Characterization of Porcine Muscle Tissue Using Ultrasound Time-Domain Correlation Techniques

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Abstract: The Ultrasound Time-Domain Correlation (UTDC) technique involves the determination of a similarity factor, the correlation coefficient. For this application, UTDC was used to calculate the maximum correlation coefficient between RF echo signals of porcine muscle tissue obtained at different times and for different echo spacings. The porcine muscle samples were procured from a slaughterhouse and data acquisition began within 1.5 hours post mortem. The echo signals were obtained with a customized ultrasound data acquisition system and analyzed using a 486 PC. The results indicated that observed trends in the correlation coefficient could be used to determine muscle activity post mortem and when this activity stoped, approximately 10 hours post morem. This paper presents a explanation of the methods used and the results obtained.

INTRODUCTION

Previous research has successfully utilized the ultrasound time-domain correlation (UTDC) technique to estimate blood flow velocity [1]. This technique is now being employed to determine physical changes occurring in porcine muscle post mortem [2]. UTDC analysis involves the determination of a correlation coefficient which is calculated using ultrasonic echo signals acquired at different times post mortem. The correlation coefficient quantitatively describes the similarity in shape of the echo signals. Values of the coefficient vary between 0 and 1, where one indicates echoes identical in shape and zero indicates total dissimilarity. Observed trends in the correlation coefficient can be used to compare post mortem muscle behavior between species, as well as supplementing the information known about the processes of rigor mortis.

METHODS

Porcine loin samples were obtained from the UIUC slaughterhouse, vacuum packed in plastic wrapping and transported to the Bioacoustics Research Laboratory. The individual samples were secured to an ultrasound absorbing material SOAB in a measurement tank containing distilled water, shown schematically in Fig. 1. Data acquisition was initiated within 1 and 1/2 hours after expiration of the animal and was performed at room temperature (23° C). The sample was imaged with a modified ATL MK500 ultrasound imaging system, consisting of the ATL Imager 860C and the ATL multifrequency 724B transducer, operated at a center frequency of 4.5 MHz and served as both the ultrasound source for the sample insonification and receiver of the reflected echoes.

The ultrasound transducer was clamped as shown in Fig. 1, with the transducer head slightly submerged in the water. The MK500 was operated in M-mode during data acquisition, which freezes the transducer beam along a selectable A-line. The A-line was positioned near the center of the sector scan field and the cursor was positioned on the surface of the tissue as shown in Fig 1. The MK500 was modified such that the RF echoes can be tapped and digitized at a point following TGC and corresponding physically to the position of the cursor in the display. The digitization was performed by a custom-built 50 MHz A/D system [3].

RF echo signals were digitized at a rate of 1 per minute during the first 3.5 hours post mortem and then 1 every ten minutes from 3.5 to 24 hours post mortem. For each data acquisition 4096 samples were taken corresponding to a depth of 6 cm. The transmitted ultrasonic energy level was adjusted to obtain the maximum dynamic range of the A/D converter. The digitized echo signals were stored on the hard drive of a 486 PC for later analysis.

The same experimental procedure was performed using a biologically inert material, a sponge. The sponge was secured to the SOAB and remained in the tank of distilled water for 24 hours before imaging.

Analysis

The echo signal analysis involved the computation of the correlation coefficients and finding of the shift at which the correlation coefficient was maximized. The shapes of the echo signals are related to the changes that occur in the sample as a function of time, which can be due to structural changes, muscle fiber movement or overall movement. The correlation coefficient is an index of this change. To isolate spatial shifts of the echo signals due to axial motion with respect to the fixed

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transducer, the second echo signal was shifted with respect to the first echo signal and the correlation coefficient was calculated at each shift until a maximum value for the correlation coefficient was found, as shown in Fig. 2. In Fig. 2, E_n and $E_{n+\Delta}$ are the digitized echo signals acquired at n minutes post mortem and at n+Δ minutes post mortem, respectively, s is the shift in data points of the second echo signal with respect to the first echo and $\rho_n(\Delta,s)$ is the value of the correlation coefficient for spacing Δ and shift s. The delta values used for the echoes for the 1 minute echo spacings were 1 minute, 5 minutes, 10 minutes, 30 minute and 60 minutes, and delta values for 10 minute echo spacings were 10 minutes, 50 minutes, 100 minutes, 300 minutes and 600 minutes. The range of the shifts for s, varies from s_{start} points back in time (with respect to the start of the echo) to s_{end} points past the start of the echo as illustrated in Fig. 2. The determination of the maximum values of the correlation coefficient are also shown in Fig. 2, where the shift at which the maximum value of the correlation coefficient ρ_{max} (Eq. 1a in Fig. 2) is found is defined as $s = s_{max}$. For this analysis 1024 points of the 4096 points were utilized. Thus, the total number of points used in the calculation (correlation range in Fig. 3) is equal to $1024 - s_{start} - s_{end}$. Assuming a speed of sound in the sample of about 1560 m/s, the 1024 point sample length in the tissue was estimated to be about 1.6 cm.

After several sets of sponge data were acquired, the correlation coefficients from the different sets, at specific deltas, were averaged together according to the expression

$$\rho_{avg}(\Delta,n) = \sum_{q=1}^{N_{SETS}} \frac{\rho_{qmax}(\Delta,n)}{N_{SETS}} \qquad (2)$$

where N_{SETS} is the number of individual correlation data sets being averaged.

RESULTS

Sponge

The sponge analysis yielded correlation coefficients (Eq. 1 in Fig. 2) of near unity for all of the deltas except 300 and 600 minutes. Deltas of 300 and 600 minutes yielded values between 0.9 and 0.8, respectively, as shown in Fig. 3. The shifts recorded for the maximization of the correlation coefficients were approximately 0.00 for all deltas, as shown in Fig. 4. The average of two sets of data (Eq. 2) yielded correlation coefficients near unity for all deltas except 300 and 600 minutes where it remained at approximately 0.90 for all time.(Fig.5)

Porcine

Two examples of typical porcine results, are shown in Fig. 6 through Fig. 9. In Fig. 6, the values of the correlation coefficient oscillated around 0.25, for all deltas greater than 30 minutes, until approximately 8 hours after death when the coefficient began increasing, reaching 1.00 after 10 hours. Delta of 10 minutes oscillated around 0.75 until 8 hours, then increased to 1.00 at 10 hours. Deltas of 1 and 5 yielded coefficients approximately equal to 1.00 for all time. In Fig. 8, the correlation coefficient for all the one minute spacings started near 1.00 decreasing to approximately 0.25 at 3 hours for deltas of 10, 30 and 60 minutes. For the 10 minute spacings the correlation coefficient for all deltas except 10 minutes, oscillated around 0.25 until approximately 8 hours after death when it increased reaching 1.00 at 10 hours. For the delta of 10 minutes the coefficient started at 1.00 decreased to 0.50 at 2 hours and then increased to 1.00 at 5 hours.

In Fig. 7, the shifts for the porcine data sample remained at 0.00 for all deltas with one minute sampling spaces. For 10 minute spacings the shifts oscillated between -1.0 μs and 0.50 μs until 10 hours post mortem when the shifts became near zero μs. In Fig. 9, for one minute spacings the shift started at 0.00 for all deltas and then began oscillating between -1.0 and 0.50 μs for deltas of 30 and 60 minutes at 3 hours. For the 10 minute spacings the shift varied between -1.00 and 0.50 μs until approximately 5 hours when it became zero.

DISCUSSION

The experiment was performed on an inert sponge to evaluate the stability of the data acquisition system and to identify any artifacts. The plots of the correlation coefficient and the shifts from the porcine experiments were compared to the same plots for the inert sponge and with each other to determine two properties: (1) When the sample stops changing and (2) If this time varies from animal to animal. The sponge correlation data sets were averaged to obtain a general trend of the correlation coefficient.

The RF echo shifts recorded could correspond to movement of the muscle fibers or a jitter in the cursor. By comparing Fig. 7 and Fig. 9 with Fig. 4, the conclusion can be drawn, since the shift in Fig. 4 is zero and the sample is immobile, that the shifts are most likely due to the movement of muscle fibers. In a tissue post mortem, the thin and thick muscle fibers contract and expand as the nerve cells die, yielding positive and negative shifts (Fig. 7 and Fig. 9). As the ATP in the sample is used up, more and more of the fibers remain contracted until after a period of time, 10 hours (Fig. 7 and Fig. 9), the muscle fibers remain contracted and the shifts become zero.

The correlation coefficient is an index of the similarity between two sets of values, the digitized echo signals. A low value corresponds to two digitized echo signals that

have very different shapes. Since neither the water nor the sample is moving, an explanation for the low coefficients before 10 hours, (Fig. 6 and Fig. 8) can be the same muscle activity as described above. When the fibers become immobile the digitized echo signals become identical and the correlation coefficient becomes near unity (Fig. 6 and Fig. 8)

CONCLUSION

From the results obtained, it appears that finding the shift corresponding to the maximum correlation coefficient and the calculation of this correlation coefficient can be used to determine the activity of muscle tissue post mortem and when the activity stops, rigor mortis. Future experimentation and analysis of existing data will include UTDC analysis of different species as well as determining the effect of pH and temperature.

ACKNOWLEDGEMENT

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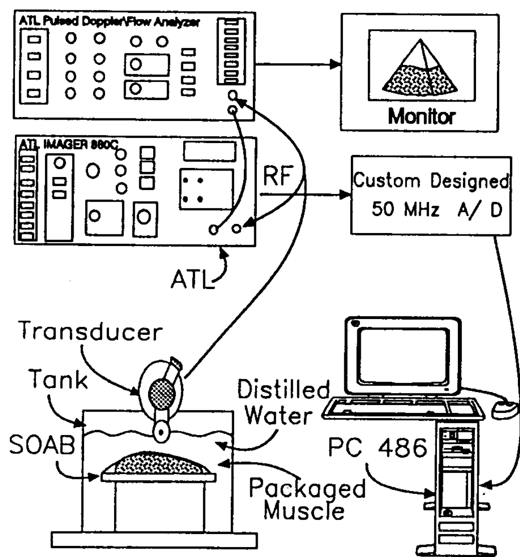
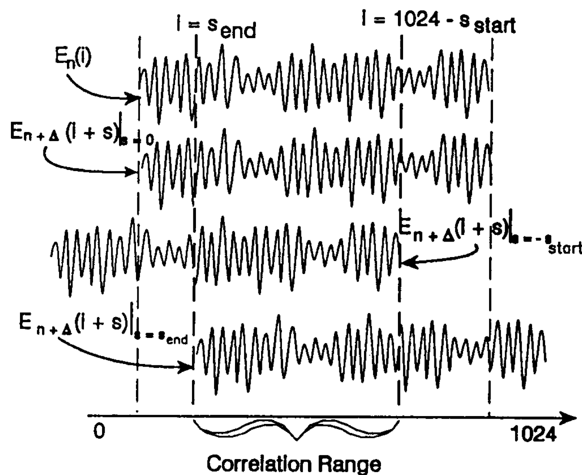


Figure 1: Data Acquisition System



$$\rho_n(\Delta,s) = \frac{\sum_{I=s_{end}}^{1024-s_{start}} E_n(I) \times E_{n+\Delta}(I+s)}{\sqrt{\sum_{j=s_{end}}^{1024-s_{start}} [E_n(j)]^2 \times \sum_{k=s_{end}}^{1024-s_{start}} [E_{n+\Delta}(k+s)]^2}} \quad (1)$$

$$\rho_{max}(\Delta,n) = \max[\rho_n(\Delta,s_{start}),\ldots\ldots\rho_{n+\Delta}(\Delta,s_{end})] \quad (1a)$$

Figure 2: Calculation of Correlation Coefficient

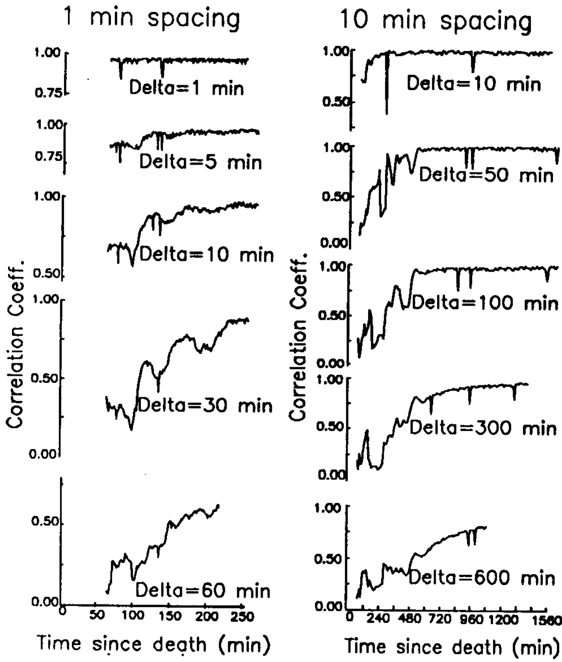


Figure 6: Delta Correlations for Porcine Sample 1

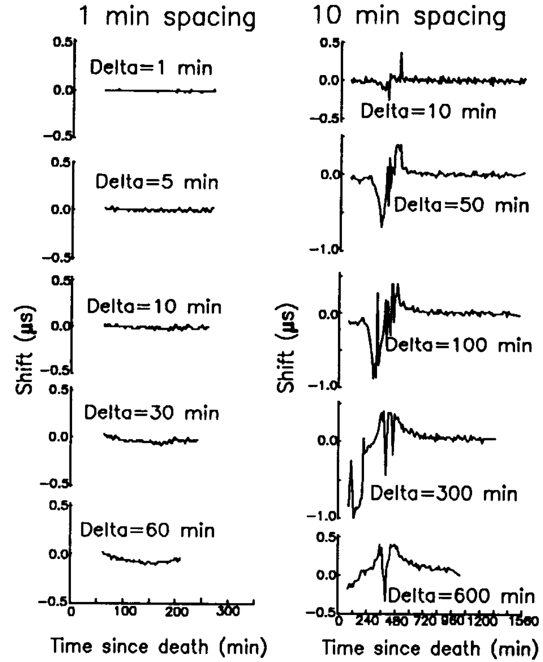


Figure 7: Shift for Max. Correlation for Porcine Sample 1

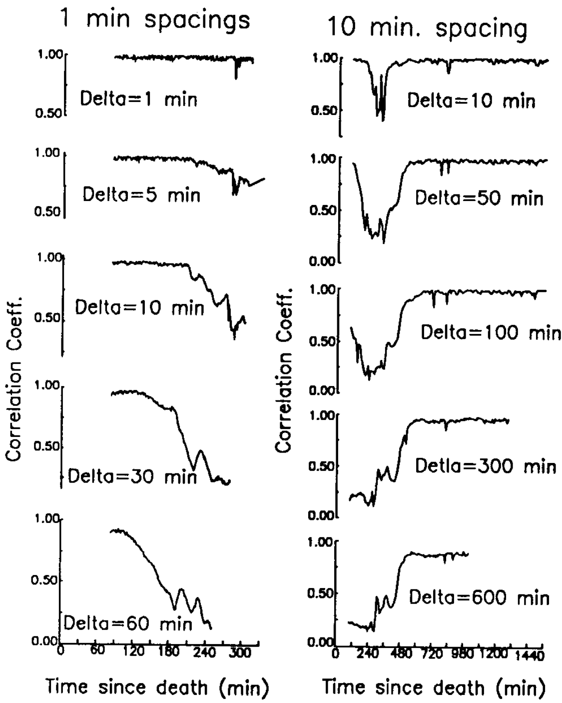


Figure 8: Delta Correlation for Porcine Sample 2

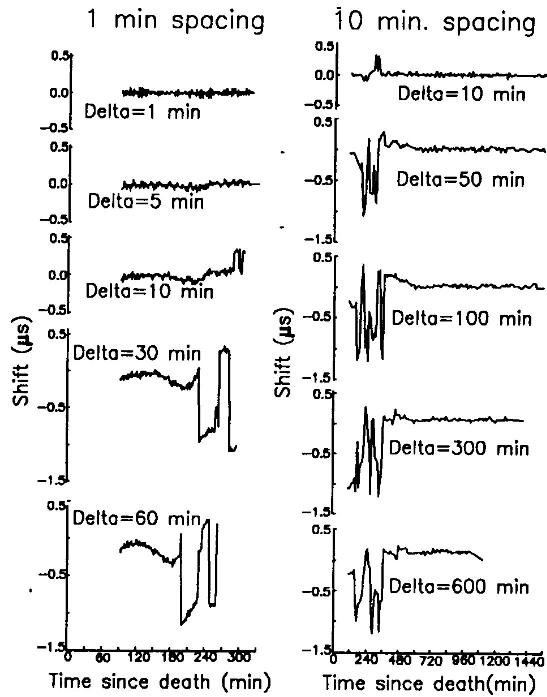


Figure 9: Shift for Max. Correlation for Porcine Sample 2

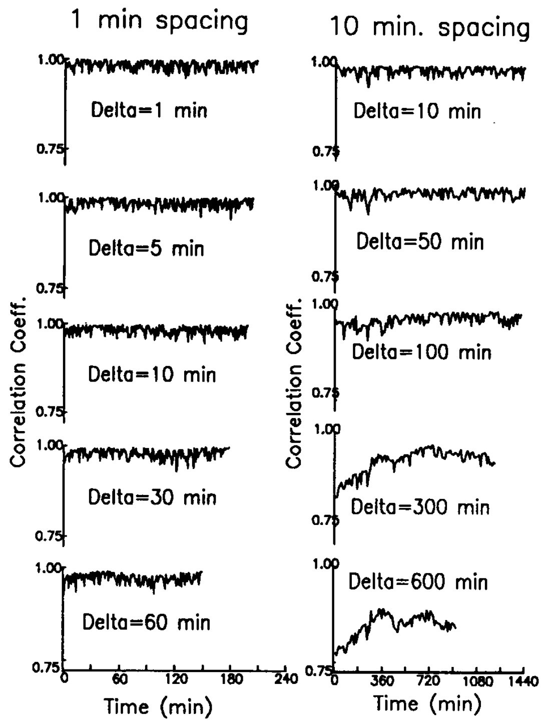


Figure 3: Sponge Delta Correlations

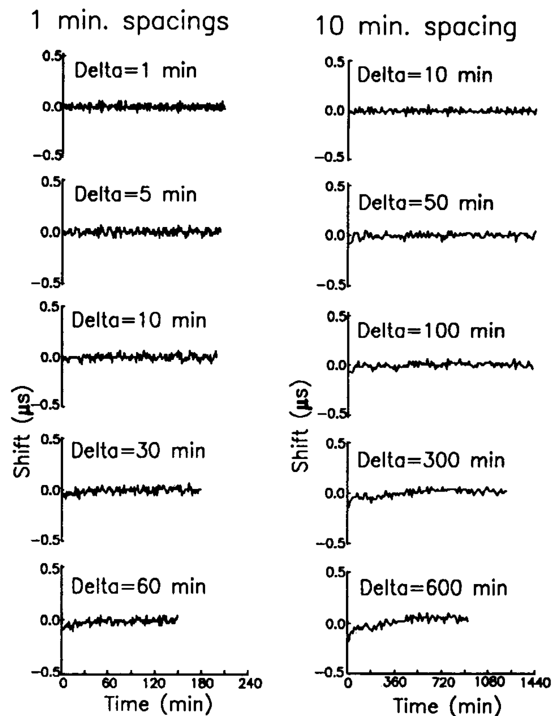
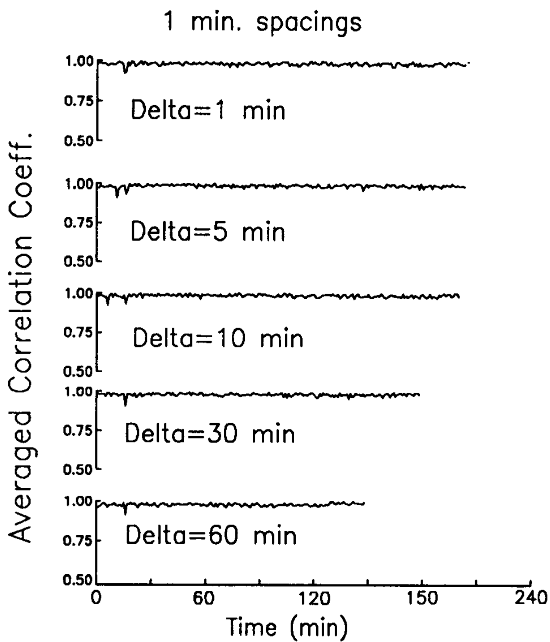


Figure 4: Sponge Shift for Max. Correlation



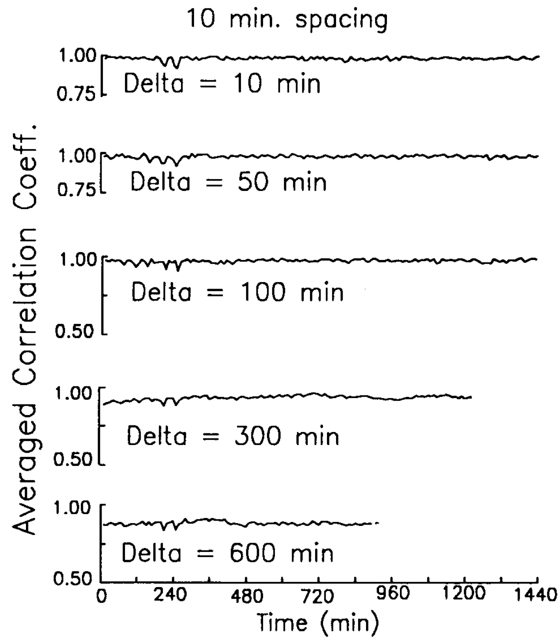


Figure 5: Average Sponge Correlation Coefficient