PE4.114 Intramuscular fat content estimation in the loin muscle of pig carcasses by ultrasound spectral parameter analysis 423.00

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Abstract— The aim of this study was to estimate the intramuscular fat content (IMF) of porcine longissimus muscle using a handheld ultrasound device with a centre frequency of 3.2 MHz. The IMF estimation method from acoustic parameters obtained by the spectral analysis of ultrasonic echo signal is described. System specific effects and sound propagation effects on the spectral analysis were analyzed and corrected. RF data acquisition was performed at a commercial abattoir at 54 warm carcasses approximately 45 min post-mortem. Muscle specific acoustic parameters, i.e. attenuation, spectral slope, midband fit, apparent integrated backscatter, and cepstral parameters were extracted from the measured rf echoes. The cepstral parameters, i.e. integrated cepstrum and cep-stral first peak value were the strongest indicators of IMF content changes (R2 = 0.36). By multivariate regression analy-sis 66 % of the IMF variation (range 0.63 to 3.16 %) could be predicted with the proposed method (RMSEP = 0.35 %). The results suggest that this method is directly adaptable for utilization in a commercial abattoir for a non-invasive IMF estimation.

Keywords— Intramuscular fat, Muscle, Ultrasound, Spectral parameters, Apparent Integrated Backscatter, Integrated cepstrum

I. INTRODUCTION

The IMF content in pig muscle is an important parameter for the eating quality of pork. To date, there is no instru-ment for non-invasive IMF estimation at slaughter, yet. Ultrasound has repeatedly been applied to predict the IMF. Ultrasonic velocity (ex vivo) was reported to have limited precision [1, 2]. Conventional B-mode ultrasonic devices were successfully used to predict bovine IMF or marbling score in living animals [3, 4] but less precise when used at pigs [5]. However, conventional B-mode images created from the envelope of the rf signal represent only the mor-phology of tissue. Additional information can be obtained by estimating frequency dependent acoustical parameters by spectral analysis of rf echos. Spectral parameters, e.g. at-tenuation and backscatter parameters provide more detailed information about tissue contribution compared to image analysis. Therefore spectral analysis of ultrasonic echo signals has become one of the prominent tools for quantita-tive characterization and differentiation of soft tissue in medical research [6, 7, 8, and 9]. However, those parameters are affected by system spe-cific effects (time gain compensation (TGC) and sound field geometry) and sound propagation effects (sound velocity and attenuation alterations in backfat and intermediate muscle) [10].

The IMF estimation from spectral parameters has been reported with a coefficient of correlation of 76 % with a RMSE of 0.36 % [11]. That study used a clinical ultrasound scanner and a large number of spectral parameters have been used in a multiple regression model for IMF estimation. The aim of this study was to develop a method to predict the IMF content of porcine loin muscle non-destructively by means of tissue characterizing parameters calculated from unprocessed ultrasound echo-signals of a commercial ultra-sound device that is already used at slaughter for backfat and muscle thickness estimation. This system was opti-mized for the acquisition of backscatter signals. Moreover, compensation function for system transfer function and intermediate medium effect corrections have been im-proved.

II. MATERIALS AND METHODS

Samples: 54 pig carcasses of highly varying IMF (0.63 – 3.16 %) were selected at a commercial slaughter plant according to carcass weight and fat to lean ratio. Mean carcass weight was 95.0 ± 7.1 kg. The ultrasonic measure-ments were made at the abattoir 45 min post mortem at suspended carcasses including skin and subcutaneous fat layers. Average muscle temperature was 38°C. Scanning localization was chosen with respect to the official site of carcass classification at 2nd/3rd last rib, 7 cm off the carcass split line. Per carcass three replicate scans were performed parallel to the split line using ultrasound contact gel. The IMF content was determined at excised loin samples by means of petroleum ether extraction with prior acid pre-treatment [12].

Experimental setup:
For rf data acquisition, the Ultra-fom300 (SFK Technology A/S, Denmark) was used.

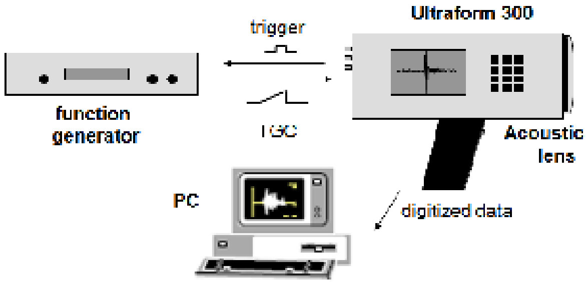

Fig. 1 Block diagram of measurement system

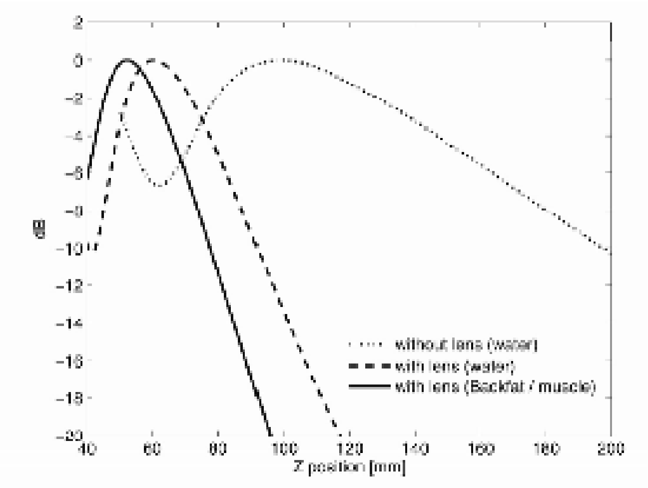

Fig. 2 Sound field plots along the depth with and without acoustic lens

It is equipped with a linear array of 64 unfocused transducer elements with central frequency 3.2 MHz with a nominal focus at 100 mm. In order to acquire desired rf signal from the muscle region, some hardware modifications had to be implemented. An acoustic lens was attached in front of the transducer to focus the sound in the central part of the mus-cle region (~ 55 mm) (Fig 2).

TGC was adjusted by a func-tion generator (HAMEG HM 8150) to optimize the signal to noise ratio over the entire depth to the muscle/rib boundary (Fig 1). After hardware modification, the centre frequency is 2.7 MHz and corresponding -6dB frequency bandwidth ranges from 2.1 MHz to 3.5 MHz. The rf data from all 64 elements were digitized with a sampling frequency of 10 MHz and stored on an PC. The effect of the TGC was cor-rected prior to any kind of spectral analysis.

A procedure was developed to correct the system specific effects and to determine the tissue acoustic parameters. For several gaus-sian time windows along the depth of the scan lines in a region of interest (ROI), the logarithmic power spectra were calculated.

The power spectra all 64 elements were aver-aged.

Then, system and sound field effects were corrected by subtracting from the averaged logarithmic spectra a ref-erence spectrum (obtained from a plane reflector positioned in a water bath the same depth). Finally, the attenuation of the overlaying fat tissue was compensated. Sound field correction: The direct measurement of a sound field for a particular transducer inside the carcass is not possible, so commonly measurements in water are car-ried out. However, water is not a scattering medium, its attenuation is much lower than that of biological tissue, and the sound velocity is not necessarily equivalent to the tissue. Therefore, the measured sound field in water is only an approximation of the real sound pressure distribution. For sound field correction verification, a tissue mimicking phan-tom with known acoustic parameters was used.

This phan-tom is made of graphite powder immersed in agar. The phantom was investigated using the same device settings as for the muscle measurements and spectral analysis was carried out with sound field and intermediate medium at-tenuation compensations. The apparent integrated backscat-ter amplitude (AIB) was estimated as a function of depth (-6dB range). For a valid sound field correction, AIB is sup-posed to be constant along the depth. Due to the curvature of the focused beam before and after the focal plane, AIBs were higher in the regions below and above the focus posi-tion (Fig. 3a).

This sound field deviation was corrected from the known phantom's normalized AIBs deviation along the depth (Fig. 3b). The position of the reference spectrum for the corresponding gated signal was determined from the backfat and muscle SOSs as given in Eq. (1). The speed of sound in muscle of 1620 m/s was obtained from [13].

$$z_{ref} = d_{BF} + (TOF_{Gateposition} - TOF_{BF/Muscle}) \times v_m / 2$$

The linear correlation between thickness, and SOS, of backfat [13] was used to estimate backfat SOS from the automatically detected backfat time of flight (TOF) from the Ultrafom300 data using an iteration method. The parameters used for the characterization of the IMF are summarized in Table 1.

Muscle attenuation:

For muscle attenuation estimation, the power spectra were calculated from gated rf signal using a sliding window (gate length: 2 pulse duration, 50 % overlap) within ROI. The sound field correction was done by normalizing the muscle spectrum with their corresponding modified reference spectrum as given in Equ. 2.

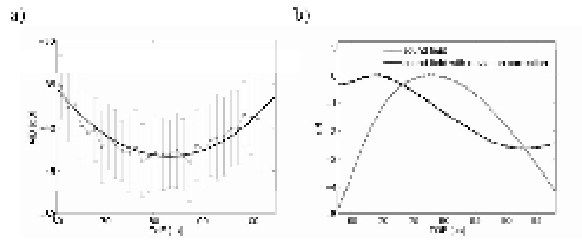

Fig. 3 Sound field correction, a) AIB in phantom before deviation correction and b) sound field with deviation correction

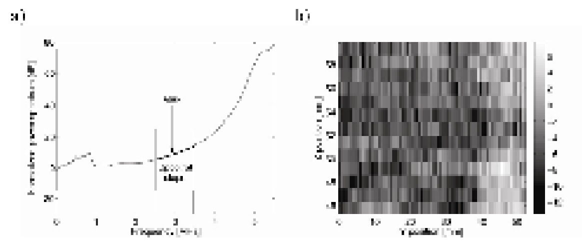

Fig. 4 Apparent integrated backscatter estimation, a) spectral slope and midband fit estimation and b) AIB distribution in muscle ROI

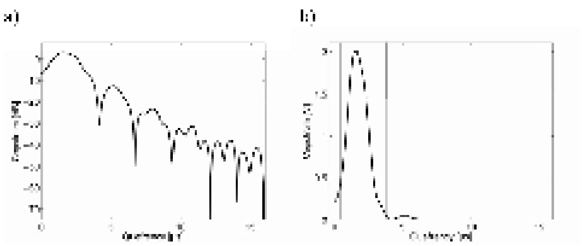

Fig. 5 Cepstral parameters estimation, a) logarithmic and b) linear cepstrum plots

$$\langle S_{cor}(f,z)\rangle = \frac{\langle S_m(f,z)\rangle}{\langle S_{ref}(f,Z)\rangle}$$

The attenuation in muscle is independent on the intermedi-ate tissue effects. The logarithmic spectral amplitudes ver-sus depth position slopes (dB/cm) were calculated for dis-crete frequencies from 2.5 MHz to 3.5 MHz. Linear regression was applied between discrete frequencies and their corresponding amplitude-depth slopes. The slope of the linear regression provides the attenuation, in dB/MHz/cm. 15 sub ROIs within a muscle region of 54 x 26 mm were always selected to get sufficient data for the amplitude versus depth position slope estimation.

Spectral parameters:

To estimate the backscatter prop-erties of tissue within a ROI it is necessary to compensate for the attenuation of the intermediate tissue (tissue between transducer and ROI). ROI size for backscatter properties estimation is 54 x 15 mm (-6dB range size along the depth). The normalized power spectra were estimated as described above with intermediate tissue attenuation compensation. Then, the AIB was estimated by taking the integral of the logarithmic compensated power spectrum within the frequency bandwidth of the transducer.

$$AIB = \frac{1}{\mathrm{V}f}\int_{\mathrm{V}f} 10\log_{10}\langle S_{comp}(f,z)\rangle df$$

This was done for all signals along the element positions and depths within the ROI. This yields the AIB distribution within the muscle region (Fig. 4b). Linear regression analysis was applied to the mean normalized spectral data of the entire ROI. Backscatter power spectral slope (BPSS), the slope of the linear regression and midband fit (MBF), i.e. the value of regression fit at the centre frequency, were estimated (Fig 4a).

Cepstral parameters:

For the cepstrum parameter calcu-lation, the normalized power spectra were estimated like before with a sliding window length 5 pulse duration and overlap 90 %. The cepstrum (Fig 5) was calculated by taking the FFT of the logarithmic power spectrum within the frequency bandwidth of the transducer. Prior to the FFT the power spectrum was preconditioned by subtracting a reference spectrum, as described before, and by removing DC and linear components. The cepstrum parameters used for IMF estimation are, the cepstrum first peak (CFP), cor-responding quefrency (CFPP) and integrated cepstrum (IC) for time range 0.5 – 4 µs (Equ. 4).

$$IC = \frac{1}{\mathrm{V}\tau}\int_{\mathrm{V}\tau} \mathrm{FFT}(10\log_{10}\langle S_{comp}(f,z)\rangle)d\tau$$

III. RESULTS

The IMF of the loin samples under investigation ranged from 0.63 – 3.16 % (1.26 ± 0.58 %). They reasonably rep-resent the commercial pig populations. To investigate the relation between the acoustical parameters and the IMF, acoustic parameters of three replicate measurements per carcass were averaged. Results of linear regressions analysis are given in Table 1. Highest correlations were observed for the cepstral pa-rameters (Linear CFP and IC; R2 > 0.3). It should be noted that these parameters are independent of the any intermedi-ate mediums effect compensation. Cepstral parameters alone predicted 38 % of the IMF variation (RMSE = 0.46 %). Moderate correlations to IMF were ob-served for AIB, its variability within the evaluated ROI, and MBF.

Table 1 Linear correlation coefficient between IMF and acoustic parameters. The contributing parameter for the multivariate IMF prediction model is written in bold letters.

Parameters	R^2
Backfat thickness [mm]	0.09
Muscle attenuation [dB/MHz/cm]	0.07*
Spectral slope [dB/MHz]	0
Midband fit [dB]	**0.18***
Apparent Integrated Backscatter [dB]	**0.17***
Apparent Integrated Backscatter std [dB]	**0.12***
Linear Cepstrum first peak [V]	**0.32***
Linear Cepstrum first peak position [µs]	0
Integrated Cepstrum [V]	**0.36***
Log Cepstrum first peak position [dB]	0.15*
Log Cepstrum first peak position FPP [µs]	0

* significant at the 0.05 level

Multiple stepwise regression analysis to estimate IMF from a combination of acoustic parameters was applied. With the parameters selected (Table 1) the multiple R^2 was 0.66 yielding an average prediction error (RMSEP) of 0.35 %.

IV. DISCUSSION

Ultrasound B-mode image analysis techniques have re-peatedly been shown to be feasible for non-destructive pre-diction of IMF content at beef but less precise when used at pigs [5]. Spectral analysis of rf signals is supposed to pro-vide additional information on tissue composition. In an earlier study [11] we reported the use of a sophisticated medical ultrasound scanner to predict the IMF at pork loin. With a high number of spectral parameters a multiple R^2 of 0.58 was obtained (RMSEP = 0.36 %). In the present study, using a modified hand held device used for pig carcass classification the IMF estimation has been increased by improving the system specific defect corrections compare to the previous study. Instead of using the fixed value for the backfat correction, the backfat thick-ness and speed of sound are predicted from the time of flight measurement using an iteration method. The number of spectral parameters in the model is remarkably reduced.

V. CONCLUSIONS

Non-destructive IMF estimation using a modified hand-held device and ultrasound spectral analysis of rf data ob-tained at pig carcasses in a commercial slaughter plant is described. Multivariate regression analysis yields an aver-age prediction error of 0.35 % (R^2 = 0.66). System specific corrections, TGC and sound field were analyzed at hot car-cass (38°C). Medium dependent effect correction has been improved by calculated backfat parameters from the ultra-sound spectroscopy rf data itself. The results suggest that the proposed method is feasible for non-invasive IMF esti-mation.

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