (1979).

Beef characteristics in dairy cattle

Beef coming as a by-product from the dairy herd makes a major contribution to overall beef production in Britain. There is a general trend to the upgrading of native British Friesians with Canadian Holsteins which is causing concern among beef producers and in the meat trade because of the poorer beefing characteristics of Holsteins. The Holsteins have considerably poorer conformation and lower lean to bone ratios than the British Friesian they are replacing, so interest in improving these characteristics has intensified.

The Milk Marketing Board (MMB) operates a national improvement scheme for the improvement of milk production characteristics and is also concerned with the progeny testing of beef bulls for use on dairy cattle. MMB in collaboration with MLC has developed a system of visual appraisal of milking heifers which, it is hoped, will enable distinctions to be drawn between Friesian bulls (both Canadian Holstein and British Friesian) in terms of the suitability of their male calves for beef. All the heifers of MMB Friesian bulls used in A.I. are being assessed visually for muscularity on a five point scale. The results will not be used in the selection of sires to return to the stud for extensive use; the intention is rather to provide information on beef shape in addition to that already given on dairy production and dairy conformation, to enable those farmers who wish to do so to take this characteristic into account when selecting appropriate sires.

The visual assessment of muscularity is simple and cheap. Moreover, used in the way indicated, the degree of selection that can be applied for dairy characteristics in the choice of young bulls for progeny testing is not reduced. The technique has yet to be evaluated; meanwhile there is no intention of culling bulls for poor beef merit. This can only be a holding position and the question of selection objectives, testing methods and selection intensity remains. A progeny test of Friesian steers by bulls selected on the basis of their heifer progeny's conformation scores was begun in 1980 to determine the effect of this work on beef carcase characteristics. The trial will be completed in mid 1982.

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TABLE 1. Prediction of carcase lean percentage using the Scanogram in three samples of cattle.

Sample 1 31 steers comprising 4 breed crosses. Overall analysis.

Sample 2 46 commercial steers and heifers. Analysis pooled within sex.

Sample 3 50 Hereford x Friesian steers.

	Sample		
	1	2	3
s.d. of lean (%)	3.19	4.95	3.77
Residual s.d. for prediction from :			
live weight	3.16	4.95	3.04
live weight + best two predicting measurements	1.84[a]	2.63[b]	1.97[c]
Maximum precision with up to four measurements	1.76	2.60	1.90

a 10th rib fat area 0 - 15 cm.
3rd lumbar vert 0 - 15

b 13th rib fat area 0 - 15
10th rib fat area 0 - 15

C 10th rib fat area 0 - 15
3rd lumbar vert 0 - 15

Best M. longissimus area was 3rd lumbar vert. in all samples. But, it contributed little extra precision.

POTENTIAL USE OF IN VIVO TECHNIQUES AND THEIR LIMITATIONS

a. POTENTIAL USE OF IN VIVO TECHNIQUES FOR BREEDING PURPOSES

J.W.B. King
ARC. Animal Breeding Research Organisation
West Mains Road
Edinburgh
Scotland

Introduction

The purpose of this paper is to discuss some of the particular problems, which arise in seeking in vivo techniques suitable for breed improvement work. It is not the intention to dwell on the technicalities of different methods but instead to examine, what is required of such techniques and to discuss the criteria, by which their effectiveness may be judged.

Requirements for Predictive Methods

There are several characteristics of alternative prediction methods, that need to be met, if particular techniques are to receive widespread use. Discussion of them can be grouped under the following headings:

i) Practicability
ii) Portability
iii) Cost
iv) Public acceptability.

The issue of practicability may seem obvious but is the criterion, by which many techniques have foundered in the past. An example of such a method would be involved methods of estimating specific gravity, requiring not only weighing in water and air, but also estimation of lung volume - potentially useful as a predictor but not lending itself to routine use. In general, if the predictive technique proves difficult to use, or the measurement of individual animals is too time consuming, then any restriction of numbers of animals considered for breeding purposes may result in an unacceptable fall in the selection intensity. Issues of practicability also apply to maintenance of the equipment in the field, since any recurrence of break-downs are likely to reduce thrroughputs.

In allied question is the ability to use the technique in different places. If the equipment is so sophisticated or delicate that it must be used in a single location, breeders are faced with the problem of bringing animals to the equipment. If this centralisation occurs automatically and with large numbers of animals, as in performance testing stations for boars, then there is no difficulty. With performance testing of bulls, however, the total numbers to be screened are usually so much less that any restriction of selection intensity would be unacceptable. In terms of breed improvement it may be more useful to screen more animals in the field, acknowledging that the accuracy of so doing may be slightly less. Such field testing does require statistical adjustments to allow for herd differences, but offers the compensation of minimising disease, which could be a risk in a centralised testing system.

The cost of the predictive method should be reasonable, otherwise it is unlikely to receive wide acceptance. What is considered reasonable will depend on the returns expected from using the particular technique. The returns can vary according to circumstances and the ways in which they are appraised. The limited viewpoint would be that it is possible to afford only those systems, which will pay for themselves in the breeder's own herd. This is a very restrictive requirement and not many techniques would qualify on this basis. From the point of view of breed improvement, a more tenable position would be the cost, which breeders can recoup by increased sales of breeding stock. Again, however, these are not likely to be very great, unless breeders are supplying a sophisticated or a large market, perhaps through the use of artificial insemination. Alternatively, we can relate costs to the returns to the nation from the application of the method. On this basis, then even highly expensive methods might be justified, although the ultimate justification will depend upon the improved stock being used on a national scale.

Finally, the methods used must be acceptable to the public at large. Perhaps two examples would serve to illustrate the problem. Firstly we have the use of radioactive isotopes, which can be administrated for various estimation processes. Although residual levels of radioactivity may be entirely safe, and indeed below the low levels that would be accepted for medical diagnosis, there will be general concern about the use of such methods and these suspicions are

not easily allayed. The second example might be the use of biopsy techniques which, although possible with levels of pain probably below those involved in restraining large animals, would certainly not be acceptable to the anthropomorphic welfare lobby. Since the animal industry is dependent for its ultimate acceptance by the public, these constraints have to be faced.

Criteria for the assessment of prediction techniques

There are no hard and fast quidelines for the acceptance or rejection of potential predictors. Although certain features seem desirable, many of them are matters of degree, where quantitative judgments will be required.

In the first place a prediction criterion should certainly be repeatable. What level of repeatability is desirable or can be accepted if, however, not easy to state. Although a particular criterion may have rather low repeatability, it is possible that repeated measurements might still offer a useful level of prediction. This depends on the ease with which repeated measurements can be made. For example, although measurements made with the EMME instrument in pigs do not appear to have high correlations with carcass composition, the pigs are required only to walk through the instrument and therefore repeated measurements can be made very easily, and are now being evaluated for selection purposes.

Acceptable levels of repeatability are not sufficient in themselves. A character may be perfectly repeatable but quite unconnected with the desired selection objective. In addition to a measure of repeatability we need to know the correlation of the predictor with the selection objective. If, for example, we are using ultrasonic measurements of fat to predict leanness of the carcass, then full scale dissection are necessary for the precise calibration of the predicting measurement. Short cuts such as the correlation between ultrasonic fat measurement and that obtained on the carcass can be misleading to the extent that carcass fat measurements are themselves only indirect measures of carcass leanness and subject to errors. So although one would expect a broad correspondence between ultrasonic and carcass fat measures, this correlation should not be used as the ultimate criterion in deciding, whether or not to accept a particular predictor.

It is important that calibration of the predictor should be carried out in a relevant population of animals. While we may be reasonable certain there is a useful connection between, say, live animal fatness measurements and carcass lean, the actual regression lines indicating the relationship between these two variables may be different in different populations. For within breed selection these differences may or may not be important. If the two regression lines for two different breeds have the same slope but differ in intercept, then this will be of no concern. If, however, the two regression lines had the same intercept but different slope then although animals would be ordered correctly, extreme individuals might be over- or under-valued, and this could affect the weighing of the predictor relative to other measures of performance in a selection index.

The stability of the predictor under selection should be considered, so that there can be reasonable certainty that the relationship does not change in such a way as to invalidate the prediction. This change could take place in two ways. For example, the thickness of fat may be reduced under continued selection to the extent that the errors of measurement are greatly increased. If so, then a reappraisal of a prediction method based on fat thickness would be necessary. A second concern would be that the process of selection might change the nature of the predictor in the course of time. Thus, for example, in using ultrasonic measurements of fat thickness we are in fact measuring a time interval for the transmission of a pulse of sound through a given distance on fat. If there was genetic variation in the velocity of conduction of sound in fat of different animals, then there might be a real danger of evolving by selection animals with high velocities and not low amounts of fat. Fortunately, this does not seem to happen but such details may not be known in the early stages of a new predictor.

It has to be recognised that the mean measurements of the predictor will change in the course of time if selection is effective. The effects of this change may not be fully appreciated, and the changes may be subject to interpretations, which are not fully justified. An example of this would be using fat measurements at a single point as a predictor of lean and exerting strong selection pressure for this characteristic. In the course of time, the fat on the animal will be reduced, but most at the point at which it is selected.

Although amounts of fat in other places will be reduced, the genetic correlation between fat measures is unlikely to be one, and the reduction at these other locations will be somewhat less. Thus, although the total amount of fat may be reduced, the altered linear measurements of fat in different places on the body may give the impression that is has been redistributed.

Required levels of accuracy

How accurate needs a predictor to be of use in a selection programme? This is a quantitative question for which there will be no single answer. Much will depend upon the relative economic importance of the carcass criteria and the returns from their improvement. While such economic assessment may be possible in terms of leanness and overall proportions of high price cuts, it is extremely difficult to quantify the value of meat quality characteristics. Furthermore, one has to presume that improvement of carcass characteristics are not the only selection objectives, and that the producer will also want to reduce production costs through improvements in growth rate and the economy of food use. If several such characteristics are assembled together in an overall selection index, then the accuracy of prediction of a carcass characteristic by in vivo measurements is likely to become much less critical. If the accuracy of, for example, carcass leanness is low, and this is built into the index calculations, then the resultant selection weights obtained will place more emphasis on other characteristics than can be measured directly. This is a realistic approach and one which can readily be changed given improved predictive methods. While it may not meet the high aspirations of the meat trade, it does ensure that animals are changed in a direction which is of overall utility.

Alternatives to performance testing

The discussion so far has centred on techniques, such as ultrasonic measurement, which can be used for the prediction of carcass composition. There are, however, other carcass attributes such as killing out % and proportions of high priced cuts, where the future availability of useful in vivo predictors looks much less promising. If no such methods are forthcoming, we are not necessarily

forced back to progeny testing and two alternative methods comprising a) sib testing and b) individual testing and gamete storage may be considered.

a) Sib Testing

In any breeding populations there will be a number of sire families, some of which will not be required for breeding and can therefore be slaughtered for carcass assessment. Although these may vary in number, and perhaps sex, it is perfectly possible in principle to take measurements on these animals into account during selection. The limitation on this method then becomes not the accuracy of carcass assessment but the genetic relationship with the individual being considered for selection. Usually with cattle this genetic relationship will only be one quarter so that the intrinsic value of sib information is low, although, if there is enough of it, then it is useful. The relative response for sib selection compared to individual selection is shown in Figure 1 for varying numbers of sibs. The lowest curve for half sibs show that for modest numbers this response is less than half that achieved with individual selection.

This discouraging situation may, however, change in that multiple ovulation and embryo transfer hold out great prospects for the more rapid improvement of beef cattle (Land and Hill, 1975). If these reproductive techniques were applied extensively they would create large numbers of full sib families. Assuming that these full sibs were born of different recipient cows, then problems of environmental correlations would be removed, and the closer genetic relationship would be potentially much more valuable (Figure 1).

b) Individual testing and gamete storage

An alternative method, which appears to have been used only on a single occasion (Magee, Bratzler and Merkel, 1968), is to collect semen fra young bulls for deep freezing and then to slaughter them for carcass assessment. There are practical problems in that some beef breeds are infamous for their poor semen quality when young but otherwise the method has great attractions. The same process might be possible on the female side, if methods could be devised on preserving oocytes in deep freeze and then fertilising ova that

were developed from them. At the moment it is only possible to preserve fertilised ova, and the choice of mate has therefore to have been pre-determined.

A further elaboration of this method now seems feasible. Developments in the manipulation of developing embryos (Willadsen, 1979) make it possible to sub-divide these and to produce idential twins to order and, depending on survival rates, some triplets and quadruplets. If this was done systematically, then it would be possible to supply one individual for slaughter while preserving an identical genotype should it be required. For some carcass characteristics there is obviously a great deal of variation, which is difficult to control, as in the measurement of killing-out %. It might indeed be possible to slaughter two or three copies of the same individual while maintaning that genotype for breeding purposes. Although at the present time, success rates make this embryo manipulation an expensive process the possibility exist of integrading it with an ova transplantation scheme for the improvement of beef cattle with potential rates of change that have never been achieved in the past.

An existing prospect for the future would be the production of much larger clones by micromanipulation. This development will require a large injection of effort, and I could perhaps leave it as an interesting administrative question as to whether money might be better spent in opening up these new techniques rather than in the refinement of many of the existing in vivo estimation procedures for body composition that we already have.

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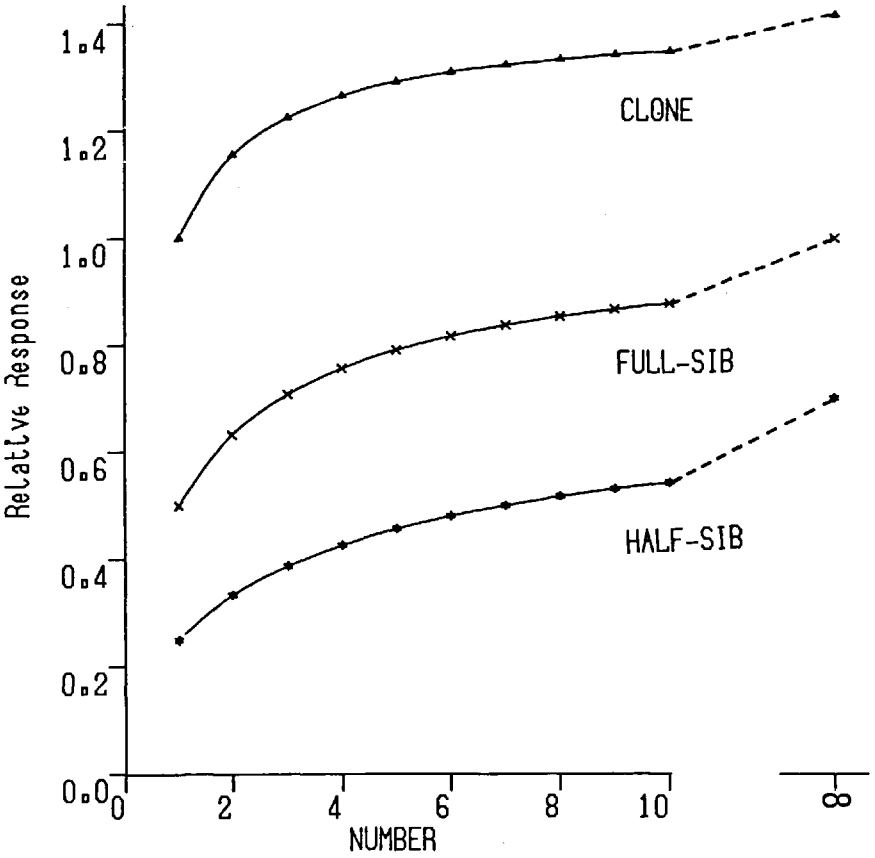

Figure 1. Expected selection responce, relative to individual selection, for family selection with various family sizes. (Non-additive effects and common environment assumed negligible, $h^2 = \frac{1}{2}$).

b. POTENTIAL USE OF IN VIVO TECHNIQUES IN A COMBINED MILK/BEEF BREEDING PROGRAMME

B. Bech Andersen
National Institute of Animal Science
Rolighedsvej 25, 1958 Copenhagen V.
Denmark

A combined milk and beef production based on dairy and dual-purpose cattle breeds is of great importance in Europe; and from a biological point of view it is also the most efficient production form.

In breeding programmes for a simultaneous improvement of milk and beef, the genetic correlation between the two traits is a very important parameter. In several scientific publications a low, but slightly positive correlation between growth rate and milk-yield has been demonstrated. We have seen in our own analysis that a genetic improvement of milk and butterfat yield in the long term will lead to an increase in growth rate and mature size, but also to a slight decrease in carcass quality (Andersen and Andersen, 1974). These tendencies are increased by import of genes from American Holstein-Friesian to the European Friesian cattle populations. Such an import will in the long term decrease both dressing percentage and carcass grading with two units approximately (a.o. Andersen, 1981). Also selection for increased growth rate, as included in the breeding schemes in many European countries, seems to have a negative, correlated effect on dressing percentage and muscularity of the actual breeds (Andersen, 1978).

It means that the total effect of import and selection in most of the dairy and dual-purpose breeds in Europe will be a significant reduction in carcass quality. The amount of produced carcass per animal will decrease, and especially in exporting countries also the price per kg carcass will be reduced. Therefore, great effort has been done to keep these negative effects within reasonable bounds, and among various objectives techniques for assessing body composition on live animals ultrasonic has had the greatest potential for practical application.

Use of ulttasonic measurements in a performance test selection

In order to avoid the reduction in carcass quality, ultrasonic measurements have been introduced to the Danish performance test of AI bulls. The loin eye area of the bulls is measured at an age of 9 and 10½ months. The muscle area is adjusted to a constant live-weight at 400 kg and presented as an ultrasonic index. Each year 600 bulls are performance tested on central testing stations.

The plan for these activities was based on results from an analysis of the direct and correlated effect of various strategies in the performance test selection (Andersen, 1978). The work included 136 progeny groups of the breeds Danish Red and Danish Friesian. In total 2330 young bulls were slaughtered at a constant live-weight of 250 kg or 450 kg. The feed consumption was individually recorded from an age of 15 days, and after slaughter all carcasses were dissected into lean, fat and bone. The data were supplemented with body measurements of 1679 mature cows after the same sires.

In table 1 some main results from the analysis are presented. An one-sided selection only for growth rate and with an intensity corresponding to an expected genetic superiority in growth capacity of 100 grams/day causes an indirect decrease in use of SFU/kg gain of both live-weight and lean tissue but also a decrease in dressing percentage and muscularity. Such a selection will also result in an indirect increase in birth weight of 3.3 kg and an increase in mature cow weight of 48 kg.

Table 1. Expected genetic effect of different indices (450 kg's young bulls) from the progeny test for beef production.

	Genetic response in:						
	Daily gain	SFU per		Muscle area	Dress-ing	Birth weight	Mature cow w.
Index	(g/day)	kg total gain	kg lean gain	(cm^2)	%	(kg)	(kg)
1. DG	100	-0.4	-1.2	-1	-1.5	3.3	48
2. MA	-5	-0.0	-0.8	11	1.7	0.9	-8
3. DG + MA	52	-0.3	-1.3	9	0.5	2.7	19
4. DG + (MA)[1)]	90	-0.5	-1.3	4	-0.8	3.5	40

1) restricted index with lean/bone ratio constant.
DG = Daily gain in grammes.
MA = Longissimus dorsi muscle area in cm^2.

Selection with the same intensity, but for ultrasonic muscle area alone, causes a marked improvement in dressing percentage and muscularity; only a slight increase in birth weight and a slight decrease in mature cow weight.

A combination of daily gain and muscle area into one index results in a selection response between index 1 and index 2. Index 3 is an economic optimal index, and index 4 is a restricted index with lean/bone ratio in the carcasses maintained constant. The results presented demonstrate that it is possible to get an important increase in growth capacity without an adverse effect on carcass quality. Such a combined index will also lead to the greatest improvement in feed utilization expressed as Scand.FU per kg lean tissue gain.

More than 3000 potential AI bulls have during the last years been measured by ultrasonic at our performance testing stations. Some main results from a statistical analysis of the collected data are shown in Table 2.

Table 2. Expected genetic effect of different indices (11 mth's young bulls from the performance test). (Jensen and Andersen, 1981).

	Genetic response in:			
Index	Daily gain (g/day)	SFU per kg gain	Muscle area (cm^2)	Weight at 42 days (kg)
1. DG	100	-0.29	-4	3.9
2. MA	-52	0.14	8	-5.1
3. DG + MA	60	-0.19	3	-0.5

(Symbols as used in Table 1).

The "nature" of the material is different from the data used in the basic study presented in Table 1. The performance tests were finished at a constant age (in contrast to constant weight); and in addition Danish Red and Danish Friesian have now been graded up with American Brown Swiss and American Holstein Friesian, respectively. The heritability for daily gain and ultrasonic muscle area (average of 9 and 10½ mth's measurements) were 0.53 and 0.71, and the genetic correlation between the two traits is -0.30. Therefore, the genetic effect of selection for ultrasonic measurements of the muscle thickness on performance tested bulls seems to be greater than shown in Table 1.

The importance of ultrasonic measurements is confirmed by preliminary results from a selection experiment with a closed population of Red Danish cattle (Hansen and Liboriussen, 1981).

Selection for muscle thickness contra fat thickness

In general measurements of the subcutaneous fat layer gives the best description of carcass fatness and lean tissue content and measurements of muscle area the best description of dressing percentage, muscularity and lean/bone ratio. This means that selection for the two traits could produce different long term responses. Selection for increased muscle area will improve dressing percentage and lean/bone ratio, and selection for decreased fat thickness will reduce the fatness and increase the lean percentage of the carcasses. It is also important to note that selection against fatness is likely to change the maturity time of the animals, and, in the long term, it could have an undesirable side effect on appetite, energy deposition, and perhaps, fertility in both dairy and beef cows.

Future development

The accuracy of the ultrasonic measurements and the genetic response can be increased by technical improvement and/or by repeated measurements on the same animals. Jensen and Andersen (1981) have shown that the correlations between muscle area measurements at an age of 9 and 10½ months is 0.60. It means that the accuracy can be increased by t. ex. three repeated measurements with some weeks' interval instead of a single measurement at the end of the test.

Other more advanced in vivo techniques could also have a great potential in the breeding work. If t.ex. introduction of "whole body scanning" on our performance test stations makes it possible on the bulls in test to follow the development of various vital organs, the deposition of energy, the deposition of minerals, the reactions on different fasting/refeeding systems etc., then it could be possible to include not only carcass quality traits, but also constitutional traits and indirectly also important dairy traits in the selection. Such a development could revolutionize the strategies in the combined milk/beef breeding programmes.

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C. POTENTIAL USE OF IN VIVO TECHNIQUES IN NUTRITION AND GROWTH STUDIES

A.J.H. van Es
Dept. of Animal Physiologi
Agricultural University
6709 PJ Wageningen
Holland

Introduction

During its growth the animal body continually changes in composition and so do its total requirements for the various nutrients. Although it is only the carcass at slaughter, which in fact is the final aim of beef cattle husbandry, nutrients are needed not only to produce this carcass but also for the other parts of the body and for the maintenance of the body from birth to slaughter. Therefore, for proper nutrient supply it is necessary to know for each day of the growth period, how much and what kind of nutrients are needed. Next it must be known what the feeding value of the varios feedingstuffs is, i.e. their potential to supply the required nutrients to the animal. Finally, also information should be available on the effect of feeding above or below the nutrient requirements on weight and composition of the carcass at slaughter. It is the purpose of nutrition to present practice with those data.

It will be clear that the continuous change in the animal's need during the growth period presents nutrition with considerable difficulties. Thus, non-destructive methods for measuring the body's composition precisely are clearly welcome: with their help it would be much easier to give the information on nutrient requirements, on feeding value and on the effect of feeding below or above requirements on the final carcass.

In the next sections it will be discussed what precision such measurements of body composition should have. Furthermore, it will be studied if a determination of the change in composition of the body during a given period of time rather than the compositions at the start and end of the period, may supply the necessary information. Finally an example of a model will be presented which from

nutritional data predicts live weight and body composition of veal calves after various times of fattening.

Precision needed in nutrition experiments

Preliminary remarks

The nutritionist's interest in an animal's weight and composition usually differs considerably from that of the butcher's interest. The nutritionist sees the weight and composition of the carcass at slaughter as the final stage of development. For him the process of development and growth itself is far more important. He has to feed the animal in such a way that it can grow rapidly during the whole growth period. Thus for him body weight and composition at any moment are important, moreover he needs also information on the non-carcass parts of the body.

With regard to the composition itself fat and protein have his main interest. For fat this is because of the high energy content, nearly 40 kJ/g. Fat-free tissue has a much lower energy content, about 6 kJ/g, because most of its consists of water (without any energy) and of protein (some 24 kJ/g) in a proportion of 3-4 to 1. It will be clear that it requires far more feed for the animal to produce a kg of fat than a kg of fat-free tissue. Thus, the nutritionist is besides in body weight hihgly interested in a very precise estimate of the fat content of the body.

Furthermore, he is interested in the protein content because of the great influence of protein deposition on live weight gain and also because the price of feed proteins usually is higher than that of other feeds.

Finally, the nutritionist needs accurate information on the live weight of the animal for each day of the period. Body weight is the main factor which determines the animal's energy and protein requirements for maintenance. In growing ruminants as much as one half up to two third of the total feed consumed is used for the maintenance.

Determination of feed requirement and effect of level of intake on rate and composition of live weight gain.

The first aim is to measure how much energy, protein and sometimes other nutrients like minerals and vitamins the animal needs daily at a given age and stage of development. In fact it is an input/output comparison, often combined as a second aim with the influence of feeding level on the production of saleable meat. Usually several experiments are needed in the course of development because of the change in requirements due to the increasing body weight and the change in composition of the body. As already one experiment is expensive because a.o. not too few animals have to be used to exclude between-animal variation, it is clear that a series of such experiments involves great costs.

In such experiments the animal should be healthy and kept and cared for in a way closely similar to the situation in practical husbandry. Intake of feed and, preferably, the digestibility of the ingested feed should be measured in order that intake of digested matter and energy can be estimated with a coefficient of variation due to random errors of less than 2%. This is not very difficult to achieve except in the grazing situation and in case of self-feeding of the animals from large batches of feed.

With regard to the output, the production of the animal's live weight does not tell enough. First the determination of live weight is not free from random errors, and, if certain precautions are not taken - like weighing at the same hour of day etc. - also not free from systematic errors. The coefficient of variation of the random errors for one single weighing can be estimated at 1-2%, so for the live weight gain it amounts to about 2% of average body weight. For cattle gaining 14 kg live weight in two weeks this amounts to 200 kg and 400 kg live weight at random errors of 4 and 8 kg, respectively. Weighing more often and more animals reduces this error. However, it should not be forgotten that weighing bulls of 400 kg and more is not without danger, except when done with special scales as used at my institute.

It is clear that the shorter the experiment lasts, the more does the weighing invalidate the interpretation of the results. Therefore,

experiments with a greater length are to be preferred. These, however, have two other difficulties. First, maintaninin the desired precision of the measurement of intake over longer periods, including weekends, is far from easy. Secondly, the animal's body composition may change during the experiment.

In growing animals the usual change of the body in the course of time is an increase of the fat content and a decrease in the content of lean tissue and of water. Lean tissue contains protein and water in a rather constant ratio of 1 to 3-4, so its energy and protein content is not far from 6 MJ/kg and 20-25%, respectively. Fat has an energy content of nearly 40 MJ/kg. When deposited, there is a tendency that it replaces some water so that fat deposition may result in an energy deposition of 50 kJ/per gram live weight change, i.e. many times more than in case of lean tissue. During normal growth both lean and fatty tissues are deposited simultaneously, but with advancing age, especially in steers, fat deposition outweighs lean depositing to a steadily increasing extent. As a result a kg live weight gain at a young age may contain as little as 8-12 MJ and at mature age 15-25 MJ. The lower figures apply to bulls of large breeds, the higher to steers of small breeds (ARC, 1980, p. 29-43). Even within the same breed there is a considerable variation in this respect between animals.

In the ruminant the feed costs of depositing energy in the tissues as protein or fat are supposed to be about the same, but because of the great variation in the energy content of live weight gain the feed costs of one kg gain may still differ considerably. Thus for a correct interpretation of the experimental results insight in the composition of the live weight gain is necessary. As to this estimate it seems fair to ask for the same precision as achieved in estimating total intake or change in live weight, i.e. a random error of 2% or less.

It is quite common in feeding trials with growing cattle to use 20 animals for one treatment and to achieve a live weight gain of 200 kg in 150-250 days. Assuming weighing the animals at the start and the end of the trial is done on three separate days for calculation of weight gain by difference or once every 14 days to derive

weight gain by means of regression and assuming a coefficient of variation of 1-2% of live weight for one single weighing as given above, the standard deviation due to random error of the average 200 kg gain of the group would be about 1 kg for the first method and of similar size for the second. It is clear that for each individual animal the standard deviation would be about $\sqrt{20}$ times larger, thus about 4,5 kg.

Thus for group estimates the error of the weight gain is small - in the neighbourhood of 0,5% - and the error of estimating its change in composition could best be of the same order of 2% which applies to the error of the intake estimate. If, e.g. for selection purposes, the conversion of feed into meat of the separate animals were to be studied, also a precision of 2% for the estimation of change in composition would be needed. Although the error of the weight gain estimate of the individual animal is higher - $\sqrt{20}$ = 4,5 kg, thus about 2% of the total gain, this is still close to the error of the intake measurement. A 2% precision for the estimate of change in composition in the above experiment would necessitate a precision of 1% for the estimate of total body composition at the start and end of the experiment.

Determination of the nutritive value of feeds for growing cattle

The nutritive value of a feed changes continuously with advancing age because of the increase in liveweight and therefore of maintenance and because of the change in deposition from lean to fat. So the importance of protein decreases, whereas that of energy hardly changes because of the increasing energy content of daily gain and of similarity in energy needed for energy deposited as fat or as protein. Most experiments mainly pay attention to the energy value of the feed. With the feeding value is usually meant the feed's energy value.

In theory the same experimental approach for a determination of the nutritive value of a feed could be followed as discussed above for the requirements. Usually this is not done. The main aim is to be able to compare the nutritive values of different feeds with their market prices. For such comparisons to be most valid, it is

necessary to exclude as many sources of uncertainty as is possible. Thus, it is preferable to work with change-over or latin-square designs to exclude variation due to the animal's individuality and due to environment as much as possible. Such designs usually have fairly short periods with the same treatment, e.g. 4-8 weeks, otherwise their total length becomes excessive. When precautions are taken that protein supply will always meet the requirements, and that so much feed is administered that the animals with different treatment grow at about the same rate, it can be assumed that the composition of the live weight gain in the same period will hardly differ between treatments. Thus, the precisions with which intake of feed energy and live weight gain can be measured, determine the accuracy of the comparison. For the intake the coefficient of variation due to random error again will be about 2%. The estimate of the weight gain of 25 to 70 kg in 4-8 weeks of one animal, however, will have an error of about 0.02 x 350 = 7 kg or 10-30% of the weight gain, and the estimate of the difference in weight gain between two treatments an error of about 10 kg. It is clear that an accurate comparison of the nutritive value of feeds in this way needs very large numbers of animals. Furthermore, an absolute measure of the nutritive value cannot be obtained unless by other means the composition of the live weight change is determined. If this is done by estimating body composition before and after the 4-8 week trial, such a measurement should be extremely precise because an error of 1% for the composition of the whole animals is far too high an error for a precise estimate of the change in composition, i.e. the live weight gain.

As the high number of animals required is seldom available, other methods are usually followed. Instead of measuring live weight gain energy and nitrogen balances are established by measuring all energy and N input and by diminishing this with energy and N lost with metahen, faeces, urine and heat. Thus, only the change in body composition is estimated; information on the composition of the animal is not obtained. Such energy and N-balances require a four week period, in the latter 10 or 14 days of which the balances are measured. For one experiment with one animal the standard deviation due to random error for an energy balance of 15-30 MJ/day is about 2-3 MJ

and for an N balance of 30 g/day about 2-4 g. The balance method is clearly more accurate than the weight gain methods, but it also needs to be performed with more animals per treatment although not so many as in case of the weight gain method. The balance method has the additional great advantages that not only data on digestibility are obtained but also data on the composition of the gain. Thus besides that relative comparisons between two feeds can be made also absolute values can be derived.

Balance trials require expensive equipment and are very laborious. Moreover, the balance is always the difference between the input data and the many output data, so all errors, random and systematic, accummulate in the balance. A more direct measurement of the balance, i.e. measuring the animal's weight and composition at the start and end of a, say, four-week trial, would be highly welcome. However, obtaning for an animal of 350 kg, containing 56 kg protein and 7000 MJ, the same precision as with the balance methods - standard deviations of 28 x 6.25×(2 to 4) = 350 to 700 g protein and 28 x (2 to 3) = 56 to 48 MJ energy for the total gain in the 28 days - would clearly require a very great precision of assessing the animal's weight gain change and body composition.

We may conclude that direct methods of assessing body composition might be sufficiently precise for nutritional studies on the feed requirements of cattle and on the effect of feeding level on development. For purposes of feed evaluation such direct assessments are probably not precise enough.

Longitudinal studies

In the literature some models can be found which aim at predicting future weight and composition of a growing animal from data on its initial weight and on quantity and composition of the feed to be fed. Serial slaughter of animals during an experiment to test such a model is expensive and hardly done with large animals. Moreover, it has a disadvantage that between-animal variation cannot be excluded. Having a good method to estimate the same animal's body composition in vivo repeatedly would be extremely useful to check such models which help to understand which factors influence growth most. In such

studies the overall accuracy reached depends on the accuracy of the weight measurement as well as of the measurement of the composition of the body. As the weight measurement usually has a random error of 1-2%, a similar precision might be asked for the estimate of composition. Although not predicting live weight and composition at slaughter with sufficient accuracy (van Es, 1970) still such models may inform well on the influence of two or more different treatments in comparison to each other.

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d. ESTIMATION OF BODY COMPOSITION BY DILUTION TECHNIQUES IN NUTRITION EXPERIMENTS

J. Robelin
Laboratoire de la Production de Viande
Institut National de la Recherche Agronomique
CRZV - Theix - 63110 Beaumont
France

The measurement of body weight gain in growing animals is often insufficient for nutrition experiments. The composition of body weight gain during the experiment is more usefull. Two kinds of techniques can be used to measure body gain composition, either calorimetric balance trial or in vivo determination of body composition at the beginning and the end of the feeding experiment. The accuracy of the balance trials in nutrition experiments has been discussed in an other paper (van Es, 1981); so, this paper deals with the second kind of technique, mainly the estimation of body weight gain composition by dilution space of D_2O. Another method, based on the size of adipose cells measured after biopsy will be briefly proposed. Finally, an example of use of D_2O space in a nutrition experiment will be presented.

Estimation of chemical body composition by D_2O dilution space

Statistical basis of the method

For a very long time, the chemical composition of the body of animals is known to be statistically related to fat free mass. The percentage of protein and water in fat free mass (empty body lipids) is fairly constant after "chemical maturity" has been reached (Moulton, 1923). We have found (Robelin and Geay, 1978) on the basis of 340 results of whole body composition of growing cattle, that the weight of water and protein was fairly well related to fat free mass (FFM) according to an allometric relationship.

$$\text{Protein (kg)} = 0.1259\ FFM^{1.096} \quad (RCV = 2.8\ \%\ \text{protein})$$
$$\text{Water (kg)} = 0.8477\ FFM^{0.974} \quad (RCV = 1.1\ \%\ \text{water})$$

The values of the allometric coefficients (1.096 and 0.974) indicate that the percentage of protein increases slowly, and the percentage of water in FFM decreases, when the FFM increases. The relationship between empty body water, lipids and empty body weight (EBW) can also be expressed in an other way (Robelin and Theriez, 1980).

Water % EBW = 74.7 - 0.824 x Lipids % EBW (RCV = 0.97 % Water)

Similarly, protein weight may be expressed as a percentage of fat free dry matter (FFDM = empty body weight - lipids - water). The weight of body proteins represents 81.0 $\pm$ 0.3 % of FFDM in cattle (Robelin and Theriez, 1980). All these relationships are statistically fairly good. Their biological meaning could be discussed, but it is not the topic of this paper. The major point is to remember that the knowledge of empty body weight and empty body water is sufficient to estimate accurately the chemical composition of the body in terms of lipids and proteins.

Estimation of lipids and proteins weight in cattle

The D_2O space and the whole body chemical composition were measured at slaughter on 21 Charolais and 21 Friesian bulls (Robelin, 1981,a). The equations of prediction of lipids weight (kg) from empty body weight (EBW; kg) and empty body water (EBWAT; kg) or body weight (BW; kg) and D_2O space (DS; kg) were as follows:

(1) Lipids = $0.866 \pm .017$ x EBW - $1.143 \pm .027$ x EBWAT RSD = 2.2 kg

(2) Lipids = $0.769 \pm .037$ x BW - $0.943 \pm .054$ x DS RSD = 5.4 kg

The mean values of the different variables were BW = 340 kg; EBW = 290 kg; EBWAT = 192 kg; DS = 236 kg, and Lipids = 39 kg. These equations had no significant constant ($P < 0.01$), and their coefficients were not significantly different between breeds (Charolais vs. Friesian).

As expected, the accuracy of prediction was better with EBW and EBWAT (RSD = 2.2 kg i.e. 5.6 % of the weight of lipids) than with BW and DS (RSD = 5.4 kg i.e. 13.8 % of the weight of lipids). This accuracy was similar to that observed in cattle (Crabtree, Houseman and Kay, 1974) or in lambs (Searle, 1970; Robelin, 1977).

The ratio between the coefficient of EBW (0.866) and that of BW (0.869) approximately equalled the ratio between BW and EBW (1.13). Similarly, the ratio between the coefficient of EBWAT (1.143) and that of DS (0.943) was approximately equal to the ratio between DS and EBWAT (1.21). Although logical, this indicates that data were unbiaised.

The equation (2) with BW and DS was computed for a given value of the gut content (for a given body weight) reported in table 1.

Table 1. Mean value of gut content (GC) in percentage of body weight in Friesian and Charolais bulls at different body weights

Number of animals in each breed	Charolais		Friesian	
	BW (kg)	GC % BW	BW (kg)	GC % BW
5	160	11.3	129	16.4
4	296	14.4	229	18.8
4	387	10.8	321	13.2
4	497	9.7	396	11.5
4	581	11.0	507	10.9

Note: Charolais bull were weaned at 300 kg BW;
Friesian bulls at 80 kg BW; after weaning they received ad libitum a 70 % concentrate and 30 % hay diet.

If this equation is to be applied to an animal with a higher gut content (for instance 5 kg), body weight and dilution space must be corrected (BW' = BW-5 kg, DS' = DS-5.0 x 0.87 ; 0.87 was the mean percentage of water in gut content in our experiments). Otherwise, the predicted value of lipids would be underestimated by approximately 300 g.

Example: Measured values: BW = 400 kg DS = 288 kg
Predicted lipids: 400 x 0.769 - 0.943 x 288 = 36 kg

Corrected values: BW'= 395 kg DS'= 283.6 kg
Predicted lipids: 395 x 0.769 - 0.943 x 283.6 = 36.3 kg

The magnitude of this kind of error is relatively small. However, when the animals received 80% roughage diet, the gut content could be increased by 3 or 4 % of body weight and the lipids weight might be underestimated by 1.5 kg.

So, when gut content can be estimated, it may be better to use an equation derived from equation 1, established with EBW and EBWAT. In this equation, EBW could be replaced by BW - GC (estimated gut content). EBWAT could be replaced by 0.968 x DS - 0.87 x GC; 0.968 x DS is the estimated value of total body water (Robelin, 1981, b) and 0.87 x GC is the estimated value of the water of gut content. This leads to the following equation:

(2') Lipids = 0.866 x (BW-GC) - 1.143 x (0.968 x DS - 0.87 x GC)

After simplification:

(2') Lipids = 0.866 x BW - 1.106 x DS + 0.128 x GC.

The equations of prediction for protein weight from EBW (kg) and EBWAT (kg) or BW (kg) and DS (kg) established for 42 animals of both breeds (Charolais and Friesian) are:

(3) Proteins = $\underset{\pm .015}{0.100}$ x EBW + $\underset{\pm .023}{0.134}$ x EBWAT RSD = 1.9 kg

(4) Proteins = $\underset{\pm .018}{0.124}$ x BW + $\underset{\pm .026}{0.058}$ x DS RSD = 2.6 kg

These equations have no significant constant terms, and they are not significantly different between breeds. The RSD of the equation with EBW and EBWAT is lower (1.9 kg i.e. 3.4 % of protein weight) than the RSD of the equation with BW and DS (2.6 kg i.e. 4.7 % of protein weight).

As stated before, protein weight is very close to 0.81 x FFDM (fat free dry matter = EBW - EBWAT - Lipids). If protein weight is computed from this relationship and the equation of prediction of lipids (eq. 1), it follows that:

(3') Proteins = 0.81 x (EBW - EBWAT - 0.866 x EBW + 1.143 x EBWAT)

(3') Proteins = 0.108 x EBW + 0.116 x EBWAT

This equation is quite similar to equation 3. The coefficients of EBW and EBWAT are very close together. It shows the poor interrest of measuring body water to predict proteins weight. This is also demonstrated by the coefficient of DS in equation 4. This coefficient (0.058) is just significantly different from zero. So, if gut content can be assessed, it would be better to calculate proteins weight directly from fat free dry matter (FFDM) as follows:

Proteins = 0.81 x FFDM

FFDM = EBW - EBWAT - Lipids

EBW = BW - GC (estimated gut content)

EBWAT = 0.968 x DS - 0.87 x GC

Lipids = ... equation 2'

(3") Proteins = 0.108 x BW + 0.112 x DS - 0.209 x GC

Accuracy of prediction of body gain composition

On a statistical basis the standard deviation (σ_D) of a difference between two variables (X1 and X2) equals $\sqrt{\sigma^2_{X1} + \sigma^2_{X2}}$. The accuracy (standard deviation) of prediction of lipies and protein weights from body weight and dilution space were respectively 5.4 and 2.6 kg. Consequently, the accuracy of prediction of gain of lipids and proteins during a feeding trial are respectively:

Lipids: $\sigma_{DL} = \sqrt{5.4^2 + 5.4^2} = 7.6$ kg

Proteins: $\sigma_{DP} = \sqrt{2.6^2 + 2.6^2} = 3.7$ kg

In fact these values have to be compared to the absolute values of lipids gain (DL) or proteins gain (DP) depending on the total body weight gain during the experiment (TBWG) and the percentage of lipids (l) and proteins (p) in body weight gain

$$\frac{\sigma DL}{DL} = \frac{7.6}{TBWG \times l} \qquad \frac{\sigma DP}{DP} = \frac{3.7}{TBWG \times p}$$

This accuracy is valuable for a single animal. It should be divided by $\sqrt{n}$ group of n animals. The variation of $\sigma DL/DL$ and $\sigma DP/DP$ according to total body weight gain (TBWG; kg) and the number of animals (n), for l = 0.20 and p = 0.17 are reported below:

	Relative error on lipids gain determination $\sigma DL / DL$		Relative error on proteins gain determination $\sigma DP / DP$	
Number of animals	1	10	1	10
Total body weight gain (kg)				
100	.38	.12	.22	.07
200	.19	.06	.11	.03
300	.13	.04	.07	.02

For a single animal, a rather good accuracy (13 % and 7 %, respectively for lipids and proteins deposition) is obtained for a total body weight gain of 300 kg. For a group of 10 animals, the same accuracy is obtained for a total body weight gain of 100 kg only. In these conditions, the accuracy of energy deposition would be near to 10 % in relative value.

Estimation of the weight of fatty tissues, muscles and carcass by D_2O dilution space

There is a good correlation between whole body fatty tissues and lipids in cattle (Robelin and Geay, 1978), so the weight of total fatty tissues could be predicted by D_2O space.

The equation of prediction for the 42 animals of both breeds is:

$$\text{Total fatty tissues} = \underset{\pm .035}{0.690} \times BW - \underset{\pm .051}{0.838} \times DS \quad RSD = 5.0 \text{ kg}$$

The residual standard deviation represents 13.3 % of fatty tissues weight. This is quite similar to the accuracy of prediction of lipids weight.

The weight of fatty tissues of the carcass can also be predicted with a fairly good accuracy.

$$\text{Carcass fatty tissues} = \underset{\pm .029}{0.512} \times BW - \underset{\pm 0.42}{0.613} DS \quad RSD = 4.2 \text{ kg}$$

The RSD represents 14.4 % of the mean weight of carcass fatty tissues.

In contrast, no significant relationship exists between D_2O space and muscles or carcass weight for a given body weight. This lack of relationship is not surprising because a difference in carcass weight between two animals, does not involve a difference in the total body water.

Estimation of body composition in cattle by adipose cells size

The development of fatty tissues results both from an increment in the size of fat cells, and in the number of cells. After birth, hypertrophy accounts for more than 70 % of the increment

of body lipids in growing cattle (Robelin, 1981, c). Consequently, the weight of body lipids is fairly well related to the mean adipose cell size.

On the basis of this relationship we have tried to develop a method of appreciation of body lipids in vivo, based on fat cells measurement on a probe of subcutaneous adipose tissue removed by biopsy.

We compared this method to the dilution technique in an experiment involving 12 dry mature cows (Robelin, 1981, d) slaughtered at different levels of fattness, between 5 and 23 % of total dissectable fatty tissues in empty body weight.

The relationships between total body fat measured by dissection (TBF in percentage of body weight), D_2O space measured before slaughter (DS in percentage of body weight) and subcutaneous adipose cell diameter (ACDμm) are as follows:

$TBF = 83.7 - 1.06 \times DS$ RSD = 1.03 (% body weight)

$TBF = 6.84 - 0.140 \times ACD + 0.0022 \times (ACD)^2$ RSD = 1.15 (% body weight)

The residual standard deviations of these relationships are quite similar and correspond to 8-9 % of total body fat. This result indicates that adipose cells size measured after biopsy could provide a fairly good estimation of body composition. However, this relationship has to be verified in other types of cattle (breed, sex etc.) before being extensively applied.

In vivo estimation of body composition in nutrition experiment

The nutrition experiment taken as an example, was planned to measure the effect of feeding level on the composition of body weight gain in Charolais and Friesian bulls.

Eight animals of each breed weighing nearly 300 kg were allocated to two groups. The animals of group I (in both breeds) received ad libitum a 80 % concentrate 20 % roughage diet. The animals of group II were restricted to a growth rate equal to 50 % of that of animals of groups I (within each breed).

The body composition of animals at the beginning of the experiment was estimated by the dilution technique (Table 2). Charolais bulls had a lower content of lipids than Friesian bulls (8.7-9.5 % v.s. 10.7-11.4 %), and a lower calorific value (1.84-1.91 Mcal/kg v.s. 2.01-2.08 Mcal/kg). However, the proteins content of empty body weight was similar in both breeds (18.4-18.7 %).

Table 2. Body composition (mean and s.e.m.)of animals estimated at the beginning of experiment by D_2O space

Breed	Charolais		Friesian	
Level of feeding	Ad lib.	Restricted	Ad lib.	Restricted
No. of animals	4	4	4	4
Body weight (kg)	318 10	301 7	294 4	298 9
D_2O space (kg)	233 7	218 5	209 2	214 8
Empty body weight (kg)	273 9	259 6	253 4	257 8
Lipids % EBW	8.7 1.0	9.5 0.6	11.4 0.4	10.7 1.1
Protein % EBW	18.7 0.1	18.6 0.1	18.4 0.1	18.5 0.1
Energy (Mcal/kg EBW)	1.84 0.09	1.91 0.05	2.08 0.04	2.01 0.09

These results for both breeds are quite similar to the values measured after slaughter for animals of similar weight (Robelin and Geay, 1978, Robelin and Daenicke, 1980).

The animals in both groups were slaughtered at the same body weight, 610 kg for Charolais and 500 kg for Friesian. Their body composition was estimated by the composition of a rib joint and the weight of the fifth quarter fatty tissues (peritoneal, mesenteric and kidney fat) according to a previously described method (Robelin and Geay, 1978) (Table 3).

Table 3. Body composition of animals at slaughter (mean and s.e.m.)

Breed	Charolais		Friesian	
Level of feeding	Ad lib.	Restricted	Ad lib.	Restricted
No. of animals	4	4	4	4
Body weight (kg)	615 17	622 6	504 12	510 11
Empty body weight (kg)	541 15	544 8	447 11	416 12
Lipids % EBW	11.5 0.6	10.7 0.3	15.2 0.8	11.5 0.4
Proteins % EBW	19.7 0.1	19.8 0.1	18.5 0.2	19.2 0.1
Energy (Mcal/kg EBW)	2.16 0.05	2.09 0.03	2.44 0.07	2.13 0.03

In the Charolais breed there were no significant differences between group I and II in the chemical composition of empty body. In contrast, ad libitum fed Friesian bulls had a higher percentage of lipids than restricted ones (15.2 vs 11.5), a higher calorific value (2.44 vs 2.13 Mcal/kg) and a lower percentage of proteins (18.5 vs 19.2).

Table 4 reports the results of composition of empty body weight gain.

Table 4. Body composition of gain of Charolais and Friesian bulls; Variation according to level of feeding and growth rate (mean + s.e.m.)

Breed	Charolais		Friesian	
Level of feeding	Ad lib.	Restricted	Ad lib.	Restricted
No. of animals	4	4	4	4
Days on feed	200 24	429 13	219 2	368 27
Body weight gain (kg/d)	1.53 0.16	0.75 0.01	0.96 0.08	0.58 0.01
Empty body Weight gain (kg/d)	1.38 0.12	0.66 0.01	0.89 0.07	0.43 0.01
Lipids % EBWG	14.5 1.2	11.8 0.6	20.0 1.8	13.1 1.3
Proteins % EBWG	20.8 0.2	20.9 0.1	18.6 0.4	20.4 0.1
Energy (Mcal/kg EBWG)	2.50 0.10	2.26 0.06	2.90 0.15	2.34 0.13

In Friesian breed, the composition of gain was significantly ($P < 0.01$) different between levels of feeding. Ad libitum fed animals had a higher percentage of lipids (20.0 vs 13.1 % EBWG), a higher calorific value (2.90 vs 2.34 Mcal/kg EBWG) and lower percentage of proteins (18.6 vs 20.4 % EBWG). In contrast, in Charolais breeds only the lipids percentage were significantly different (14.5 vs 11.8 % EBWG). This interaction between breed and feeding level has been noted previously by Geay, Robelin and Beranger (1976). The effect of a reduction of energy intake on the composition of gain, and mainly on lipid deposition, is higher in early maturing than in late maturing animals.

Conclusion

In cattle, measurement of deuteriated water space gives a rather good estimate of body composition, mainly of body lipids. Most interestingly the relationship between D_2O space and body lipids does not seem to vary between breeds. Logically, this relationship should vary slightly with the gut content of animals, but this variation can be taken into account in the proposed equations.

The accuracy of determination of D_2O space has been discussed in another paper (Robelin, 1981, b). The accuracy of determination of body lipids is closely related to the accuracy of determination of the "mean" body weight of animals. For this reason several recording of body weight of animals should be made before and after the day of measuring D_2O space. Obviously, such measurement should be avoided during a period of change in nature or level of feeding.

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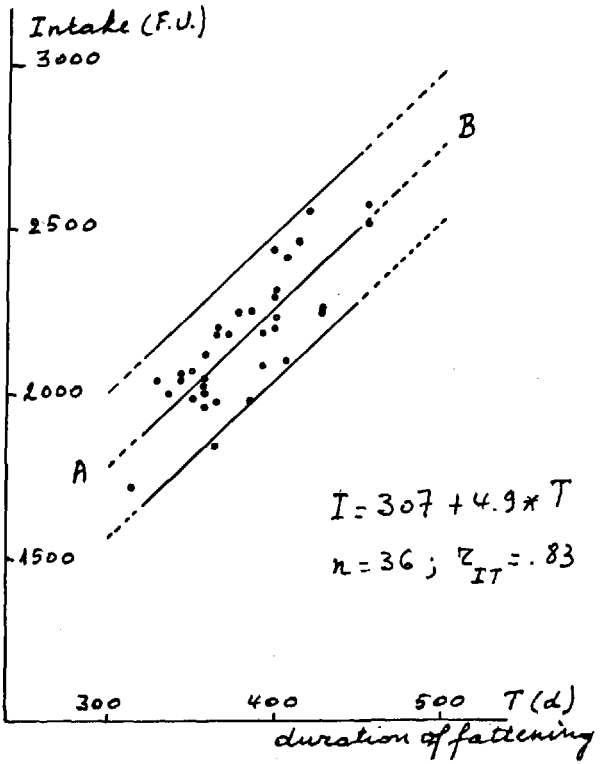
e. ESTIMATING CARCASS COMPOSITION OF YOUNG BULLS FROM WEIGHT FOR AGE AND FEED INTAKE DATA

G. Torreele
Department of Animal Breeding
Faculty of Agricultural Sciences
State University
Ghent - Belgium

The start of our investigations into the subject dates back to the end of '61 and beginning of '62. Before publishing the first report of the Study Center for Meat Production, Martin and I discussed the meaning and implications of the graph depicting the association between total feed intake and the time an animal needed to attain a live weight of 500 kgs. Figure 1 is a copy of this graph as it appeared in our May 1962 report. Initially, our attendtion was directed to the explanation of the variability in feed intake, more specific, to the possibility of estimating total feed intake from current (in our experiments) observational data as were weight for age recordings and data about carcass composition. In fact, we were looking for an escape for feed intake recording (at that time, there were very few fattening trials recording individual feed intake, secondly, the literature was full of high correlations between feed intake and growth rate, and third, we had developed a very fine method of estimating carcass composition).

Figure 1. Total Feed Intake (I, in fodder units) as a function of Age (T) for constant live weight (We = 495 kgs). (Report No. 1, 1962)



This first data includes 50 animals and means, standard deviation and simple correlations are shown in the following:

	$\bar{x}$	s_{x_i}	X2	X3	X4	X5	X6
X1	2210	220	.81	.34	-.11	.20	.02
X2	56.1	5.3		.20	-.25	.05	.06
X3	70.4	15.6			-.35	-.32	.33
X4	57.2	10.4				.67	-.39
X5	19.7	10.3					-.25
X6	478.6	7.4					

In this table X1 represents feed intake in fodder units; X2 = duration on fattening in weeks; X3 = total extramuscular fat + intestinal fat (kgs); X4 is initial weight (kgs); X5 initial age (days) and X6 is weight just before slaughter (kgs).

Partial and multiple correlations of direct interest here are:

$r_{12.56} = .82$; $r_{12.356} = .82$; $r_{12.3456} = .80$

$r_{13.56} = .44$; $r_{13.256} = .46$; $r_{13.2456} = .46$

$r_{23.56} = .22$; $r_{23.156} = -.26$; $r_{23.1456} = -.26$

and $r_{3.1256} = 0.55$.

Much effort has been devoted to an amelioration of this correlation.

Figure 2 sketches roughly the situation with regard to the prediction of X3 (total fat) from X1 (total feed intake) and X2 (duration of fattening).

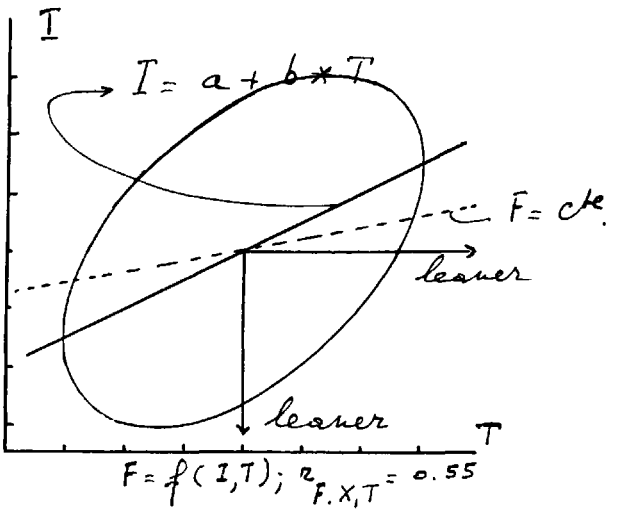


Figure 2. Prediction of total fat from total feed intake and duration of fattening (Torreele, 1963).

These associations have been confirmed on several occasions and have been studied very extensively at the Study Center within different breeds and sire within breeds. Subjects were the relations at constant live weights varying from 150 - 500 kgs with steps of 50 kgs; at constant ages varying from 2 - 12 months with steps of 1 month; at constant feed intakes up to 2000 F.U. with steps of 200. As to the estimation of carcass composition, only situations at 450 kgs and 500 kgs could be included in our analysis.

From our viewpoint, in the relations mentioned above, age merely functions as a substitute for maintenance requirements. As maintenance needs are thought to be proportional to some power of live weight, W^x, a better estimate of total non productive feed could possibly have been obtained by using surface area between the age axis and some (weight)^x for age curve.

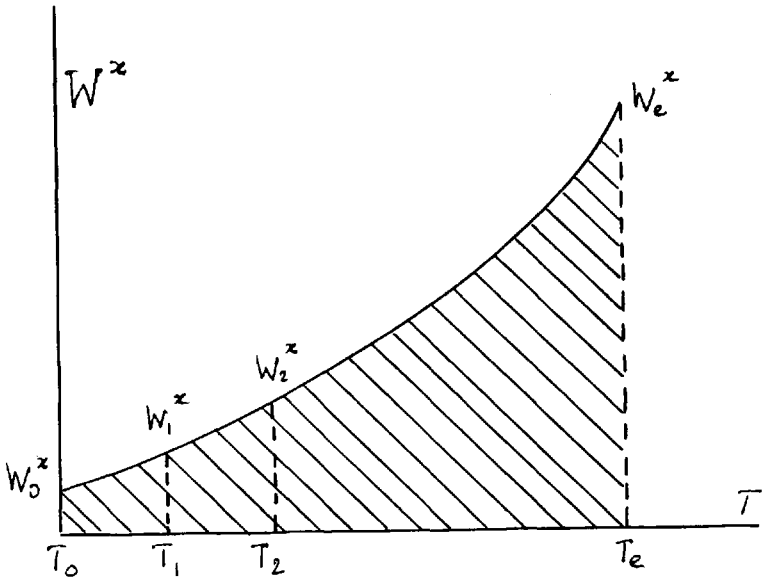


Figure 3. Calculation of surface area (Ax) (Torreele, 1964).

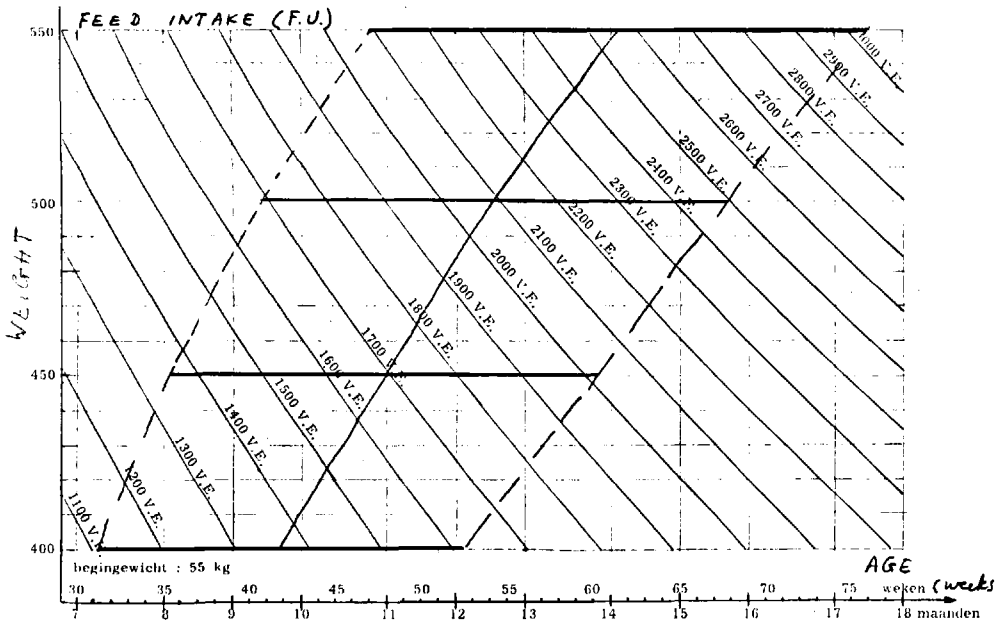


Figure 3. Feed Intake as a function of final weight and growth rate. (Martin and Torreele, 1965).

So, we recalculated the above associations using a series of individual surface areas A(x) with $x \in \{0.4, 0.5, \ldots, 1.2\}$ and looked for an x-value that would maximize the correlation $r_{X1.A(x)}$. For each of the 4 breeds included in this study, a slight curvature in the relationship $(x, r_{X1.A(x)})$ has been observed with a maximum between x = 0.4 and x = 1.2. However, at first sight, no appreciable amelioration could be obtained using this surface areas versus a model including initial weight together with final age and feed intake. As, in this view, differences in A(x) due to differences in W_0 (initial weight) are dependent upon age at final weight, and vice versa, it was decided that, for a later definitive analysis, surface area A(x) should be splitted into the components corresponding to the intervening differences.

There exist several ways of bringing in feed intake into the relationships considered: as total feed intake, as a feed conversion coefficient, etc.. Also, as feed procured is composed of several (gross) components, different "nutritional" values of the different components can be introduced and tested in view of maximizing the relationship under investigation. In our situation, feed intake includes 4 components: skim milk (value 1.333), hay (value 0.4), concentrates No. 1 (value 0.96) and concentrates No. 2 (value 1.0). Total feed intake, in fodder units, is thus = I = kgs skim milk x 1.333 + kgs hay x 0.4 + kgs No. 1 x 0.96 + kgs No. 2 x 1.0.

A correlation study was run on a very heterogeneous material (60 animals, 15 of each of 4 breeds, all having a different sire, fattened up from about 14 days old to 450 kgs). The variables included were X1: kgs of muscle and X2: kgs of fat, Y1 (kgs of hay), Y2 (kgs of No. 1), Y3 (kgs of No. 2) and Y4 (duration of fattening, in days). As $r_{X1.Y1Y2Y3Y4} = .32$, $r_{X2.Y1Y2Y3Y4} = .31$ versus $r_{X1.T1} = .24$ and $r_{X2T1} = 0.24$, it is clear that our previous "nutritional" values were not optimal for predicting total amount of muscle or total amount of fat in the carcass.

In addition, for this same heterogeneous group of animals, a cannonical correlation analysis was performed for the data set: [(X1, X2, X3), (Y1, Y2, Y3, Y4)] with X(3) describing carcass composition and Y(4) the growth-intake data. X1=total amount of muscle, X2 = total amount of fat, X3 = total amount of bone; Y1 = kgs hay, Y2 = kgs concentrate No. 1, Y3 = kgs concentrate No. 2 and Y4 duration of fattening. The canonical correlation coefficients R(3) = (r_1, r_2, r_3) were 0.36, 0.19 and 0.08. Based on R(3) and the associated matrices X(3,3) and Y(3,4) it is possible to work out a procedure for estimating X1 resp. X2 resp. X3. Fig. 4 gives the results for estimating X1 = kg of muscle out of the canonical correlation data. We found $r_{X1\hat{X}1} = 0.30$. This coefficient compares good with $r_{X1.Y4I)} = 0.24$ and $r_{X1.Y1Y2Y3Y4} = 0.32$.

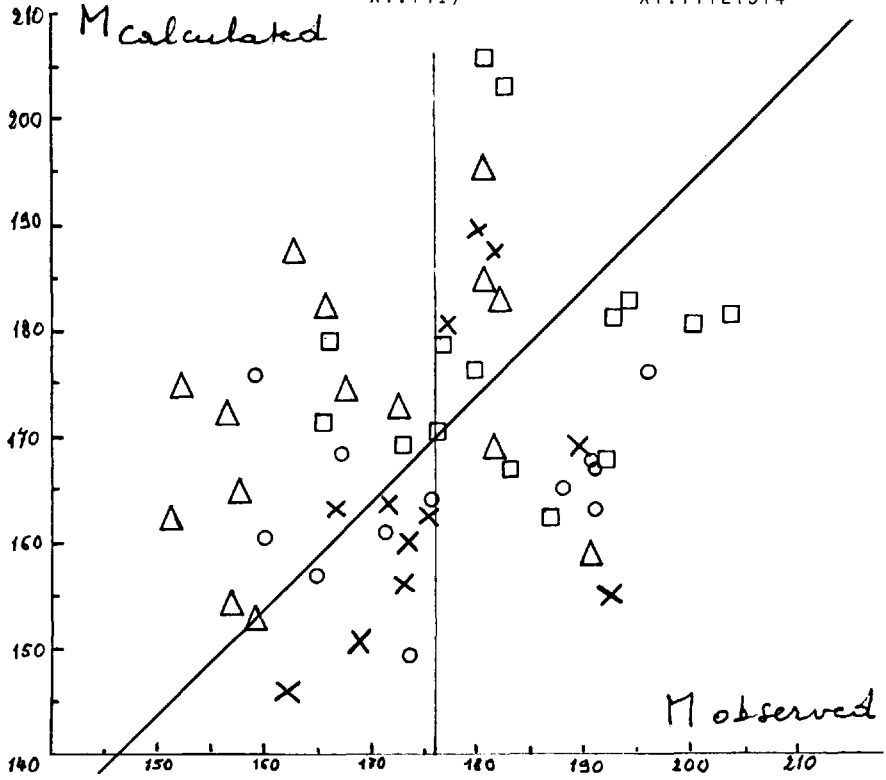


Figure 4. Estimation of M from canonical corr. (Torreele and Slawinsky, 1970).

There is also some discussion about the critera that are best fit for a description of carcass value by carcass composition. Is percentage composition to be preferred, or is composition best expressed as total amount of muscle, fat and bone? The last case is equivalent of expressing % composition of the live animal at constant live weight.

A study including 50 animals of one breed and weighing 450 kgs gave correlations of .46 for percent muscle and for total amount of muscle, .54 for total amount of carcass fat and percentage of fat in the carcass.

Some effort has been devoted to make estimations of specific weight of live animals in an air pressure chamber. This approach has been abandoned because of insurmountable technical difficulties.

Another approach to the problem has been the search for a relationship between growth curve parameters and carcass composition (Torreele, 1977).

Hereby, different growth models were fitted to a series of individual (age, live weight) data. Growth curve parameter-estimates and derived growth characteristics were analysed together with data relative to the slaughter value of the animals. From this study, it was seen that the estimated growth curve parameters did not procure any substantial information relative to composition. Dressing percentage showed correlation with all growth characteristics except feed intake. Of importance was also the zero correlation between age at 450 kgs and carcass value. Total feed intake at 450 kgs is correlated with percentage muscle and fat percentage, muscle over bone proportion and the meat production coefficient.

Although these results tempered much of our expectation for such apporaches, a new search has been opened as to the feasability of estimating growth curve parameters from incomplete growth data. The aim of the study is to give indications as to the data necessary to evaluate with some degree of confidence the underlying parameters. In our study, the model is thought of as

"the expected value" of the growth of an animal. We use for the moment as an example the curve W = A1 + A2 + TANH (A3 x (T - A4) for different sets of T-vectors (covering age intervals af 1,, 1.5, 2, 2.5, 3, 4, 5 years and different weighing schemes). Different "error structures" may be simulated, and the model and data may be fitted by one of several non linear least square programs.

Unless this workshop brings in hard evidence that a tackling as ours is unfruitfull, we intend to continue our research in the sense we started, i.e. given partially growth- and intake-data, we fit a (weight, age, intake)-model. For a given weight sequence (say 50, 75, 100 ...., 425, 450 kgs), the corresponding dw/dt, di/dt and dw/di -vectors are obtained, and we analyse the correspondance with carcass value taking into account some or all of the techniques and/or remarks given above.

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F. USE OF IN VIVO TECHNIQUES AND THEIR LIMITATIONS FOR COMMERCIAL MANAGEMENT AND SELECTION OF CATTLE FOR SLAUGHTER

A. J. Kempster

Meat and Livestock Commission, P.O. Box 44, Queensway House, Bletchley, Milton Keynes, MK2 2EF

Prediction of body composition on the live animal is necessary in a whole range of circumstances from the producer selecting those of his stock that are ready for slaughter, through the selection of superior sires on the basis of performance tests, to the scientist monitoring changes in body composition during growth. Research has tended to concentrate on the more complex techniques rather than on simpler techniques suitable for on-farm use, although the latter is a very important area commercially.

Efforts to develop accurate predictive techniques have been relatively unsuccessful. The precision achieved with the most sophisticated equipment has been little better than that obtained by simple fat and muscle measurements taken on the carcase and that with simple techniques suitable for on-farm use often substantially worse. To some extent this has been due to the lack of clear objectives but it is also important that there are significant problems associated with the development of accurate predictors for use on live animals. The animal is anatomically and structurally complex and is rarely conveniently unmoving like the carcase.

The techniques suitable for on-farm use are limited essentially to live weight, visual assessment and handling methods and simple linear measurements.

Live weight

As animals grow their carcase composition changes: the proportion of fat increases at the expense of muscle and bone. For animals of similar type grown contemporaneously, live weight will, therefore, normally show a high positive correlation with the proportion of fat in the carcase and, because of the close relationship between muscle and bone, a high negative correlation with the proportion of lean in the carcase.

Even in mixed breed populations with animals coming from different production systems, there is often an association between weight and fatness although the degree of correlation will be variable. Used sensibly, therefore, live weight can be a guide to carcase composition. It can be used most effectively when a sample of cattle within a contemporaneous batch are slaughtered early to establish the relationship between weight and composition.

The need for contemporaneity when using live weight to estimate slaughter point is important. The relationship between live weight and fatness is such that it will be sensitive to the way animals are fed, the environment in which they are grown and any subclinical disease which may alter their growth rate. Live weight, and its relationship with composition, is also very dependent on the contents of the digestive tract which can vary from 10 to 20% of live weight in cattle depending on the type of diet fed.

Any relationship developed to predict fatness from live weight in one set of circumstances is therefore unlikely to apply with acceptable accuracy in other circumstances.

For these various reasons it is difficult to set out guidelines: the producer should be monitoring his own performance and weight - fatness relationships. Figure 1 shows typical weight-fatness relationships for cattle on different systems of production in Britain.

Body dimensions

There has long been interest in the use of external body measurements of the live animal to predict carcase composition. While there are a number of reports of their use in experiments to record changes in growth and shape, they have not been used widely in commercial practice on farms. The early results appeared promising but were often obtained within groups of animals showing wide variation in size and shape, and interpreted only by correlation coefficients. High correlations with tissue weights were obtained reflecting variation in live weight and its association with body dimensions.

Some relationships can be established between external body measurements and skeletal characteristics (such as the weights and dimensions of bones) particularly where there is little interference by overlaying fat and muscle. But accurate estimates of soft tissues are more difficult to obtain. Little is known about the effect of variation in each tissue independently on body dimensions and distinguishing the effects of fat and muscle on shape is difficult: animals can be blocky because they have thick well-developed muscles or because they are fat.

A further problem concerns the accuracy with which the measurements can be taken. There are many reports to indicate that the accuracy involved is inadequate to discriminate between members of relatively homogenous groups of animals. Estimates of skeletal structure tend to have the highest repeatabilities, followed by measures of bone and flesh (e.g. width of the shoulders) where the skeletal structures involved help to stabilise the relationships. Estimates of soft tissue only (e.g. circumference of hind leg) are least repeatable. Taylor and Craig (1965) outlined some of the problems of obtaining reliable live animal measurements and the subject has been reviewed more recently by Fisher (1976).

Once the important effect of a large range in weight was appreciated, the results examined in this new light were disappointing. Only with a large number of measurements do dimensions add significantly to the information provided by live weight in estimating carcase composition (for example, (Green et al 1971). But even then the advantage is small and, of course the use of many measurements and prediction equations is unsuitable for on-farm use.

There has recently been a resurgence of interest in the USA in the use of measurement systems for determining the genetic merit of cattle. These systems, which include growth characteristics as well as body measurements, use advances in computer and video-technology (for example, Genetic Profiles, Arlington, Texas) and have been heavily promoted to cattlemen.

Visual assessment and handling

Visual assessment and handling methods are the live animal evaluation techniques used most commonly in practice.

A major problem in visual assessment as with linear measurements is to distinguish between muscling and fatness both of which can improve the appearance. Fatness has the effect of filling in the indentations between muscles and where they insert giving the rounded appearance of more muscular animals. Visual assessments of conformation are, therefore, likely to be more effective as indicators of muscling within a narrow range of fatness and particularly when levels of fatness are low.

Results in the experimental literature on the precision achieved with these techniques is very variable indeed, influenced particularly by the range in fatness and conformation in the group of animals examined. Picking out the very fat and lean animals is relatively easy especially when there are differences in breed and sex in the groups. But, with the limited variation which is found within breeds in improvement schemes when animals are compared at the same weight or age, the difficulties are greater. Useful reviews on the value of live animal visual assessment were published by Barton (1976) and Kallweit (1976).

Handling the animal to assess fatness can add usefully to the accuracy achieved both with visual scoring and linear body measurements, particularly if the assessor is experienced and knows what he is feeling for.

Fatness in beef cattle can be assessed (Figure 2), by varying finger pressure at four key points. The condition of the flank is also commonly used but, although useful as a guide to cattle of extreme fatness, it is less reliable in helping to assess cattle in the middle of the range. The brisket is not recommended because it is impractical to use when handling cattle under farm conditions. The cod fat may be deceptive as size and fullness are affected by the method of castration. The presence of considerable quantities of kidney fat may interfere with the assessment of the fat cover over the loin. Differences between the positions of the left and right kidney affect handling, therefore the left side of the animal, as seen from behind, should be used rather than the right.

A number of standardised systems have been developed to obtain a more precise description of a live animal by visual method. Most of the standardised systems depend on graphic or photographic standards as exemplified, for example, by the East of Scotland College of Agriculture (1976) condition scoring for cattle or the USDA feeder cattle grades. The value of these standards is that they cause the judge to concentrate his attention only on the key points. An additional advantage is that different judges in different places and at different times will give similar scores to similar animals. This allows more confidence to be placed in comparison from place to place and generation to generation.

Charles (1974) examined the measurements of the 'anal fold' of fat using calipers as a means of estimating carcase composition in live cattle. He found that the precision of carcase lean prediction was comparable with that achieved with fat thickness measurements taken over the M. longissimus on the cut surface of the carcase. There was quite a range of fatness in these data and several breed types were involved, but the technique certainly merits further study because of its simplicity.

A significant limitation of handling methods to assess fatness is that they are based largely on the subcutaneous fat cover of the animal when it is known that there are important differences between breeds in the partition of fat between depots (Kempster, 1981). Cattle which appear relatively lean by handling methods may have proportionately more fat in other depots than cattle which appear fatter by handling methods. This point was demonstrated clearly by Wright (1981) who found a range of 10 percentage units in chemical fat in the empty body as a percentage of live weight between purebred Friesian and Hereford x Friesian cows of the same fat score (body condition score).

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Figure 1. Average live weight and age at slaughter for steers of several breeds and crosses on different production systems. Typical classification for fatness and conformation using the terminology of the EEC beef carcase classification scheme.

Breeds are coded as follows :

CHxF	Charolais x Friesian
SMxF	Simmental x Friesian
F	Friesian
HxF	Hereford x Friesian
AAxF	Aberdeen-Angus x Friesian

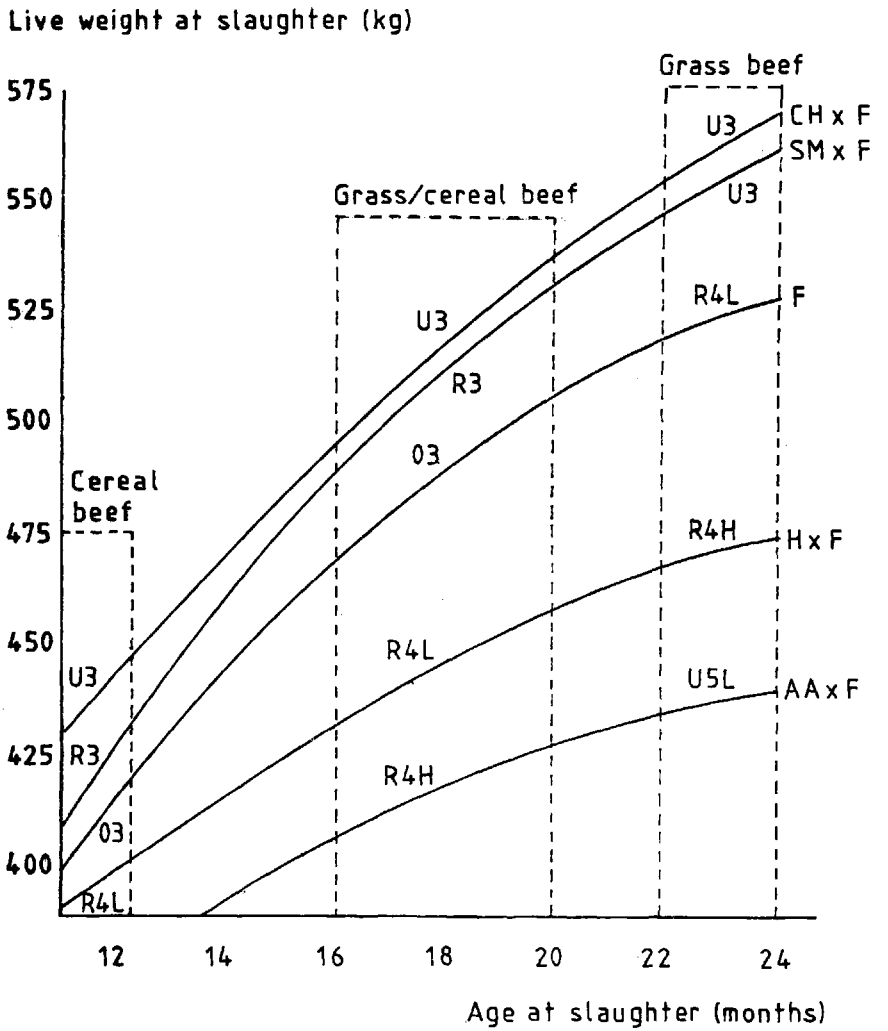
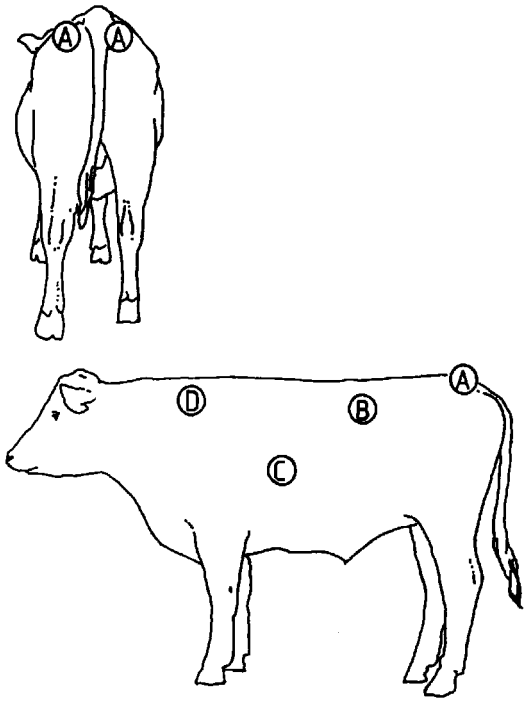


Figure 2. Recommended positions for handling beef cattle to assess fatness (MLC, 1977)



A Over the pin bones and on either side of the tail head

B The transverse processes of the loin

C Over the ribs

D The chine and the shoulder blade ridge

REVIEW OF IN VIVO TECHNIQUES FOR POSSIBLE FUTURE USE

a. SOME IN VIVO ULTRASONIC TECHNIQUES FOR POSSIBLE FUTURE USE

Peter A. Lewin*)
The Danish Institute of Biomedical Engineering
Park Allé 345
DK - 2600 Glostrup
Denmark

INTRODUCTION

The importance of ultrasound in medicine is continuously increasing, and as a diagnostic tool ultrasound is now used as an alternative to X-rays and nuclear visualisation methods.

After suitable adaptation, many of the techniques and procedures of the medical ultrasonics can conveniently be used in the breeding work in test stations including the evaluation of body composition. A list of the reviews on ultrasound techniques published recently is given in the reference section. Therefore, the aim of this communication is not to give yet another review, but to present some according to the author's opinion important developments in ultrasonic techniques, which can have bearing on the practically oriented work, e.g. in the performance testing stations.

MEASUREMENT TECHNIQUES

Measurement of tissue properties

One of the primary objectives in the breeding work is in vivo tissue characterization or evaluation of the body composition.

A comprehensive review of the current empirical and theoretical approaches to ultrasonic tissue characterization can be found in the yearly proceedings of the Conference on Ultrasonic Tissue Characterization (1). Briefly, these approaches may be divided into the following groups: echo amplitude analysis, A-scan shape analysis,

*) Present affiliation: The Industrial Acoustics Research Group, Technical University of Denmark - 2800 Lyngby, Denmark.

A-scan pattern recognition, B-scan pattern and texture analysis and bulk tissue property measurements including speed of sound, attenuation (including absorption and scattering), acoustic impedance, frequency dependence of attenuation, averaged frequency dependence on backscatter and finally angular dependence of scattering coefficients. All these approaches have been widely applied in medical (human) ultrasonics; of them especially those involving measurements of basic tissue parameters seem to be particularly suitable for estimation of animal body composition. Moreover, in vivo measurement of acoustic impedance of skin might be of potential interest in breeding work. Also, the development of the animal can, to a certain extent, be evaluated by measurement of skin thickness. This can be done with a desirable accuracy with recently developed high frequency transducers (10 MHz), which ensure a resolution of $\pm$ 0.5 mm.

Volume determination of different organs

It may also be of interest to follow the development of various vital organs in breeding cattle (livestock) and the reaction of these organs to e.g. different schemes of fasting and feeding. It was demonstrated (2) that ultrasound may be used as a tool for liver volume determination. Most likely, the procedure developed can also be used for volume assessment of other organs such as e.g. kidneys.

Whole body scanning

Whole body scanning would also be of importance in the breeding work, as such scanning would make it possible to follow the development of various organs and response of the animal to different fasting/feeding schemes. So far the radiologic methods are most frequently used for the whole body scanning. However, it was recently demonstrated that a real time acoustic transmission imaging system using a waterpath coupling technique can successfully be employed to obtain useful images (3). Part of the attractiveness of such system can be ascribed to the fact that that image presented resembles that obtained with X-ray fluoroscopy. Moreover, the system seems to be less expensive than the X-ray equipment.

INSTRUMENTATION

Novel transducers

Peformance of the piezoelectric transducers is of primary importance in ultrasonic imaging systems. The quality of the echogram or image obtained, including high spatial resolution, large field of view, depth penetration and sensitivity depends mainly on the transducers employed in the imaging system. Therefore, it is worthwhile to briefly review the latest development in transducer design and technology. In the recent years transducer arrays consisting of a row of equidistant piezoelectric elements and associated elektronics gained attention in ultrasonic applications. The basic advantage of transducer arrays is that they allow real time, two dimensional imaging of the examined part of the body. Another advantage is that the arrays allow focus to be automatically moved to any desired range along the acoustic axis by introducing appropriate delays for each element in the transmitted and received electrical signal paths. They also make possible to electronically control deflection of the transmitted/received beams. Currently, two basic types of arrays are available, namely linear (including phased arrays) and annular arrays. Additionally, two dimensional arrays based on integrated circuit technology have recently been developed. A fairly comprehensive review of the recent development in transducer design and signal processing, mentioned briefly in the next section, can be found in the yearly proceedings of the IEEE Ultrasonic Symposium (5).

Apart from the improvement in the quality of the image obtained the transducer arrays will undoubtedly improve the flexibility of the ultrasonic systems.

Compound scanners

High quality and high resolution echograms are desirable in all research work. Improved resolution, grey scale echograms can be obtained using specially developed UI Octoson scanning system (4). This system completes compound scan of excellent quality within 2 seconds only. The scanning system employs a waterpath coupling technique, in which the patient lies on the thin polythene membrane of

a water tank, in which transducers are immersed. The eight transducers are moved mechanically through an angle of 50°. It may well be that the UI Octoson scanning system, after suitable adaptation to the requirements of the test performance station, may offer an economically practical alternative to the currently employed X-ray systems for whole body scanning.

On/off-line processing

Echo signals obtained during ultrasonic investigation may be stored (digitized) in the memory of the scan convertors of the ultrasonic imaging systems for later processing. Thus, different filtering techniques may be applied to the echograms received in order to improve their image quality. This filtering and associated signal processing is frequently controlled by microcomputers, whose role in the ultrasonic imaging systems is steadily increasing.

CONCLUSION

Some of the recent advances in ultrasonic imaging outlined above seem to be applicable to in vivo evaluation of body composition in beef. On the other hand, however, the methods discussed require extensive development before they can reliably be applied to obtain valuable information relevant to the breeding research.

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b. NOTE ON ULTRASONIC TECHNIQUES FOR POSSIBLE FUTURE USE

Hans Busk
National Institute of Animal Science
Rolighedsvej 25, 1958 Copenhagen V.
Denmark

In Denmark the ultrasonic equipment Danscanner is used for measurings on both cattle, pigs and sheep. We have achieved good results with this equipment, but even then we still try to improve the accuracy of the measuring. In connection with the routine measurements we have met some problems, which we are trying to solve. We have seen i.e. that some animals are difficult to measure, and also that some breeds are more difficult to measure than other breeds. Maybe the reason can be:

1. The shape of the transducer
2. Sound velocity in different tissues
3. Intermuscular fat (fat marbling).

In an experiment in progress we investigate, if some of these questions are the reasons to the problems.

Ultrasonic equipments used for measuring of both muscle area and fat area can be difficult and complicated to use, because there are a lot of possibilities for adjustments under the measuring. Therefore, it takes time to learn to use the equipment in a right way. In the actual experiment we try to automatizise the equipment as much as possible.

In the future I think, measuring of live animals will tend into two different ways: 1) development of equipments for measuring of carcass quality on live animals, and 2) development of other equipments for special measurings. An equipment for use in routine performance test should alway be robust, easy to handle and specialized to measure a few fat and muscle traits. The other type of ultrasonic equipments should be developed for use in different research stations and can be used for organ measurements etc.

c. NOTE ON ULTRASOUND TRANSMISSION

C.A. Miles, M.O. Woods and G.A.J. Fursey
Agricultural Research Council
Meat Research Institute
Langford, Bristol
Great Britain

INTRODUCTION

Ultrasonic methods for measuring the fatness of farm livestock appear to have the greatest potential for practical applications at the present time. Ultrasound can be directed into the body to interrogate deep tissue structures, yet it is safe for the operator and animal alike; it is painless, practical to use and the equipment is portable and relatively inexpensive.

The ultrasonic pulse-echo technique has been used in the UK and elsewhere for many years to select lean boars for breeding, but its application to cattle has not been straight-forward:

(a) ultrasonic scans of cattle are not as clear as those of pigs and consequently errors of subjective interpretation are more important.

(b) much of the fat in cattle is not deposited subcutaneously and is therefore not depicted in pulse-echo analysis.

(c) it is generally thought that 2-dimensional scanning is required for cattle, and this requires photography and subsequent lengthy analysis.

Nevertheless, the technique is used, because there is a requirement for a practical method to use, and there is no better commercially available alternative.

The method of ultrasound transmission overcomes some of the problems of the pulse-echo technique yet retains many of its advantages. The method:

(a) gives a digital reading, which is directly related to fatness and does not require subjective interpretation by experienced judges.

(b) responds equally to inter- and intramuscular fat as it does to the subcutaneous depots.

(c) gives the fatness prediction on the spot and requires no subsequent lengthy analysis of photographs.

The purpose of this note is to outline the basis of the method. Some examples of its use on cattle will be presented at the meeting.

THE VELOCITY OF ULTRASOUND IN MUSCLE AND FATTY TISSUE

Muscle

The speed of ultrasound in skeletal muscle, excised from carcasses and reheated to body temperature, is about 1.6 km/s and only slight variations, of the order of a percent are discernable between samples (Table 1).

Table 1. Measurement of the speed of ultrasound in tissues excised from carcasses.

Tissue	Species	Condition	Nominal frequency f MHz	No. of carcasses measured	Mean speed and range (km/sec)	Temperature (°C)
Muscle[1)]	Cattle	Immediately post mortem	2	6	1.59 (1.59-1.60)	35
	Cattle	Refrigerated[2)]	2	7	1.61 (1.59-1.63)	37
	Pig	Refrigerated[2)]	2.5	5	1.60 (1.59-1.61)	37
	Sheep	Refrigerated[2)]	2.5	11	1.60 (1.58-1.61)	37
Fatty Tissue[3)]	Cattle	Refrigerated[2)]	2	4	1.43 -	35-37
	Pig	Immediately post mortem	2	7	1.44 (1.43-1.44)	35
	Pig	Refrigerated[2)]	2	9	1.43 (1.42-1.44)	35-37
	Sheep	Refrigerated[2)]	2	2	1.43 (1.43-1.44)	35-37

1) Various: m. semitendinosus, m. sternomandibularis, m. extensor carpi radialis, m. semi membranosus and m. longissimus thoracis et lumborum.

2) Chill temperature + 1°.

3) Subcutaneous, from back.

Although the velocity along the fibres is slightly higher than that across the fibres of post rigor muscle (the difference is about 0.6% at 37 degrees C, see Table 2), the speed appears to be relatively unaffected by gross changes in structure or by difference in physiological state. For example Miles and Fursey (1974) reported that they measured no significant change with time in the velocity across the fibres of beef M. stenomandibularis undergoing the process of rigor mortis. Cold shortening of the muscle prior to reheating to 37 degrees C also produced no significant change.

Table 2. Velocity[1)] of ultrasound measured across and along the fibres of post rigor beef m. semitendinosus at 37° C.

Number of muscles	16
Mean fat content %	2.1
Mean water content %	74.9
Across fibres km/s	1.595
Along fibres km/s	1.605
Significance of difference	***

1) Harmonic mean

The speed in finely comminuted and degassed muscle was found to be virtually the same as that measured across the fibres (Miles and Fursey, 1977). When commminuted muscle was freeze-dried and rehydrated to its original level, the speeds in both native and rehydrated tissues were the same, within the limits of the experimental uncertainty (Table 3).

Table 3. Speeds of ultrasound in two samples of minced beef muscle and in subsamples that were dehydrated and rehydrated to the same water content (74% water). Data in km/s.

Temperature °C	0	20	37
Natural muscle	1.541, 1.552	1.569, 1.574	1.593, 1.599
Rehydrated muscle	1.536, 1.548	1.571, 1.577	1.591, 1.599

Adipose tissue

Equally the speed of ultrasound in adipose tissue appears to be governed primarily by its composition and temperature. It is the

same in intact tissue, as it is in degassed, comminuted tissue (compare, for example, the data of Miles and Fursey, 1977). As with muscle, the slight differences that do exist between the speeds in different samples are largely explained by differences in chemical composition (Table 4).

Table 4. Effect of composition on the speed of ultrasound in beef muscle and fatty tissue.

Tissue	n	% variance explained	% fat ± SD
Muscle			
LD	19	71.9	5.9 ± 2.4
ST	13	42.4	2.9 ± 1.0
LD + ST	32	75.2	4.7 ± 2.4
Fatty Tissue			
IM	12	36.0	66.5 ± 5.4
SC	11	-(NS)	83.2 ± 2.6
IM + SC	23	82.4	74.5 ± 9.5

LD = M. longissimus dorsi
ST = M. semitendinosus
IM = intermuscular fatty tissue
SC = subcutaneous fatty tissue

Thus, for example, the speed in a sample of adipose tissue containing a high proportion of water and protein will be higher at body temperature than that in a tissue, which is high in fat and low in water and protein.

Mixtures of adipose tissue and muscle

There is a linear relationship between the reciprocal of the speed of ultrasonic and the proportion of fat in homogenous mixtures of comminuted muscle and adipose tissue. This relationship is similar, if not identical, with that found in the individual tissues themselves (Figure 1).

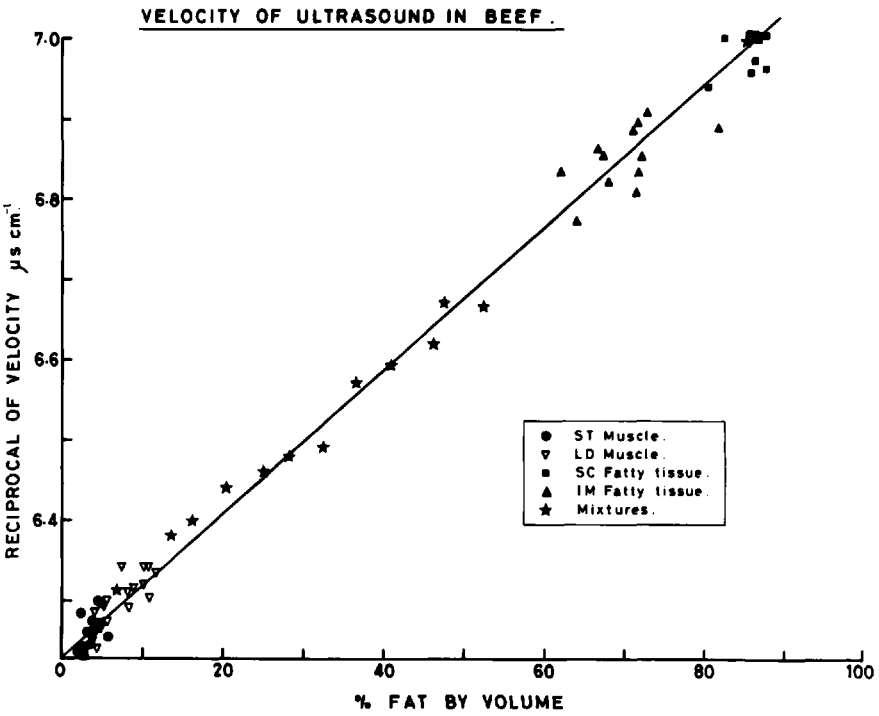

Figure 1. Speed of ultrasound transmission in comminuted fatty tissues and muscles at 37° C. The fat content determined by Soxhlet extraction with 40° to 60° petroleum spirit (as described by Hanson, 1973).

Consider a slab of meat at 37° C bounded by two parallel planes, X = 0 and X = L. Suppose the meat consists of multiple parellel layers of muscle and fatty tissue, there is being an arbitrary number of layers and these are arranged in any combination. All the tissues may be of different arbitrary fatness. The results of Fig. 1 show that in all these tissues the volume fraction of fat, Y, could be estimated from the same relation:

$$Y = \frac{b}{v} + a$$

where a and b are constants and v is the speed of ultrasound.

The mean volume fraction of fat is given by:

$$Y = \frac{\int_o^L \left[\frac{b}{v} + a\right] dx}{\int_o^L dx} = b\,\frac{T}{v} + a$$

where (T/v) is the transmission time divided by the distance travelled, a quantity that can be measured directly on living animals.

MEASUREMENTS OF LIVING CATTLE

Accurate measurements of the speed of ultrasound transmission through the soft tissue of the hind limbs of living cattle may be made by timing the passage of pulses across a known thickness of tissue, from one side of the animal to the other. Ultrasonic transducers are held in line and opposite one another using an adjustable frame. As with pulse-echo measurements the transducers must be coupled to the animal's skin with an appropriate couplant, e.g. liquid paraffin. The transit time and distance measurements are made with a resolution of $\pm$ 0.1 microsecond and $\pm$ 0.2 mm, resepctively.

In practice the overall accuracy of the measurement of 1/v is limited by the accuracy of the data for pulse transit time. This is, in the limit, determined by the frequency of the ultrasound; the higher the frequency, the better the resolution. However, attenuation increases as the frequency is increased and a compromise must be made to satisfy the conflicting interests of resolution and adequate signal/noise. For cattle of commercial size a frequency of between 1-2 MHz has been found suitable. We have generally used a nominal frequency of 1.25 MHz with transducers that are 20 mm in diameter.

PRACTICAL MEASUREMENTS ON ANIMALS

In order to utilize the relationship between the velocity of ultrasound and the composition of soft tissues in a method for ranking animals, or for monitoring changes in fatness during growth, it is necessary to define positions on the animal, which can be located reproducibly from animal to animal and from occasion to occasion.

Sites on the hind limbs have been defined relative to the position and size of skeletal features.

The reproducibility, with which measuremnts can be made at a given site provides a fundamental limit to the precision of fatness prediction. The variance of repeated measurements has been studied in various groups of animals ranging from 500 days old bulls to 70 days old calves. These data have shown that it is possible to measure the speed of ultrasound transmission in living animals reproducibly from one occasion to another and from one site on the body to another.

The actual experimental uncertainty of measurement depends on the frequency employed and the thickness of tissue. At 1.25 MHz and 40 cm the overall uncertainty is no more than $\pm$ 0.02μs/cm and this gives useful discrimination between animals and between sites even at a young age (e.g. Table 5).

Table 5 (a). Mean reciprocal velocities measured at 1.25 MHz in two groups of Hereford bulls over a two weeks period. Group 1: 400 days old, Group 2: 500 days old. Each datum is the mean of replicate measurements taken at two sessions and at two sites (B & B). Data are in μs/cm.

TAG NO.	Group 1			TAG NO.	Group 2		
	2.7.80	9.7.80	16.7.80		15.10.80	22.10.80	29.10.80
573	6.274	6.271	6.264	436	6.313		
460	6.282	6.288		562	6.320	6.318	
538	6.291			517	6.320	6.309	
548	6.310	6.323	6.307	477	6.322	6.328	6.327
541	6.313	6.290	6.291	587	6.339	6.337	6.337
519	6.319			456	6.340	6.336	
451	6.337			462	6.341	6.325	6.339
490	6.337	6.351	6.322	528	6.343	6.339	6.326
463	6.370	6.369		547	6.358		
497	6.397	6.390		495	6.377		
Significance of difference between animals		***				**	
SED		.0051				.0047	

Table 5 (b). Two way analysis of variance of the means of three measurements of the reciprocal velocity taken on four separate occasions. Measurements were made at each of two sites (B and B1) in the hind limbs of 10 British Friesian bull calves aged 10 weeks, at a nominal frequency of 1.25 MHz.

Source of Variation	Degreees of Freedom	Mean Square	F ratio	Significance
Animals	9	0.0008267	3.0	**
Sites	1	0.0057291	20.7	***
Animals - Sites Interaction	9	0.0001882	0.7	N.S.
Residual	60	0.0002766		
Total	79	0.0003982		

*** $P < 0.001$, ** $P < 0.01$, N.S. $P > 0.05$

$r.s.d. = 0.017\ \mu s\ cm^{-1}$

Correlation with carcass composition

Useful correlations have been found between the speed of ultrasound transmission in the live animal and the fatness of the carcass determined by dissection.

Acknowledgment

The Hereford bulls were supplied by the Animal Breeding Research Organization.

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d. ESTIMATION OF BODY COMPOSITION IN LIVE ANIMALS BY USE OF COMPUTERIZED TOMOGRAPHY

Harald Skjervold
Department of Animal Genetics and Breeding
Agricultural University of Norway
1432 Ås-NLH
Norway

In 1979 the Nobel Price in medicine was given to A.M. Cormack and G.N. Houndsfield for their development of Computed Tomography (C.T.), "a presentation of anatomical information by computed synthesis of an image from X-ray transmission data obtained in many different directions through the plane under consideration". Their contribution can be described as follows (Cormack 1980, Houndsfield 1981).

In his Nobel lecture Houndsfield pointed out three weaknesses by ordinary X-ray pictures (Fig. 1).

1. Because we are using a film, we do not get a numerical estimate of the quality of X-rays, which pass through the body.
2. X-rays picture cannot differ between diffeent types of soft tissue.
3. X-ray picture does not give eny depth-effect.

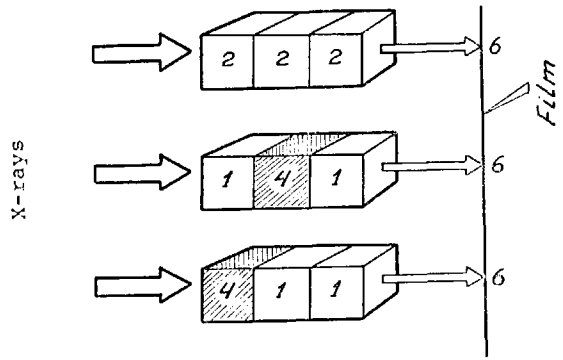

Figure 1. An x-ray photo of these three objects will show the same picture.

Instead of using film, as is done in a traditional X-ray picture, special cells (detectors) were developed in order to express the amount of X-ray beams passing through the body. It was possible to calculate the density of body tissue in different distances from the X-ray tube through letting the X-ray tube rotate around the object. This is illustrated in Figure 2.

By help of a computer connected to the X-ray unit, a system which made it possible to calculate the density in each point and thereby reconstruct the picture of a slice through the object, was developed. An example of such a reconstruction, a density matrix, is shown in Fig. 3.

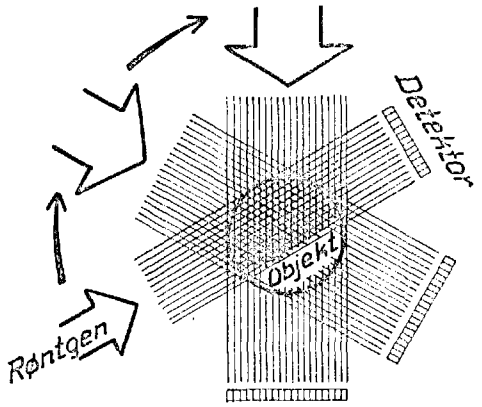

Figure 2. Illustration of the system with rotating X-ray tube.

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/7	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94
23	-15	-6	-8	-6	-12	-18	-26	-32	-40	-41	-42	-38	-40	-34	-37	-33	-34
19	-12	-9	-7	-5	-10	-14	-25	-28	-38	-42	-33	-28	-18	-19	-30	-30	-27
20	-20	-10	-7	-4	-7	-7	-16	-20	-28	-27	-23	-15	-13	-23	-32	-35	-41
30	-22	-14	-8	-10	-4	-2	-9	-20	-28	-25	-15	-11	-18	-33	-42	-44	-52
30	-22	-16	-10	-11	-4	-3	-13	-22	-25	-24	-16	-19	-24	-36	-43	-52	-55
25	-26	-16	-8	-8	-9	-6	-11	-15	-20	-16	-21	-26	-33	-39	-48	-51	-57
25	-21	-16	-9	-8	-9	-3	-4	-6	-9	-19	-22	-33	-43	-46	-49	-56	-59
14	-14	-7	-10	-11	1	1	1	5	-7	-14	-28	-39	-47	-48	-55	-60	-6
16	-11	-4	-2	1	3	3	8	-2	-5	-15	-25	-39	-46	-46	-55	-62	-6
16	-4	10	4	3	6	5	-5	-3	-12	-20	-26	-33	-43	-48	-56	-60	-5
18	-8	3	6	10	-7	-19	-27	-23	-21	-30	-34	-37	-40	-49	-56	-57	-
14	-7	-2	-6	-9	-16	-39	-45	-38	-42	-45	-41	-41	-45	-52	-61	-62	
11	-9	-12	-10	-23	-39	-49	-56	-56	-55	-54	-50	-47	-47	-52	-59	-59	
-8	-11	-17	-24	-37	-52	-59	-58	-60	-64	-59	-53	-50	-51	-55	-60	-63	
24	-26	-17	-32	-48	-54	-55	-62	-64	-65	-63	-56	-52	-52	-58	-59	-59	-
12	-41	-31	-33	-46	-54	-62	-64	-66	-67	-68	-59	-55	-56	-60	-62	-61	-
36	-50	-41	-37	-42	-52	-63	-70	-65	-66	-65	-62	-64	-59	-62	-65	-65	-6
58	-57	-54	-45	-46	-55	-63	-68	-64	-67	-66	-65	-62	-61	-64	-65	-64	-6
7	-61	-63	-55	-54	-59	-67	-64	-63	-65	-68	-69	-64	-64	-64	-63	-64	-6
0	-63	-58	-63	-57	-62	-65	-61	-64	-65	-69	-67	-69	-68	-63	-63	-66	-6
1	-67	-64	-68	-61	-66	-58	-63	-65	-69	-69	-67	-64	-66	-64	-63	-63	-
8	-70	-68	-69	-64	-62	-66	-64	-64	-66	-66	-68	-66	-64	-65	-62	-67	-
.1	-64	-66	-65	-63	-62	-64	-59	-63	-65	-68	-68	-68	-66	-61	-62	-62	-
37	-68	-63	-60	-60	-60	-65	-68	-63	-64	-66	-69	-66	-68	-64	-57	-48	-
64	-67	-66	-67	-63	-67	-65	-65	-64	-63	-66	-67	-61	-62	-60	-32	-32	-1
89	-70	-65	-67	-66	-66	-67	-65	-65	-67	-66	-59	-50	-45	-28	-20	-12	
5	-66	-66	-66	-67	-61	-67	-66	-67	-60	-57	-48	-34	-26	-11	-1	11	-5
4	-64	-67	-64	-62	-65	-65	-60	-58	-54	-40	-36	-24	-7	8	0	-3	-7
5	-64	-09	-67	-56	-62	-62	-51	-38	-25	-26	-18	1	0	-1	-3	-6	-4
6	-66	-67	-63	-61	-49	-36	-31	-18	-7	-1	4	-5	-3	-4	-6	-8	-7
3	-63	-49	-48	-39	-36	-20	-9	3	2	-1	-8	-3	-6	-7	-6	-1	-2
6	-43	-36	-20	-5	0	7	-5	-10	-5	-3	-3	-5	-1	0	2	1	-2
8	-8	-5	4	-6	-8	-7	-2	-4	1	4	-1	-6	1	-6	-6	-9	-8
3	-6	-3	1	-2	0	-1	-3	-2	-2	-7	-4		-2	-6	-3	5	-

Figure 3. The computer is calculating the density in each square and is building up a photo on the basis of these density numbers. This is an example of the density matrix of the chest of a patient. The densities around zero are water.

The computer is calculating the density in each square of less than 0.5 mm^2. The density in such a square can vary with 1000 units or more, depending upon the type of computer tomograph and the accuracy needed.

The technique was first introduced in human medicine in USA in 1973, and the first whole body scanning was done in 1974 (Hounsfield, 1980). Computerized tomography has later been an important aid in human medicine.

In figure 4 is shown the density of different body tissues. As the figure is indicating each type of tissue shows a range of CT-numbers. For example, fat tissue shows CT-values of -20 to -80, while muscle tissue shows a range of CT-numbers from +40 to + 100.

Why this wide range of CT-numbers of the same type of tissues?

Does this range of CT-numbers of fat tissues depend more or less on the water content?

Does this range on CT-numbers of the muscle tissues to some extent depend on inter- and intra muscular fat content?

These were questions weasked ourselves, and if that was part of the reason of this range of CT-numbers, it was expected that the frequency distribution of CT-numbers for different tissues would be an estimate of the energy content of the body.

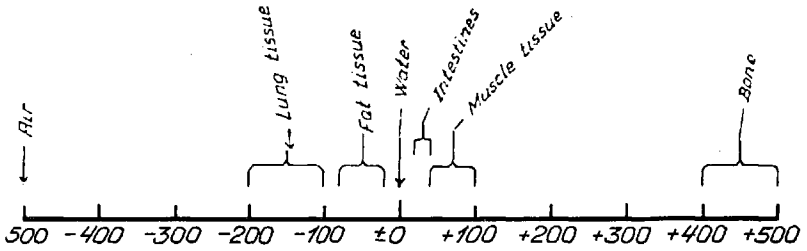

Figure 4. Density (CT-numbers) of different body tissues.

Feed efficiency is across species the far most important trait in animal breeding. In Norway feed costs represent between 1/2 and 3/4 of the cost in animal production. The difficulties in improving biological feed efficiency is connected to the problems of estimating body composition and energy content of live animals. The limited possibilities of improving meatquality is connected to the same problem.

It was therefore reasonable to see, if there through computerized tomography could be possibilities for estimating body composition.

From preliminary studies X-raying (EMISCAN/CT 5005) musculus longissimus dorsi from 40 pig carcasses with different degree of fatness, it was concluded that there were large differences in CT-numbers between muscle and fat and within fat and meat from the different carcasses.

RESULTS FROM SCANNING LIVE PIGS

Because of the very high correlation we got in this preliminary study between CT-number and energy content of fat tissues, we planned to use computerized tomography on live pigs

In co-operation with the department of X-ray photography, Ullevaal Hospital, we were able to examine 23 live pigs with an average body weight of 57.85 $\pm$ 4.62 kg. The pigs were anesthetized and then scanned just between the last ribs.

After the scanning the pigs were slaughtered, and the carcasses dissected. A separate dissection was done for a 1 cm thick slice of the carcass, where the tomographic picture had been taken. Chemical analysis of fat, protein and water of the whole carcass and the slice were taken, and energy content calculated. The regression model used in order to predict body composition on the basis of the relative distribution of CT-numbers is described by Skjervold et al. (1981).

Table 1. Prediction of body composition of pigs on basis of the relative distribution of CT-numbers from one tomographic plane. Data from scanning of 23 young pigs (Skjervold et al., 1981).

Chemical analysis of	Prediction of body composition based on CT-numbers			
	R^2-values			
	% fat	% protein	% water	Energy content
The slice	0.89	0.80	0.85	0.85
The whole carcass	0.89	0.83	0.82	0.85

The results are shown in Table 1. It wass possible to obtain a rather good prediction of body composition on the basis of the relative CT-distribution from one tomographic plane. This *in vivo* prediction was extremely good compared with results, which can be obtained with other known methods. It is surprising that the prediction is almost as good for the body composition as for the slice. However, removing from the tomographic slice CT-values, which describe intestines stomach etc., organs not included in the dissection analysis of the carcass, would of course increase the R^2-values especially for the slice.

FUTURE ASPECTS OF COMPUTERIZED TOMOGRAPHY

The results of the reported study is rather promising. However, increased accuracy is expected to be obtained when combining information from several tomographic planes thorugh the animals. Improvement in accuracy would also be expected by increasing the number of individuals, on which the linear model is based. There is obviously a need for larger scanners, which can accept larger animals.

In every feeding experiment, where one wants to know the energy content at the start of an experiment, to look at changes in body composition during the experiment etc., this new technique could be most useful. In alle stations testing of potential breeding animals, where carcass traits are involved in the breeding goal, the use of computerized tomography would largely reduce the need of sub-tests in order to record carcass characteristics through relatives. Future carcass grading at slaughterhouses is another possible use of body scanners. Hopefully, the use of this technique in animal science will increase rapidly as it is now seen in human medical science.

DEVELOPING WORK

In Norway we now get a new SOMATOM 2 from Siemens for use in animal science.

Before this equipment can be used in animal breeding much developing work has to be done.

We are planning a minute scanning of about 300 live pigs and about the same number of lambs.

After dissection and chemical analysis of these carcasses we hope to get data enough for a rather accurate estimate of:

% protein
% fat
% water
% bone
energy content

It is a question, on which place should the scans be taken, and how many scans should be taken?

A soft ware should be developed giving us these percentages at the same time as we do the scanning.

We should also like to get a tomograph, which makes it possible to scan cattle.

We are infomed that such developing work is under consideration.

Just now it is announced (New Scientist, Dec . 1981, No. 1282) a new equipment, which seems to increase the possibility of utilizing the computer tomograph in evaluating body composition. I am here referring to the socalled Magiscan. This equipment can by programming be able to identify particular items in an image, select those items and then make measurements such as:

- how many items there are
- what size do these items have
- what orientation etc.

Applications range from counting asbestor fibres in samples of air to measuring the size of the heart in constructive X-ray images, to find out, whether it contracts and expands in the right way for a healthy person.

This aim seems to be able to add to the tomograph for continuous estimation of the size of e.g. different muscles etc.

In years to come it is in this field expected a development of new technique, which can be of great importance in animal science (Vangen et al., 1981). In addition to the computer tomograph, the arrival of Positron-Emission Tomograph (Ter-Pogossian et al., 1980) and Dynamic Spatial Reconstructur (New Scientist, October 1980) are announced.

SUMMARY

Computerized tomography means a presentation of anatomical information by computed synthesis of an image from X-ray transmission data obtained in many different directions through the plane under consideration. By this technique it is possible to calculate the density (CT-number) of different body tissues in different distances from the X-ray tube. Computerized Tomography (CT) is today widely used in human medicine.

In animal breeding we are interested in estimating body composition and energy content of living animals. This is important in order to improve biological feed efficiency and meat quality. The Computer Tomograph has now been tried out for this purpose at Ullevaal Hospital in Norway. By scanning 23 anestized pigs and thereafter slaughter them and dissect carcasses, it was possible to calculate the R^2 for prediction of body composition based on the relative distribution of CT-numbers from one tomographic plane. It was possible to describe 85% variation in energy content of the living animal. This in vivo prediction was extremely good compared to what can be obtained by other known methods.

Improved technique, Computer tomographs more suited for scanning animals etc. gives great possibilities for a future development of a new field in animal breeding.

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e. MEASUREMENT OF BODY WATER IN LIVING CATTLE BY DILUTION TECHNIQUE

Laboratoire de la Production de Viande
Institut National de la Recherche Agronomique
CRZV - THEIX - 63110 BEAUMONT
France

The chemical components of the whole body of animals (water, lipids, proteins, ash) are statistically well related to each other. The water and protein content of fat free mass (FFM) is fairly constant in mature animals (Moulton, 1923). More precisely, the percentage of water in FFM decreases slowly during growth, whereas the percentage of protein increases (Robelin and Geay, 1978). The estimation of body composition by dilution technique is based on these relationships. Body water can be measured in vivo by the dilution space of a tracer, and lipids or proteins weight can be estimated from the water content of the body. The aim of this paper is mainly to describe the method of measuring dilution space of water tracer. The estimation of lipids and protein weight in cattle during nutrition experiments will be examined elsewhere (Robelin, 1981 a).

BASIS OF DILUTION TECHNIQUE

The method consists of measuring the dilution space in the body of a water tracer. The tracer infused into the body water, by way of blood or mouth, diffuses into extra-cellular and intra-cellular water compartments. During this equilibration period, the concentration of the tracer in the blood water decreases very rapidly. Once equilibrium is reached, the concentrate of the tracer (C) is the same in all the water compartments of the body (blood, extra-cellular or intra-cellular). It decreases with time (t), more slowly and according to an exponential function ($C = Co^{-\alpha t}$) (see fig. 1). The coefficients of this function (Co and α) can be determined experimentally by serial measurements of C (concentration of tracer in blood water) at different time t (hours) after the infusion. The coeffici-

ent Co corresponds to the initial concentration of the tracer at infusion time (t = o). The coefficient λ is the rate of decrease (dC/C) of the concentration of the tracer; it corresponds to the turnover rate of body water (kg/kg/hour). The dilution space of the tracer (Ds) is calculated as the ratio between the amount ot tracer infused (Q) and the initial concentration (Co) : DS = Q/Co.

Several water tracers may be used. However, it must be born in mind that a tracer should not be toxic, must not be metabolized, should be easily measurable, and must diffuse homogenously into all the volume to be measured. Among the different tracers used in various species, Antipyrene and N-Acetyl-Antipyrene (Dumont, 1958; Panaretto and Till, 1963) denteriated water (D_2O) or tritiated water (TOH) (Foot and Greenhalgh, 1970; Searle, 1970) D_2O and TOH appeared to be the most suitable. In addition D_2O seems to be preferable, as it is not ratio active.

METHOD OF MEASUREMENT OF D_2O

Infusion of the tracer and blood sampling.

In the experiments reported here, D_2O (purity 99.8%) was weighed in plastic syringes and infused into the jugular vein by way of a catheter. After infusion, the catheter was rinsed with saline and the syringes (possibly with a small amount of tracer) were tared. The amount of tracer infused was determined by the difference between the weight of the syringes before and after infusion to the nearest 0.5 g. In all cases the amount of tracer infused was appr. 0.5 g/kg body weight, to obtain a concentration of the tracer in blood water in the 500-1000 p.p.m. range. This was done at 8-9 h00 in the morning; the animals were fed 7h 00 and 15h 00.

At least three blood samples were taken at 6, 9 and 24 hours after infusion, in 30 ml plastic vials. In some animals, 4 additional blood samples were taken at 3, 12, 30 and 48 hours after infusion. Blood water was picked up by freeze-drying and the concentration of D_2O was measured by I.R. spectrometry according to the method described by Robelin (1977) and Tissier et al. (1978).

Equilibration and elimination of the tracer

The evolution of the D_2O concentration of in blood water (mean value for 62 cattle) is reported in figure 1.

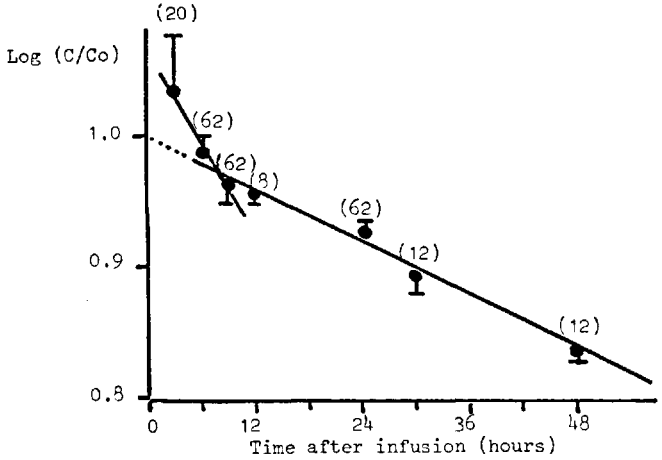

Figure 1. Evolution of D_2O concentration in blood water after infusion in cattle (the number of data are indicated between parenthesis).

During the first 6-9 hours after injection, the concentration of the tracer decreased very rapidly (1% per hour). Equilibrium was reached between 6 and 9 hours after infusion. After equilibrium the concentration of D_2O decreased at a mean rate of 0.00330 (h^{-1}). This means that the turnover rate of body water was almost 0.33% per hour, or approximately 25 kg per day for a 550 kg body weight cattle. This rate was not significantly different between Charolais and Friesian bulls (Robelin, 1981 b), or between bulls and mature dry cows (0.0033 vs 0.0036), but it varied widely between animals (from 0.0020 to 0.0050 in our population of 62 animals). Analysis of the deviations from the regression line (Fig. 1) showed that the concentration of the tracer fluctuates with the filling level of animals. In the middle of the day (9 and 30 hours after infusion), the concentration was under the regression line, whereas, just before the second meal of the day (6 hours after infusion) or in the morning (24 hours after infusion) it was above the regression line.

Consequently, blood sampling must be adequately widespread thorughout the days after infusion to remove systematic biais in Co determination. Due to the time taken by equilibration (6-9 hours), infusion must occur in the morning (8-10 h00). Two blood samplings near equilibrium (6-9 hours after infusion) on the day of infusion and two blood samplings the day after infusion (in the morning and afternoon) seem necessary. Additional blood sampling the second day after infusion could provide a more accurate determination of Co and dilution space (see later).

BODY WEIGHT FLUCTUATIONS ALONG THE DAY

The variations of body weight in 12 Charolais bulls weighing 480 kg, between 7 h00 (time of the first meal of the day), 14 h00 (1 hour before the second meal) and 18 h00 (3 hours after the second meal) were measured. The body weight increased by 6.0 kg (1.25% of body weight) between 7 h00 and 14 h00 and increased again by 6.4 kg (1.33% body weight) between 14 h00 and 18 h00. These variations result from changes in gut content, and, consequently, in total body water, assuming that the percentage of water in gut content does not vary widely as shown by Beranger (unpublished data).

Similar variations occured in our experiments on D_2O space measurement. The animals were fed at 7 h00 and were infused at 8 h00 - 9 h00. They received a second meal at 15 h00 and were slaughtered on the next morning (without any meal) at 9 h00 - 10 h00. Body weight was recorded at infusion time (BWI) and just prior slaughter (BWS). Empty body weight (EBW) was measured after slaughter. In addition, the "mean" body weight of animals, in the middle of the day of infusion (between the two meals) was estimated by regression analysis as follows: animals were weighed on two consecutive days at 14 h00, 15-16 days and 1-2 days before infusion. A regression equation was computed with these 4 weights, and the value of body weight on the day of infusion was calculated from this equation. This "regression body weight" (BWR) amounts to the theoretical mean weight of the animals in the middle of the day.

Such body weight variations on the day of infusion in 21 Charolais and 21 Friesian bulls are presented in table 1.

Table 1. Variations of body weight after infusion.

	Charolais Bulls (n = 21)		Friesian Bulls (n = 21)	
	Mean	Se	Mean	Se
EBW (kg)	332	31	267	28
BWI/EBW	1.12	0.005	1.15	0.010
BWR/EBW	1.13	0.007	1.17	0.010
BWS/EBW	1.11	0.010	1.13	0.005

Body weight increased by 1 and 2% respectively in Charolais and Friesian bulls between infusion time (2 hours after the first meal) and the middle of the day (regression body weight). It decreased by 2% and 4% respectively in Charolais and Friesian bulls between the middle of the day and slaughter time.

Similar variations in total body water could be assumed (table 2). Empty body water (EBWAT) and total body water (TBWAT) were measured after slaughter. In addition, total body water in the middle of the day of infusion (TBWATR) was calculated from the regression body weight, assuming that the percentage of water in gut content did not vary with gut fill.

Table 2. Variations of body water after infusion.

	Charolais Bulls (n = 21)		Friesian Bulls (n = 21)	
	Mean	Se	Mean	Se
EBWAT (kg)	218	19	167	15
TBWAT/EBWAT	1.14	0.006	1.17	0.006
TBWATR/EBWAT	1.17	0.009	1.22	0.010

Water in the gut content represents 14 and 17% of empty body water respectively in Charolais and Friesian bulls at slaughter; these values reached 17 and 22% of empty body weight in the middle of the day of infusion.

These results show that total body water can vary by 3 to 5% in relative value along the day and could explain the fluctuations in the tracer concentration in blood water quoted before.

RELATIONSHIP BETWEEN BODY WATER AND D_2O SPACE

Three water compartments have been considered in this analysis:

1) empty body water (EBWAT); 2) total body water measured at slaughter (TBWAT); 3) total body water estimated in the middle of the day of infusion (TBWATR). Similarly, two dilution spaces have also been considered. 1) The dilution space calculated from the value of Co estimated by regression analysis (DSCo); 2) the dilution space calculated from the concentration of the tracer 6 hours after infusion (DSC6 = Q/C6). Such method of dilution space estimation has often been used, due to the fact that only one blood sampling is needed.

Total body water estimated in the middle of the day (TBWATR) is more closely related to dilution space (either DSCo or DSC6) than the other water compartments (table 3); the residual standard deviations is near 4 kg, i.e. approximately 2% of total body water. D_2O space seems to be a poor estimate of empty body water- the residual standard deviation equals 6-7 kg or 3.4% of empty body water. This is explained by the fact that the tracer D_2O diffuses in the gut content (Smith and Sykes, 1974) and that the dilution space is not limited to empty body water.

Table 3. Regression analysis between total body water measured at slaughter (TBWAT), total body water estimated at the middle of the day (TBWATR) or empty body water (EBWAT) as dependant variables. (Y) and D_2O space calculated from estimated initial concentration^2(DSCo) or the concentration of the tracer 6 hours after infusion (DSC6) as independant variables (X) : $Y = bo + b1X \pm RSD$.

		Residual standard deviation (RSD; kg)		
		TBWAT	TBWATR	EBWAT
Charolais bulls (n = 21)	DSCo	4.52	4.40	7.19
	DSC6	5.01	4.82	6.71
Friesian bulls (n = 21)	DSCo	5.28	4.51	6.01
	DSC6	5.82	5.28	6.02

The dilution space calculated by regression analysis gives a more accurate estimation of total body water than DSC6. This is firstly due to the fact that DSCo is calculated from several measurements of tracer concentration in blood water, whereas, DSC6 is calculated from only one measurement. Another reason is that the concentration of the tracer 6 hours after infusion depends on the turnover rate of water, which varies widely between animals. So the regression method might be used to calculate the dilution space.

So, only the relationship between TBWART and DSCo could be considered. The two equations for Charolais and Friesian bulls are:

Charolais TBWATR = 0.36 + 0.971 DSCo RSD = 4.40 kg

Friesian TBWATR =-2.95 + 0.973 DSCo RSD = 4.51 kg

In these two equations, the coefficients 0.36 and -2.95 are not significantly different from zero ($P < 0.01$). So, the following equations without constant have been computed:

Charolais TBWATR = 0.972 DSco RSD = 4.41 kg

Friesian TBWATR = 0.961 DSCo RSD = 4.64 kg

The slopes for Charolais (0.972 ± 0.003) and Friesian bulls (0.961 ± 0.004) are not significantly different ($P < 0.01$), and the same equation for both breeds can be used:

TBWATR = 0.968 DSCo RSD = 4.63 kg

This equation shows that dilution space is approximately 3% greater than total body water. This value corresponds to the one found in the same conditions of measurement in lambs (Robelin, 1977).

The overestimation is partly due to the fact that the tracer is eliminated more quickly than expected by the regression ($C = Co\ e^{-\alpha t}$) during equilibration, and also to the fact that a small amount of tracer is included in organic compounds (lipids and proteins) and disappears from the body water compartments.

ACCURACY OF THE ESTIMATION OF TOTAL BODY WATER

The residual standard deviation was found to be close to 4.6 kg in 42 bulls (with a mean body water of 220 kg); it accounts for approximately 2% of body water and comes from the error in measurement of D_2O space and the error in body water measurement.

The first source of error can be analysed. The dilution space is calculated as the ratio between the amount of tracer infused (Q) and the concentration of the tracer in blood water (Co). The error in the measurement of Q is very small (approximately 0.5 g for 200 g infused), as long as no loss of tracer occurs at the level of the catheter; to prevent this loss, it is better to use sealed catheter. The error in the Co determination is more difficult to estimate; the error on the determination of D_2O concentration in one sample of blood water is close to 1% in relative value for a duplicate measurement. Theoretically the error of Co estimation by regression analysis could be estimated. Statistically it depends on the residual standard deviation of the regression $C = Co\ e^{-\lambda t}$, on the number of C determination and the range of time of blood sampling. For this reason blood sampling must be made for at least 24 hours, and preferably for 48 hours. But the main point is that this measurement of the evolution of tracer concentration should account for actual evolution of concentration as much as possible according to the fluctuations in body water during the day.

The second source of error is related to the determination of body water after slaughter. Its magnitude is difficult to estimate, due to the possible variation of gut content during the day. It should be close to 1% of body water.

CONCLUSION

Technically speaking, this method of measurement of body water is fairly good, as long as enough blood samplings, and body weight recordings are made.

Their limitations are mainly the cost of the tracer, and the need for a very good IR spectrometer to make the measurement of D_2O concentration. The usefulness of this measurement in nutrition experiments will be discussed in another paper.

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f. OTHER TECHNIQUES AND FUTURE POSSIBILITIES

C.A. Miles
Agricultural Research Council
Meat Research Institute
Langford, Bristol
England

INTRODUCTION

The purpose of this paper, the last of the symposium, is to asses briefly the potential and limitations of some methods not covered in previous presentations, namely:

Density
Dieletric methods
Methods using X-ray or gamme radiation
Hormone measurements
Nuclear macnetic resonance
Potassium-40
Neutron activation analysis

Ultrasonic and dilution methods will have been dealt with already and these are not considered here nor are methods based on the measurement of external size and shape, or visual appearance or sensory assessments by experienced judges.

DENSITY

Several studies (see the review by Miles, 1975) have shown that the correlation between the density and chemical composition of beef carcasses could be useful when a rapid, if rough, comparison between groups of carcasses is required. While measurements of density have been used successfully to assess the composition of living human bodies (see for example Brozek, Grande, Anderson and Keys, 1963) there are few, if any, reports of successful applications of the method to live cattle. The problems of measurement are not inconsiderable and corrections would have to be applied for lung volume. However, it is the variable affect of the contents of the digestive system, particularly the marked affect of any air spaces, that cast doubt on the likely accuracy of predictions based on the density of living cattle.

DIELECTRIC METHODS

The dielectric properties of biological tissues vary rapidly with frequency and are governed to a large extent by the water content. Thus,at a given frequency and temperature, the electrical properties of fatty tissue differ widely from those of muscle (Fig. 1 ; see also Ede and Haddow, 1951 and the data of several authors quoted by Schwan, 1957).

Electrode polarisation is a major problem of measurement (Schwan, 1963) and is especially important at low frequencies, less than 100 kHz. Results and conclusions based on measurements at frequencies < 100 kHz are often criticised because this effect has not been allowed for adequately. Audio frequencies would be particularly convenient to work with in commerce and a four terminal device, which largely overcomes the effects of electrode polarisation, has been developed at Torry Research Station, Aberdeen for measuring fish quality.

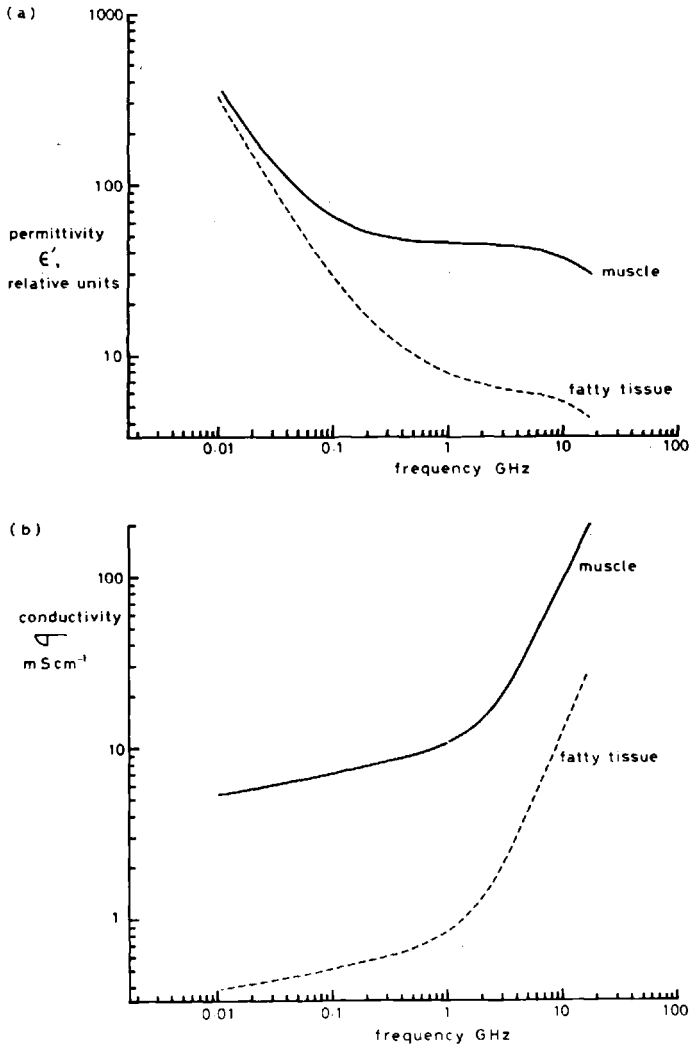

Figure 1. (a) Dielectric permittivity and (b) electrical conductivity of skeletal muscle and fatty tissue at 37 degrees C. Muscle: 79.5% water; fatty tissue: 9% water by volume. Data of Schepps and Foster (1980).

Several conductivity probes for measuring the subcutaneous fat thickness of carcasses have been developed. CSIRO have made a two terminal version (West and Andefson, 1972), while a 3 terminal system employing a differential measurement, has been produced by the Danish Meat Research Institute, Roskilde (Pedersen, Busk and Boeskov, 1972).

Kirton, Nichols and Philips, (1965) measured the reactive and resistive components of a parallel plate air capacitor with, and without a sheep interposed between the fixed plates. They found statistically significant relations between the electrical measurements and composition but it would seem that in their arrangement the air gaps would have a marked and variable effect on the readings obtained.

Eddy current testing

Induction coupling has been used in an American apparatus, the EMME, for measuring the fatness of comminuted meat, commercial boxes of boneless meat, and living pigs. Eddy currents are induced in the object by the action of an alternating magnetic field produced by a radio frequency current passing through a coil surrounding the specimen. The eddy currents themselves generate their own magnetic fields which can be picked up either by a secondary coil or by a change in impedance of the primary (Fig. 2). The effect depends on the magnitude, position and phase of the eddy currents. These factors depend, to some extent, on the composition of the specimen, since the conductivity of muscle is much higher than that of fat.

In view of the large number of assumptions, mostly unsubstantiated, that must be used to derive a relation between the EMME reading and composition, it is difficult to assess reports of statistically significant relations between EMME readings of live pigs and the composition of their carcasses (Somermuth, W.F., Kenm, T.L., Alexander, M.A., Hedrich, H.B. and Clark, J.L., 1973).

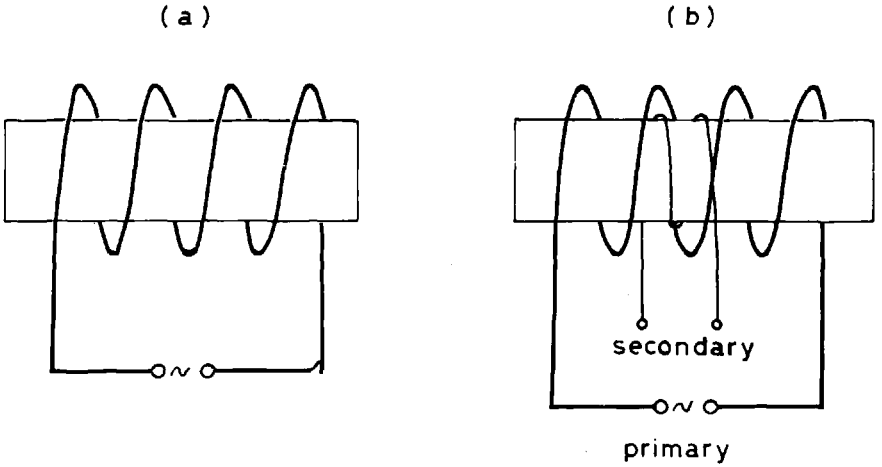

Figure 2 Diagram to illustrate the principle of eddy current testing. The specimen is placed in a coil carrying a radio frequency current. Eddy currents induced in the specimen generate their own magnetic field which can be detected with a secondary coil (Fig b) or by measuring the change in impedance of the primary (Fig a).

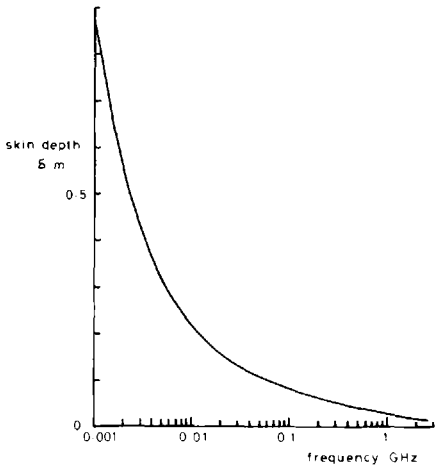

Figure 3 Characteristic depth of penetration of electromagnetic radiation in muscle. Represents the depth at which the amplitude of the wave is 1/e of its value at a plane surface. Smooth curve drawn through data of Jason (1974) and Bottomley and Andrew (1978).

Microwaves

At high frequencies (in the region of,or in excess of,1 GHz) electromagnetic radiation can be directed in a narrow beam to interrogate a region of interest. The absorption of microwaves in tissue is largely produced by its liquid water component alone and thus microwave attenuation can be useful to measure the unfrozen water content of tissue (eg Kent and Jason) and also correlates with the fatness of frozen meat (Miles, 1972). However, microwave attenuation is much too large in unfrozen aqueous tissues to give reasonable signal to noise values at large depths of penetration and therefore any possible future use of microwave measurements in livestock evaluation studies is likely to be limited to examination of tissues near the surface of the body (Fig.3).

X-RAY AND GAMMA-RADIATION METHODS

X-ray and gamma-radiation are both very short wavelength electromagnetic waves which differ in the way they are produced. X-rays are emitted from the target of X-ray tubes and have a continuous spectrum of energy with a sharp line spectrum superimposed, whereas gamma radiation is emitted from radioactive nuclei at discrete energies.

X-radiography

The application of X-radiography to fat muscle assessments in animals has never been very successful and has been reviewed by Stouffer (1963) and Brozek (1965). Conventional X-radiography works well for showing up bone structure,but is less useful in discriminating between tissues with similar attenuation coefficients, fatty tissue and muscle, for example, where detectors more sensitive than photographic film are required. More important, the technique loses information by projecting a three dimensional body onto a two dimensional film and confusion results when several structures are

superimposed on the same point on an X-ray photograph. To overcome this, multiple irradiation from a number of incident directions may be used, followed by complex mathematical analysis, to reconstruct a clear image. (Plate 1). This is called computerised X-ray tomography.

Computerised X-ray tomography

As this technique is the subject of a paper presented earlier, this section is restricted to brief comments about Plate 1. This scan was taken at 120keV using an EMI brain scanner at EMI's Central Research Laboratory. The total image area of 24 cm x 24 cm was made up of a matrix of 160 x 160 picture elements, each corresponding to a cuboid of tissue 1.5 mm x 1.5 mm x 13 mm. Coefficients representing the attenuation in each element were generated by the equipment and printed on an arbitrary scale upon which water was 0, and air and bone -500 and +500 respectively. In the example, attenuations of +50 and above appear white, and areas of -50 or less appear black. Intermediate values are spread over a grey scale. The following points are pertinent:

1. Scanning produces numerical data.

2. Scans give very clear discrimination between fat and muscle.

3. Unlike sonar, which detects boundaries, the X-ray method gives a matrix of values (i.e. a 'shaded' picture). The result is that the method not only locates areas of different tissue types, but also indicates, by the value of the attenuation, the type of tissue.

4. It has been claimed that X-ray attenuation is an index of tissue fatness. This is the basis of the Anyl-Ray, a commercial fatness tester. In so far as this is true, the technique, with suitable calibration, might be used to give indirectly the chemical fat content of the muscle and fatty tissues.

5. The technique can resolve fine structure within a given tissue type.

6. The technique will be limited by signal/noise problems as tissue thickness is increased. (Table 1)

Dual energy photon attenuation

Consider a parallel beam of photons passing through a homogeneous slab of matter made up of two components. The attenuation of the beam depends on two parameters: the thickness of the slab,and its composition. If the attenuation spectra have different forms (as they do for fat and muscle, see Fig. 4) then measurement of the attenuation at two energies allows simultaneous calculation of the thickness of the slab and its composition.

This method has been used to measure the fat content of human soft tissues (see for example Witt and Mazess, 1978) and a study of the low energy photon attenuation properties of beef is to be published shortly (Miles and Fursey, 1982). That work showed that it was possible to use dual energy photon attenuation for rapid, if rough, estimations of the proportion of lipid in mixture of beef fatty tissue and muscle. The method has the following attractive features:

1. It does not require contact with the sample.

2. It is insensitive to the presence of voids and to fluctuations in sample temperature.

3. It is rather insensitive to differences in the connective tissue content, in the fatty acid composition of the fat, and to changes in the water content of the fat-free tissue.

4. Good estimates of the attenuation in tissue can be obtained from the pro-rata sum of the mass attenuation coefficients of the elements of

Table 1 Effect of tissue thickness on signal: noise problems in computerised X-ray tomography. Calculations are based on the following values for the linear attenuation coefficients of 100 keV photons in bone and soft tissue: 0.27 cm^{-1} and 0.18 cm^{-1} respectively.

Thickness in cm	Transmitted / Incident		Photons out for 10^8 photons in:		Use
	Soft tissue	Bone	Soft tissue	Bone	
25	10^{-2}	10^{-3}	10^6	10^5	Brain scanner
40	10^{-3}	10^{-5}	10^5	10^3	Human body scanner
75	10^{-6}	10^{-9}	10^2	10^{-1}	Cattle scanner (?)

which it is composed. It is therefore possible to assess by calculation the affect of potential perturbations on the predictions.

Against these advantages must be weighed the fundamental limitations of a reduction in signal to noise as the thickness of tissue structures is increased. The method relies on the discrimination in photon attenuation that exists at low energies only, at which penetration is poor (Fig. 4).

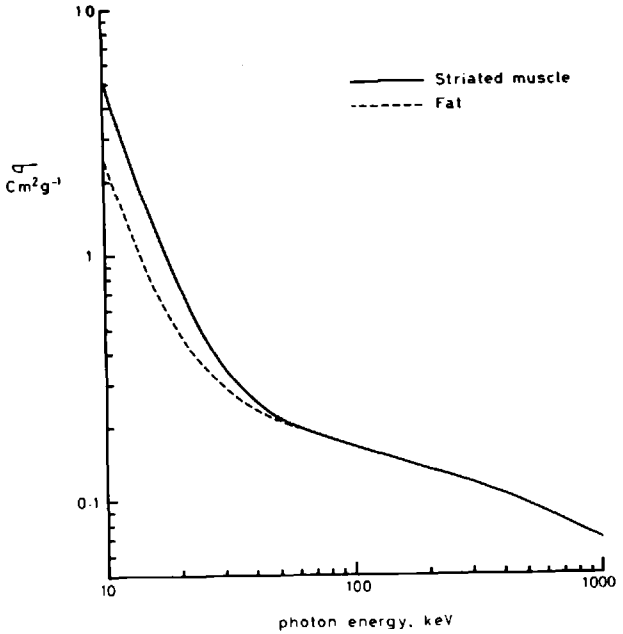

Figure 4 The photon attenuation coefficients of soft tissues are similar at energies above about 100 keV but there is useful discrimination at low energies. Curves are based on data from National Bureau of Standards (1969) and Veigele (1973).

HORMONE MEASUREMENTS

Hormones are chemical substances that are secreted by glands and which act in a specific manner on the function of other organs in the body. They play an important role in the growth and development of mammals and on their rates of metabolism (Table 2).

Insulin, for example, is secreted by the pancreas into the bloodstream where it regulates carbohydrate metabolism and influences protein synthesis. In many mammals a high insulin secreting ability has been found to be associated with body fatness and a low ability with leanness. Gregory, Lovell, Wood and Lister (1977) found, for example, that lean Pietrain pigs had a lower insulin secreting response to intravenous injection with tolbutamide, glucose and arginine than fatter Large White Pigs.

However, Gregory, Truscott and Wood (1980) reported that, whereas, in Hereford and Friesian steers, a high insulin secreting ability was associated with age-related fatness within animals, it did not correlate with differences between animals of the same age.

Poor correlations were also reported by Truscott (1980). His study of plasma concentrations of various hormones and metabolites in Friesian and Hereford cattle is summarised in Table (3).

NUCLEAR MAGNETIC RESONANCE (n.m.r.)

A recent publication (Phil Trans R Soc Lond B 289, 379-553) has reviewed the nuclear magnetic resonance (n.m.r.) of intact biological systems.

When the nuclei of certain atoms are placed in a magnetic field they can absorb electromagnetic radiation of a particular frequency. These nuclei include ^{1}H, ^{31}P and ^{13}C and n.m.r. measurements of these have been made in

Table 2. Some important hormones

Gland	Hormone	Function
Pancreas	Insulin	Secreted directly into the blood where it regulates carbohydrate metabolism, influences protein and RNA synthesis and storage of lipids.
Thyroid	Thyroxine (T4)	Regulates carbohydrate, fat, protein and mineral metabolism. Stimulates growth and maturation.
	3,5,3 Triiodothyronine (T3)	Same as T4 but more potent in regulation of growth and metabolism.
Pituitary	Growth hormone (G H)	Stimulates skeletal and muscle growth.
Adrenal medulla	Adrenaline	Stimulates increases heart rate and output. Facilitates heat production.
	Noradrenaline	Facilitates heat production.

Table 3 Correlation coefficients between % lipid in the empty body and some plasma parameters, measured in 15 Hereford and 15 Friesian steers throughout a 2 d fast at 20 months of age. (Data summarised by N.G. Gregory from Truscott (1980)).

Plasma parameter	Number of samples per animal	Across breed	Pooled within breed
Insulin	9	0.11	0.33
ITT+	7	-0.20	-0.01
Free fatty acids	14	-0.19	-0.17
Growth hormone	14	-0.25	-0.28
Adrenaline	6	-0.08	0.02
Noradrenaline	6	0.05	0.22
T_3	3	0.16	0.31
T_4	3	0.22	0.26

+ Insulin response to tolbutamide at 27 h starvation

intact biological tissues including muscle. Various n.m.r. techniques and equipment are noted in Table (4).

The most common isotopesof some elements, eg ^{12}C and ^{16}O do not give n.m.r. and low abundance isotopes have to be used for n.m.r. studies of them: ^{13}C and ^{17}O. The frequency at which absorption takes place is proportional to the magnetic field strength and in the case of protons, the constant of proportionality is 42.6MHz per tesla.

High resolution n.m.r.

Several papers (eg. Dawson, Gadian and Wilkie (1980), Ackerman, Bore, Gadian, Grove & Radda (1980))have analysed the phosphorus n.m.r. spectrum of intact muscle (frog or toad skeletal muscle (Dawson et al.) or the beating heart of small mammals (Ackerman et al.)). The phosphorus n.m.r. spectrum of intact muscle shows 5 narrow peaks: 3 derived from the nuclei of the 3 phosphorous atoms of ATP, one from the phosphorus in phosphocreatine and the other from 'free' phosphorus. Experiments have involved simultaneous n.m.r. measurements of the time course of the concentration of these components under a variety of physiological conditions, eg. oxygen starvation, contraction and relaxation at various states of exhaustion. pH was measured from the shift in the phosphorus spectrum.

Potential of high resolution n.m.r. of tissues

1. n.m.r. is a non destructive analytical method, which can be used to measure the concentration of various chemicals in intact tissues but, (a) it is insensitive and only useful for relatively high concentrations, $10^{-4}M$ at best, and (b) the resonances must be narrow and is, therefore, restricted mainly to small molecules such as ATP, phosphocreatine, sugars and adrenalin. It does not 'see' nuclei in large molecules such as DNA, RNA, large proteins or molecules fixed in the membranes.

Table 4 Some n.m.r. methods and equipment

TYPE	MANUFACTURERS	TYPICAL PRICE	TYPICAL USE
High resolution n.m.r.	Perkin Elmer Varian Nicolet Bruker Joel	up to £140k-£150k	molecules in solution eg phosphorus metabolites
High power	Spinlock	£3k and magnet + self assembly	mobility measurements
Quality control (Minispec, quantity analyzer)	Bruker Newport Instruments	£20k	solid/liquid ratios water/fat content
High power + High resolution (C x P)	Bruker Nicolet + conversions by Varian & Joel	£180k+	high resolution n.m.r. in solid materials
n.m.r. imaging (proton density mapping)	GEC[1] EMI[2]		head and body scanning in hospitals (note head scan 30s, body scan 2 mins) 128 x 128 matrix
Topical n.m.r. (High resolution in narrow region of body)	Oxford Instruments		In vivo measurements of biochemistry in organs

1. Instrument under test at a Nottingham hospital (Designed at Nottingham University, Physics Department)
2. Instrument under test at Hammersmith hospital (Designed at Nottingham University, Physics Department)

2. n.m.r. can show the biological compartment within which a chemical occurs, notably extracellular or intracellular.

3. n.m.r. can give the time course of changes in the concentrations of several components simultaneously during physiological processes. It could be used for example to measure changes in the pH and concentration of ATP, phosphocreatine and inorganic phosphate during rigor mortis, cold-shortening, thaw rigor, electrical stimulation.

4. It can be used to study molecule/molecule association equilibria.

5. Signals are affected by the chemical environment.

6. n.m.r. can be used to measure the mobility of molecules in tissue, eg. proton n.m.r. can be used to study water mobility.

Low resolution proton n.m.r.

n.m.r. can be used for very accurate measurements of the fat in small heated samples of dried meat (Nilsson and Kolar 1971; Casey and Miles 1974) or for measuring solid to liquid ratios in fats.

N.m.r. imaging

Biological tissues produce strong proton n.m.r. signals from water and fat and these have been used to produce cross sectional pictures of whole organisms including fruit, vegetables, small mammals and living human beings, using methods similar to those employed in X-ray computer tomography. The essence of the method is shown in Fig. (5). If a linear field gradient is superimposed on the highly uniform field in an n.m.r. spectrometer, the n.m.r. spectrum is a one-dimensional graph of proton density along the field gradient. A variety of techniques are employed to convert such measurements into two-dimensional images of cross sections of solid objects. These are described and reviewed by Andrew (1980).

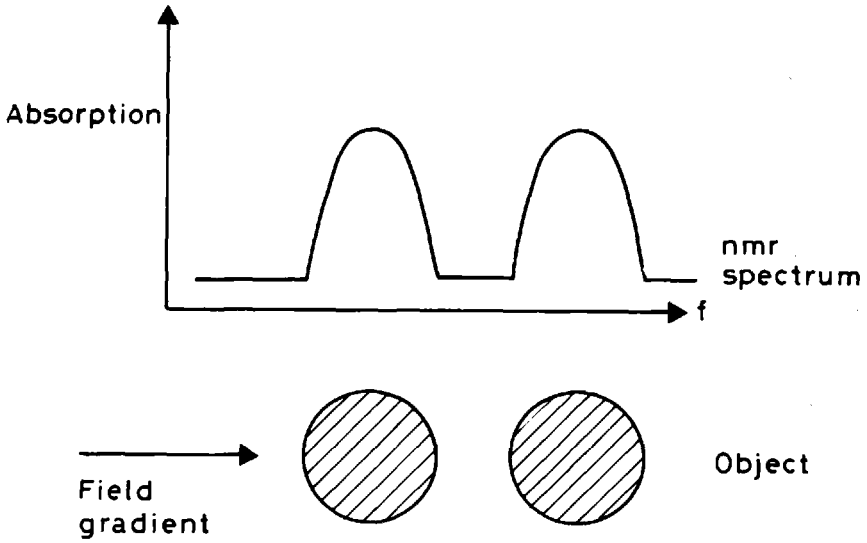

Figure 5 Diagram to show how the n.m.r. spectrum of an object in a linear field gradient is a projection of the mobile proton density along the field gradient. The principle is ued in n.m.r. imaging (redrawn from Andrew, 1980).

On the whole, the n.m.r. images of mammalian tissue that have been published so far do not appear as clear as those obtained with computerised X-ray tomography. However Andrew (1980) draws attention to the following advantages of the n.m.r. imaging technique:

(a) it is a non-invasive and uses a non-ionising radiation. It is without known hazard.

(b) the electromagnetic radiation penetrates boney tissue and deep into the body without significant attenuation.

(c) it measures the density distribution of hydrogen, the most abundant element in the body, and does so with useful tissue discrimination.

(d) the method might be applied to obtain other proton measurements such as mobility, flow and diffusion.

Topical n.m.r.

Recently it has been found possible to focus an n.m.r. spectrometer on a particular region of the living mammalian body and to obtain high resolution spectra. The extent of this region can be made large or small and its position can be manipulated. It is therefore possible to measure the concentration of important chemicals at specific positions inside the living mammalian body.

POTASSIUM-40

Approximately 0.0012% of all naturally occurring potassium is made up of the radioactive isotope ^{40}K which has a half-life of 1.3×10^9 years; the rest is comprised of the stable isotopes: ^{39}K (93.22%) and ^{41}K (6.77%) (Kaye & Laby 1973).

^{40}K emits gamma radiation at 1.46MeV. Thus the intensity of 1.46MeV gamma emission from a body can be used to estimate its total potassium content. From this figure total body protein can be estimated if it is assumed that the mass of protein/potassium is constant.

The method has proved useful in research for measuring total body potassium in human beings and animals including farm livestock and is reviewed extensively in the book 'Body Composition in Animals and Man'. The method appears to be a useful research tool but it relies on bulky and expensive apparatus and facilities which must be specially shielded from background radiation because of the low levels being measured. This restricts its use.

Uncertainties in the measurement of total body potassium arise from various sources including: random errors due to counting statistics, instability of the counting apparatus, and variations in sensitivity due to differences in body geometry and position. Lohman, Coffman, Twardock, Breidenstein and Norton (1968) reported that their standard error of an estimate of total mass of potassium in beef carcasses was 3.4% and the corresponding figure for carcass lean muscle mass was 4.2%. These figures are comparable with measurements of human beings reported by Smith, Hesp and MacKenzie (1979) to range from 3.0-3.4% potassium in two types of counter.

NEUTRON ACTIVATION ANALYSIS

Radioactivity can be induced in the body by irradiating it with neutrons. Spectroscopic measurement of this activity allows the radioactive elements to be identified and their amounts estimated. This is called neutron activation analysis. The technique has been reviewed in two recent publications by IAEA (1979, 1980) and was first used for in vivo measurements of human beings by Andersen, Osborn, Tomlinson, Newton, Rundo, Salmon and Smith (1964). Using radiation doses that were considered acceptable for

human patients, the technique has been used in medicine for estimating body sodium, chlorine, calcium, nitrogen and phosphorus (see for example Williams, Boddy, Harvey and Haywood, 1978; Haywood, Williams, McArdle and Boddy, 1981). The technique does not appear to have been used for measurements of farm livestock, although there does seem some potential for its use in research.

For convenience the principle of the method is described below for the measurement of body sodium. If an animal is exposed to neutrons some of its naturally occurring sodium, ^{23}Na, will interact with the neutrons to form the radioactive isotope ^{24}Na. This has a half-life of 15 hours and emits gamma radiation at characteristic and known energies, mainly at 2.8 MeV and 1.37 MeV. If the neutron exposure is known, or fixed, the amount of ^{24}Na induced is proportional to the quantity of ^{23}Na irradiated. Quantitative measurements of body sodium may therefore be made by comparing the intensities of the characteristic gamma radiation emitted by the body with that emitted by a phantom of known sodium content exposed to neutrons under identical conditions. Actual measurements require corrections for background radiation (eg. that from naturally occurring ^{40}K and from any fallout nuclides eg. ^{137}Cs) and for any interfering neutron activation reactions (eg. in the case of sodium analyses ^{24}Na may be induced by the action of neutrons on ^{24}Mg) and for any variations in sensitivity with size or composition. Calibration procedures have been the subject of some doubt (see for example a discussion and references quoted in Haywood et al. 1981a). When actual bodies are irradiated with neutrons radioactivity is induced in other elements which can be measured similarly. The principal reactions are given in Table (5).

Recently Haywood et al (1981b) claimed that a department which already had access to a high efficiency whole body counter for ^{40}K, could extend its investigations of body composition to include the elements phosphorus,

Table 5 Principal neutron activation reactions *in vivo* (taken from Williams *et al.* (1978)).

Element	Reaction	Gamma ray energy (MeV)	Yield (%)	Half-life (min)
Calcium	$^{48}Ca(n, \gamma)^{49}Ca$	3.1 4.1	89 10	8.72
Sodium	$^{23}Na(n, \gamma)^{24}Na$	1.37 2.75	100 100	901.8
Chlorine	$^{37}Cl(n, \gamma)^{38}Cl$	1.6 2.17	38 47	37.18
Phosphorus	$^{31}P(n, \alpha)^{28}Al$	1.78	100	2.243
Nitrogen	$^{14}N(n, 2n)^{13}N$	0.511	200	9.97

calcium, nitrogen, chlorine and sodium by the addition of a neutron irradiation facility at a cost of 75 m^2 of floor space and £28000 (1979 prices).

A transportable neutron source for Neutron Activation Analysis has been developed to study the feasibility of its use on patients in ambulances (Oxby, Oldroyd and McCarthy, 1980) and several papers have described neutron installations suitable for irradiating parts of the human body (eg. the foot: Evans, Leblanc and Johnson, 1979; the hand: Cohen-Boulakia, Mazier and Comar, 1981).

CONCLUSIONS

1. The dielectric properties of tissues are to a large extent governed by their water content and therefore at a given frequency and temperature, the electrical properties of fatty tissue differ widely from those of muscle. There is therefore potential for using dielectric measurements in body composition analyses but it is difficult to assess some of the dielectric methods used so far, eg. the eddy current and parallel plate methods, because of a number of underlying assumptions which are difficult to justify.

2. The potential for using microwave methods may be limited to examinations of tissues near the surface of the body due to high attenuation in aqueous tissues such as muscle.

3. Physical techniques for producing images of internal anatomy, eg. X-ray tomography and n.m.r., have advanced rapidly in recent years. X-ray tomography produces images of remarkable clarity in body tissues the size of the human torso but the technique may be limited by signal to noise problems in much thicker objects. The equipment is expensive and bulky.

4. Measurements of the attenuation of gamma radiation at two low energies may be used to estimate the fatness of mixtures of muscle and fatty tissue. Equipment is quite simple but the technique gives no information about where the fat is located, merely how much there is of it. Signal to noise problems are likely to be important in the measurement of thick tissue structures.

5. The intensity of gamma ray emissions resulting from the decay of unstable nuclei, either naturally occurring such as ^{40}K, or produced by the action of a neutron beam, may be used to estimate the quantities of elements such as potassium, nitrogen, calcium, sodium, chlorine and phosphorus. While neutron activation analysis does appear to have some potential for use in research, it does not appear to have been applied to the measurement of farm livestock. These techniques are particularly interesting because the measurements are specific to particular chemical elements, not indirect like many physical methods. The apparatus is bulky and expensive and there has been some controversy about calibration.

6. There is scope for the application of various n.m.r. techniques in body composition analysis. Tissues produce strong n.m.r. signals from water and fat and these have been used to produce cross sectional pictures of fruit, vegetables, small mammals and living human beings. To date, n.m.r. images do not appear to be as clear as those obtained with computerised X-ray tomography but at the frequencies employed electromagnetic radiation penetrates deep into the body with little attenuation. Topical n.m.r. allows examination of the biochemistry of specific parts of the living body.

7. Hormones play an important role in the growth and development of mammals and on their rates of metabolism. More research is needed to provide a fundamental understanding of the function of hormones in the body and their

relation to body composition. Initial simple attempts to relate plasma hormone levels to the body composition of cattle have been unsuccessful.

8. The variable affects of the contents of the digestive system, particularly the marked affects of any air spaces cast doubt on the likely accuracy of prediction of body composition from measurements of the density of living cattle.

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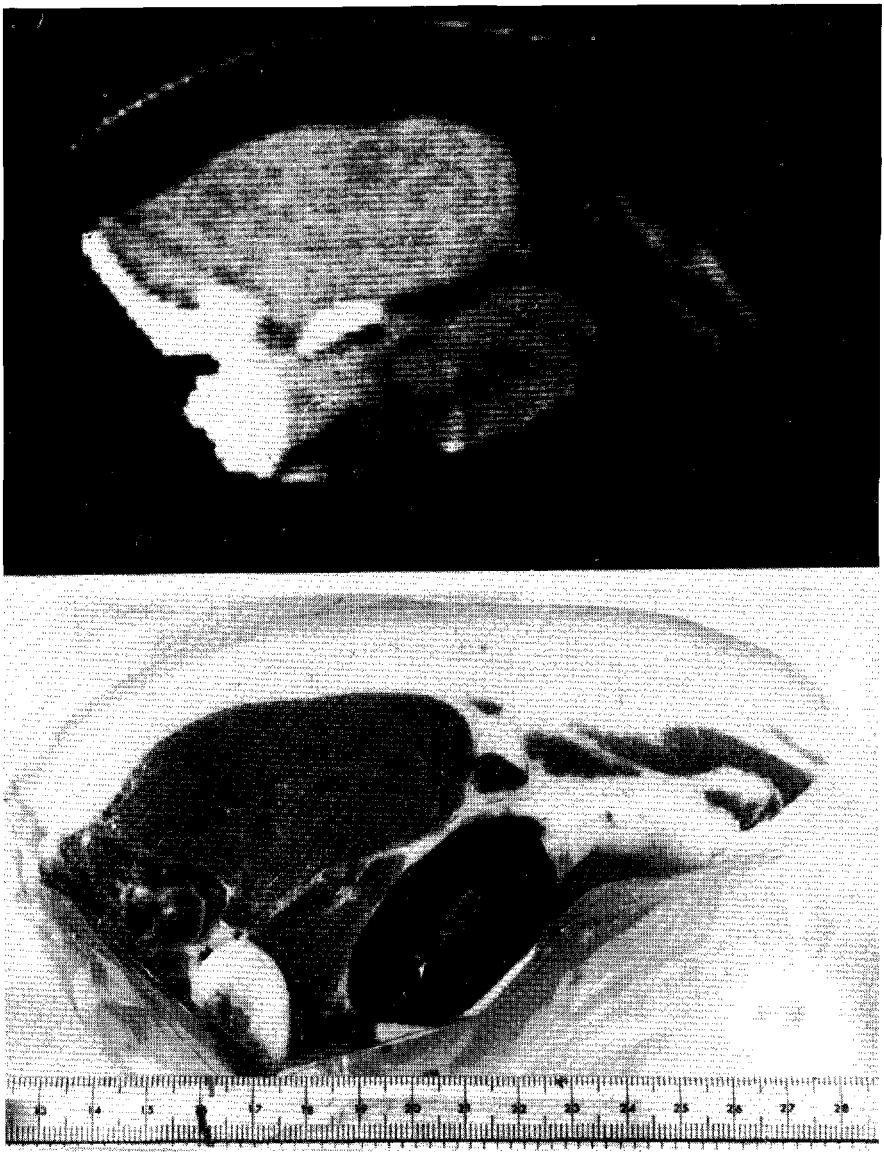

Plate 1. X-ray scan of a length of pork loin from a carcass of pork weight. Scanning was performed at the level of the first/second lumbar vertebra perpendicular to the spine. The original polaroid print was produced with different magnifications in the x- and y- directions and this has been adjusted photographically to give an approximately undistorted image in this print.

CONCLUDING DISCISSION

The papers presented in the workshop demonstrated very rapid technical development in the area of in vivo techniques. The development seems to go in two directions. One for relatively robust and simple equipments easy to apply under farm conditions; and the other for more advanced techniques to be used on testing and research stations. Examples of techniques in the first direction of development are visual assessments, body measurements and ultrasonic scanning using machines based on a relatively simple technique. Examples of a more advanced techniques are dilution space of D_2O, real-time ultrasonic scanning and computerized tomography from x-ray transmission data.

New in vivo techniques have great potential use in several areas in nutrition, breeding and management. However, objectives and problems can be different. In breeding the more advanced in vivo techniques can be used in indirect selection for dressing percentage and carcass quality among performance tested young bulls. It is not unlikely that technical development will make it possible to follow the development of various vital organs,the deposition of energy and the reaction on different fasting/refeeding systems.If this proves possible, it will increase the importance of in vivo techniques drastically. In nutritional experiments there is a great need to obtain more information on growth and development, including the possibility of being able to follow the continuous changes in histological and chemical body composition during feeding experiments. A fully developed in vivo technique could possibly be a subtitute to the very costly procedure of serial slaughtering.

In testing and comparisons of various in vivo techniques emphasis must be concentrated on factors like their value in predicting the components of interest, as well as their repeatability and reproducability. The reference basis in such comparisons will depend on the objective of the technique. Preliminary analyses have shown that some techniques have very favourable cost/benefit ratios and that considerable investment in equipment can sometimes be justified. However, further analyses are necessary, based on various assumptions.

Further development and experiments with in vivo techniques should be given high priority in the near future. However, development and testing is expensive and, since the results are of general interest in many countries, close co-ordination and co-operation between countries is recommanded. When new techniques are tested, it is concidered important to build in comparisons with one or more previously established in vivo methods. It is also important to follow very closely developments in human medicine.

The workshop recommands that a seminar is arranged on the use of in vivo techniques in breeding and nutrition experiments. Such a seminar could give further progress in the area and also add to the international co-ordination. It was agreed that a multidisciplinary seminar would be the most appropriate. The seminar should concentrate especially on further elucidation of problems and prospects of in vivo techniques in relation to breeding and selection, and of the role of in vivo techniques in relation to physiological studies and also on cost/benefit analysis. Experts on the use of in vivo techniques in human medicine should be invited to take part in the seminar and give a review and evaluation of the use of the techniques in their field.

LIST OF PARTICIPANTS

Dr. P. Allen, Meat Research Department, Dunsinea Research Centre, Castleknock, Dublin, Ireland.

Dr. B. Bech Andersen, National Institute of Animal Science, Department of Cattle Experiments, Rolighedsvej 25, 1958 Copenhagen V., Denmark.

Ir. H. de Boer, Institut voor Veeteeltkundig, Onderzoek "Schoonoord", Driebergseweg 10d, 3700 AM Zeist, Holland.

Dr. H. Busk, National Institute of Animal Science, Department of Cattle Experiments, Rolighedsvej 25, 1958 Copenhagen V., Denmark.

Mr. J. Connell, CEC Direction General de l'Agriculture, DG VI, 200 Rue de la Loi, B-1049 Brussels, Belgium.

Dr. A. Cuthbertson, Meat and Livestock Commission, P.O. Box 44, Queensway House, Bletchley, Milton Keynes MK2 2EF, England.

Professor E. Ernst, Institut für Tierzucht und Tierhaltung, Olshausenstrasse 40-60, D-2300 Kiel, B.R.D.

Dr. A.J.H. van Es, Dept. of Animal Physiologi, Agricultural University, 10 Harrweg, 6709 PJ Wageningen, Holland.

Dr. J. Jansen, Dept. of Animal Breeding, Landbouwhogeschool, Marijkeweg 49, P.O. Box 338, 6700 AH Wageningen, Holland.

Dr. Just Jensen, National Institute of Animal Science, Department of Cattle Experiments, Rolighedsvej 25, 1958 Copenhagen V., Denmark.

Professor, Dr. E. Kallweit, Institut für Tierzucht und Tierhalten FAL, 3051 Mariensee/über Wunstorf, B.R.D.

Dr. A.J. Kempster, Meat and Livestock Commission, P.O. Box 44, Queensway House, Bletchley, Milton Keynes MK2 2EF, England.

Dr. R.C. Roberts, Animal Breeding Research Organization, King's Buildings, West Mains Road, Edinburgh EH9 3JA, Scotland.

Dr. K. Kjærgaard, Danish Meat Research Institute, Maglegårdsvej 2, 4000 Roskilde, Denmark.

Dr. H.K. Krag, National Institute of Animal Science, Department of Cattle Experiments, Rolighedsvej 25, 1958 Copenhagen V., Denmark.

Dr. F. Lauritzen, National Institute of Animal Science, Department of Cattle Experiments, Rolighedsvej 25, 1958 Copenhagen V., Denmark.

Dr. P. Lewin, The Danish Institute of Biomedical Engineering, Park Allé 345, 2600 Glostrup, Denmark.

Dr. T. Liboriussen, National Institute of Animal Science, Department of Cattle Experiments, Rolighedsvej 25, 1958 Copenhagen V., Denmark.

Professor J. Matsoukas, Department of Animal Husbandry, School of Agriculture, University of Thessaloniki, Thessaloniki, Greece.

Dr. C.A. Miles, Meat Research Institute, Langford, Bristol BS17 7DY, England.

Professor, Dr.med.vet. A. Neimann-Sørensen, National Institute of Animal Science, Department of Cattle Experiments, Rolighedsvej 25, 1958 Copenhagen V., Denmark.

Mr. E. Rehben, Institut Technique de l'Elevage Bovin, 149 Rue de Bercy, 75595 Paris, France.

Dr. G. Renand, Centre National de Récherches Zootechniques, Station de Genetique Quantitative et Appliqué, Domaine de Vilvert, 78350 Jouy en Josas, France.

Dr. J. Robelin, Laboratoire de la Production de viande, C.R.Z.V. de Theix, 63110 Beaumont, France.

Dr. E. Ryan, Dept. of Agriculture, Agriculture House, Dublin 2, Ireland.

Dr. J. Scheper, Bundesanstalt für Fleischforschung, 8650 Kulmbach, Blaich 4, B.R.D.

Professor H. Skjervold, Agricultural University of Norway, Department of Animal Genetics and Breeding, Box 24, Ås-NLH, Norway.

Dr. M.T. Sørensen, National Institute of Animal Science, Department of Cattle Experiments, Rolighedsvej 25, 1958 Copenhagen V., Denmark.

Dr. Sv. E. Sørensen, Danish Meat Research Institute, Maglegårdsvej 2, 4000 Roskilde, Denmark.

Dr. G. Torreele, Leerstoel voor Veeteelt, Faculteit Landbouwwetenschappen, Rijksuniversiteit, Gent, Coupure, Links, 9000 Gent, Belgium.

Ir. R. Verbeke, Leerstoel voor Voeding en Hygiëne, Faculteit Landbouwwetenschappen, Bosstraat 1, B-9230 Melle, Belgium.

Dr. P. Walstra, Institut voor Veeteeltkundig, Onderzoek "Schoonoord", Driebergseweg 10d, 3700 AM Zeist, Holland.