INVESTIGATION ON SPECTRAL ANALYSIS OF ULTRASOUND ECHO SIGNALS FOR NON-DESTRUCTIVE ESTIMATION OF THE INTRAMUSCULAR FAT CONTENT OF THE LONGISSIMUS MUSCLE OF PIGS IN VIVO AND POST MORTEM

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Background

The intramuscular fat content (IMF) of the longissimus muscle (LD) of pigs is widely regarded as an important parameter influencing sensory characteristics of porcine meat. However, an implementation of IMF in breeding programs or payment systems would require an objective and reliable real-time procedure to non-destructively determine IMF in living pigs and carcasses.

Several studies indicate the potential of ultrasound techniques to predict bovine IMF or marbling score on living animals. Most investigations have been conducted on analysis of digitized B-mode images (Brethour [1994], Hassen et al. [2001], Kim et al. [1998]) or on ultrasonic velocity measurement (Whittaker et al. [1992], Benedito et al. [2001]).

However, conventional B-mode images use only little information from the backscattered ultrasound. Few studies have been published on the use of spectral analysis to predict the IMF content (Park et al. [1994], Abou El Karam et al. [2000]). Spectral analysis of ultrasonic echo signals has increasingly been investigated in medicine to quantitatively characterize and differentiate tissue (Topp et al. [2001], Jenderka et al. [2000], Raju et al. [2001], Watson et al. [2000], Nair et al. [2001]).

Objectives

The aim of this study was to predict the intramuscular fat content of porcine M. longissimus to non-destructively by means of tissue characterizing parameters that were calculated from unprocessed ultrasound echo-signals of a clinical B-mode-device.

Methods

34 pigs of 4 different genotypes (Duroc, German Landrace, Pietrain, Pietrain*[German Large White*German Landrace]) were fattened in order to obtain highly varying IMF, and slaughtered in 2 groups in a commercial abattoir. The ultrasound investigations were made with a clinical B-mode-device (KONTRON SIGMA 44 HVCD). The animals were insonified with a (focussed) 5 MHz center frequency mechanical sector scanner (KONTRON type Wobbler AA 5A) in vivo and post mortem at slaughter after carcass grading about 45 min post mortem without dissection of skin and backfat. Their mean carcass temperature was 40 °C. Sonogel was used as coupling medium. 3 scanning localizations (SCANLOC) were chosen with respect to the longitudinal variation of the IMF content in the LD muscle: cranial (CR; 5./6. thoracic vertebra), medial (ME; $2^{nd}/3^{rd}$ last rib), caudal (CA; 5./6. lumbar vertebra). The scanning direction (SCANDIR) was both lateral-parallel (L) and cross-sectional (Q) to the LD muscle fibers. The cross-sectional scans were made 3 times shifted about 3 cm in ventral direction each resulting in overlapping scanned areas. The unprocessed analogue HF-data, except for time gain compensation (TGC), were picked up from the B-mode device and digitized by means of a SPECTRUM PCI 2.12 A/D transducer-card and stored on a personal computer (PC). Based on PASCAL a special software was developed that allowed real time data acquisition comfortably.

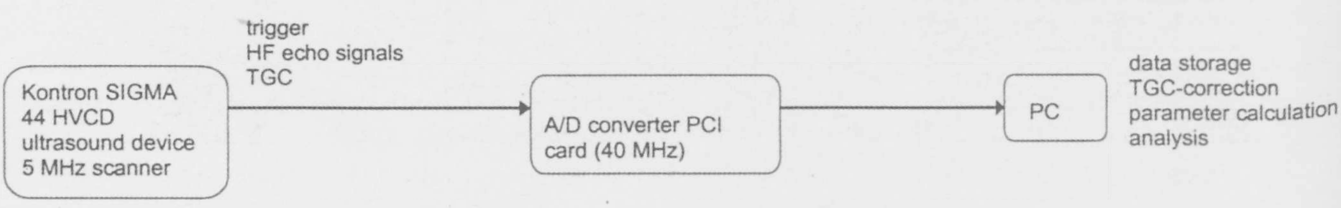


figure 1: Flow chart of the data acquisition system

The time gain compensation (TGC) that is necessary for clinical imaging, was corrected before further processing of the HF data.
From the signals stored B-mode images were reconstructed to select regions of interest (ROI) within these images. Each scan line within an ROI was windowed with a Gaussian function. The windows were overlapping 91%. The dimension of the ROI was 50 lines wide x 40 windows deep (about 8.4 cm² respectively). The gated data from the ROI were then Fast-Fourier-transformed to obtain the spectra. The spectra were cepstral-smoothed to eliminate modulations of the spectra caused by scatterers in the tissue. The smoothed spectra of each window were then averaged over the width of the ROI. From the average spectra the following parameters were calculated: frequency dependent attenuation $\alpha(f)$, frequency dependent absolute backscatter parameter Ra(f), frequency dependent relative backscatter coefficient Rr(f), power amplitude A(f), center frequency down-shift cfds, Integrated-Attenuation-Coefficient IAC, area below cepstrum CA. Parameters from 3 cross-sectional scans (Q_1, Q_2 and Q_3 respectively) were averaged as Q_{MEAN}. For determination of IMF one slice each was removed from the scanned sites of LD. The samples were homogenized within 24 hrs. post mortem and stored at –18 °C. IMF content was in duplicate determined similar to ISO 1444:1996 (E) by chemical extraction with n-hexane using Soxhlet apparatus. IMF content [%] is related to fresh matter. Statistical Analysis was done using STATISTICA software (STATSOFT, version 5.5).

Results and discussion

As expected from the genotypes, the IMF content of the pigs used in this study varies remarkably (table 1). According to earlier studies (Wicke et al. [1997] Heylen [1999]) the present results confirm the longitudinal variation of IMF in porcine longissimus muscle. IMF of LD is higher both at cranial and at caudal site compared to medial region. Overall, IMF cranial is significantly higher than IMF at medial site.
Discriminant analysis was performed to prove the usability of the parameters calculated from HF echo-signals. Therefore, the animals were divided in 3 classes according to the IMF content (FATCLASS) (table 2). Ultrasound parameters chosen for discrimination model are listed in table 3.

table 1: Actual IMF-content of LD dependent from the longitudinal site and carcass weight dependent from group (IMF extracted with n-hexane; mean ± s.d.)

group	n	cranial	IMF [%] medial	caudal	weight [kg]
A	16	1,84 ± 1,04	1,40 ± 0,86	1,63 ± 0,94	80,5 ± 7,1
B	18	1,66 ± 0,63	1,27 ± 0,43	1,45 ± 0,71	97,4 ± 14,0
A+B	34	1,75 ± 0,84	1,33 ± 0,66	1,54 ± 0,82	98,4 ± 14,1

table 2: IMF-classes for discriminant analysis (SCANLOC medial)

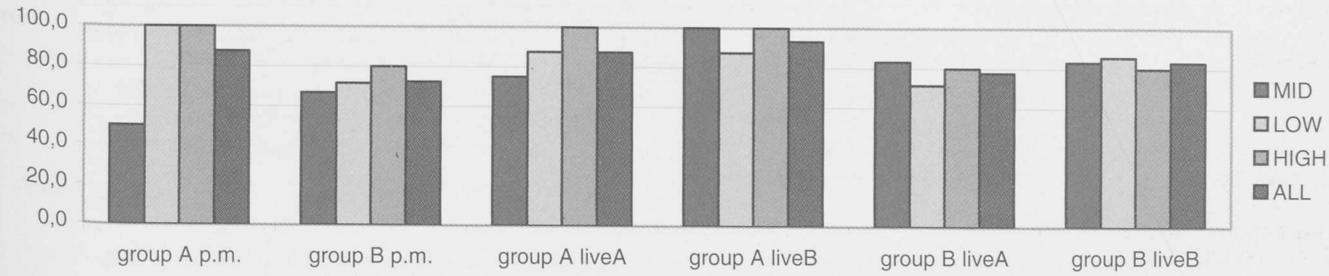
FATCLASS	IMF [%]
LOW (< mean – ½ s.d.)	X < 1,0
MID	1,0 ≤ x <1, 66
HIGH (≥ mean + ½ s.d.)	X ≥ 1,66

table 3: Ultrasound parameters in model for discriminant analysis

abbreviation	description
α(3,0)	attenuation at 3,0 MHz
Ra(4,5)	absolute backscatter parameter
Rr(4,5)	relative backscatter coefficient
A(2,0)	power amplitude at 2,0 MHz
A(4,75)	power amplitude at 4,75 MHz
CA	area below cepstrum
CFDS	center frequency down-shift
IAC	Integrated Attenuation Coefficient

The selected parameters allow correct classification of the animals in group A and B respectively to a high degree (figure 2). Parameters from both in vivo measurements and from post mortem scans discriminate at about the same level. Correct classification was higher for animals from group A, probably because of higher variation of IMF content at the medial site within this group. Within each single groups the medial site of measurement seems to be most suitable for correctly classifying the animals according to their IMF content with the model described above. However, HF-parameters from cranial and caudal site of LD show better performance concerning average correct classification when considering both groups as one due to higher variation of IMF at those localizations. Multiple regression analysis confirmed these findings.

figure 2: Correct classification in IMF-classes by means of ultrasound parameters calculated from SCANLOC medial and SCANDIR Q (Q_{MEAN}) dependent from group and moment of measurement (p.m. = single run post mortem; liveA/B = in vivo run A/B, respectively)



Conclusion

Quantitative tissue characterization with ultrasound is a promising technique. Parameters calculated from unprocessed echo signals of a B-mode system have the potential to predict intramuscular fat content non-invasively in swine in vivo and post mortem. Further research is aimed at evaluating the parameters with more sample carcasses from a commercial abattoir at different stages post mortem. Subjects to be cleared are the influence of carcass temperature and back-fat thickness on sound propagation as well as scan direction that is assumed to cause anisotropy of ultrasound parameters.

Acknowledgements

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