# MATHEMATICAL MODELLING OF SHORTENING DURING CHILLING OF BEEF *M. SEMIMEMBRANOSUS*

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S-VII.06

## SUMMARY

Shortening during chilling with a time-temperature gradient was calculated using a mathematical model derived from shortening data achieved at 9 different constant temperatures (1-37°C). The model used considered the time-, temperature- and pH-dependence of the rigor process. Shortening thus obtained was compared with the real shortening achieved on muscle strips chilled with two different time-temperature gradients.

The maximum shortening of the muscle strips, chilled with these two gradients (slow and fast chilling), was 41.6 and 30.7%, whereas the model predicted a shortening of 40.3 and 3.1%, respectively. Shortening calculated from the mathematical model based on data obtained at constant temperatures does not provide complete information on the actual shortening during chilling with a temperature gradient, except in the case of very slow chilling. This is suggested to be due to the fact that the decline in ATP has not been included in the model, to control the progressive change from a reversible to an irreversible process.

## Introduction

Since Locker (1960) showed that shortening of pre-rigor muscle is a factor governing meat tenderness, and Locker and Hagyard (1963) found that shortening during rigor is temperature-dependent, considerable research has been conducted in this field. Most of the research on the temperature dependence of shortening has been carried out at constant temperatures to be able to draw conclusions regarding the mechanisms governing shortening at rigor (Honikel et al., 1983). However, chilling of the muscles on the carcass at the abattoir is, by necessity, performed with a temperature gradient. Experiments on the muscle of the carcass have also been done in order to investigate the rigor process (May et al., 1992) and difficulties appear in comparing the results from the two types of experiments. By using mathematical modelling of shortening at constant rigor temperatures, the shortening during carcass chilling, i.e. with a temperature gradient, can be simulated. Comparing the simulated shortening-time dependence at different chilling rates with the real ones doesn't only provide information on whether rigor development at constant temperatures is similar to that of chilling by a temperature gradient, but may also tell us something about the complicated mechanisms governing shortening at rigor. This is the issue to be dealt with in this paper.

## Materials and methods

Shortening: *M. semimembranosus* from young bulls of the Swedish Lowland breed was sampled 30 minutes post mortem (pm). The animals were electrically stimulated (85V, 14Hz for 32 seconds) 25 minutes post mortem. From each muscle sample, two strips (35 mm and 1 gram) were cut and the shortening was registered as described by Hertzman et al. (1993). Four samples at 9 different constant temperatures (1, 4, 5, 7, 10, 15, 22, 29 and 37°C) were used for the modelling part and two different time-temperature gradients were studied. One was slow, chilled linear in two steps from 39°C down to 35°C for 4 hours and then further down to 10°C at 24h pm (n=3), the other one was a fast gradient, differing from the slow gradient by chilling for 4 hours down to 20°C instead of 35°C (n=3).

Modelling: The shortening-time curves at constant pre-rigor temperatures were found to be best fitted to a sigmoidal expression minimising least square distance; shortening= $A/(1+B*t^c)$, where t=time. The temperature-dependence of the constants (A, B and c) was modelled, using different equations, thus giving an expression describing shortening at temperature T and time t; Shortening=$A(T)/(1+B(T)*t^{c(T)})$. The modelled

shortening was calculated by accumulating delta shortening / delta time for each time- and temperature-interval of the gradient until pH dropped below 5.8, where shortening was considered to be fully developed.

## Results and discussion

The shortening curves at constant pre-rigor temperatures were fitted to a sigmoidal expression: Shortening= $A/(1+B*t^c)$, where A is the maximum shortening. B and c describe the shape of the curve. The mean values and the variances of the constants A, B and c are given, for each rigor temperature, in Table 1.
When the shortening was very intense, i.e. at 1, 4 and 37°C, the sigmoidal expression described the obtained data less accurately. However, it was of great value for the coming steps of the modelling evaluation to use the same expression for all the temperatures.

The temperature-dependence of the constants A, B and c was modelled to be :

$$A = 61*10^{-0.22*T} + 1.17*T-6 \qquad s^2=0.38 \quad (1)$$

$$\text{Log } B = -6.43*10^{-4}*T^3 + 2.25*10^{-2}*T^2 + 7.86*10^{-2}*T + 1.14 \qquad s^2=0.15 \quad (2)$$

Two different equations had to be used for the constant c, since large changes in the shape of the shortening-time curve take place between 5-10°C, which is the temperature region where cold shortening starts to operate for this muscle.

$$T<7°C: c = -(10.5*T^2 + 0.012*T + 3.36)$$
$$T>7°C: c = -(-5.29*10^{-4}*T^3 + 2.21*10^{-2}*T^2 + 2.75*10^{-4}*T + 1.31) \qquad s^2=0.04 \quad (3)$$

By using equations 1, 2 and 3 for A(T), B(T) and c(T), an expression describing shortening at temperature T and time t for *M. semimembranosus* is obtained; shortening= $A(T)/(1+B(T)*t^{c(T)})$ (4). For other muscles, new models have to be made, since the shortening response to temperature differs between muscles (Hertzman et al., 1993, Olsson et al., 1994). Figure 1 shows the calculated shortening, according to equation 4, as a function of time for constant temperatures between 1 and 37°C. A temperature region of minimum shortening between 7-10°C is observed and this region has the longest delay period before shortening starts.

Since the model only considers time and temperature as variables, another equation is needed in order to stop the calculations when, depending on the chilling rate, rigor mortis has fully developed. The data from Marsh (1954), who studied the effect of 7 different constant temperatures (7-43°C) on the post-mortem pH-decline of LD, was used for modelling the temperature-dependence of the logarithmic rate of pH-decline (kpH, units/hour).

$$T<34°C: kpH = -0.042*1.043^T$$
$$T>34°C: kpH= -25*10^{-5}*1.209^T \qquad (5)$$

Shortening, calculated according to equation 4, was accumulated until pH dropped below pH 5.8, a point where it was considered that the maximum shortening had been reached. The time needed for the lowering of pH from 6.75 to 5.8 was calculated for both the chilling rates, according to the following: using a stepwise procedure, the temperature was changed every 10 minutes according to the particular chilling rate. The kpH was then calculated according to equation 5 for each time interval and the drop in pH during those 10 minutes was subsequently subtracted from the preceding pH. The calculated time to reach pH 5.8 agreed well with the measured one (data not shown).

In Figures 2 and 3, the modelled and the actual shortening is given for the two time-temperature gradients. The actual maximum shortening for the muscle strips, chilled with two gradients (slow and fast chilling), was 41.6 and 30.7%, whereas the model predicted a shortening of 40.3 and 3.1%, respectively. The agreement between the modelled and the measured shortening, in the case of slow chilling, was great both with regard to the level and the point where the maximum was reached. In the case of fast chilling, the model totally failed to predict the final level of shortening, as well as the time end point. Even if shortening was accumulated until pH 5.5 was reached (9% shortening instead of 3%), there was still a large disagreement between the model and reality. Shortening caused by either high or low temperature is reversible as long as the level of ATP is high (Bendall, 1973), but it becomes progressively less so as the level of ATP decreases. The prerequisite for the mathematical model presented here is reversible processes, since the model does not take into account

anything about the ATP-status. In the slow chilling example (Figure 2), all the shortening occurs in the high temperature region from 39°C down to 35°C and then the temperature gradient and the constant temperature experiments are not that different, with regard to the ATP-status too. Therefore the model predicts pretty well the actual shortening in that case, whereas at fast chilling the inevitable $Ca^{2+}$ release at higher temperatures in real chilling, which presumably cannot be re-accumulated to the same extent as when the ATP-level does not decrease (prerequisite of the model), causes a larger degree of shortening than can be predicted from the model.

## Conclusions

The maximum shortening of the muscle strips, chilled with two gradients (slow and fast chilling), was 41.6 and 30.7%, whereas the mathematical model predicted a shortening of 40.3 and 3.1%, respectively. Shortening calculated from the mathematical model based on data obtained at constant temperatures does not provide information on the actual shortening during chilling with a temperature gradient, except in the case of very slow chilling. This is suggested to be due to the fact that the decline in ATP has not been included in the model, to control the progressive change from a reversible to an irreversible process.

## References


Bendall, J.R., (1973). The biochemistry of rigor mortis and cold-contracture. XIXth European Meeting of Meat Research Workers, Paris

Hertzman, C., Olsson, U. and Tornberg, E., (1993). The influence of high temperature, type of muscle and electrical stimulation on the course of rigor, ageing and tenderness of beef muscles. Meat Sci., 35, 119

Honikel, K.O., Roncalés, P. & Hamm, R., (1983). The influence of temperature on shortening and rigor onset in beef muscle. Meat Sci., 8, 221

Locker, R.H., (1960). Degree of muscular contraction as a factor in tenderness of beef. Food Res., 25, 304

Locker, R.H. and Hagyard, C.J., (1963). A cold shortening effect in beef muscles. J. Sci. Food. Agric., 14, 787

Marsh, B.B., (1954). Rigor mortis in beef. J. Sci. Food Agric., 5, 70

May, S.G., Dolezal, H.G., Gill, D.R., Ray, F.K. & Buchanan, D.S., (1992). Effects of days fed, carcass grade traits, and subcutaneous fat removal on postmortem muscle characteristics and beef palatability. J. Anim. Sci., 70, 444

Olsson, U., Hertzman, C. and Tornberg, E., (1994). The influence of low temperature, type of muscle and electrical stimulation on the course of rigor mortis, ageing and tenderness of beef muscles. Meat Sci., 37, 115


Legends

Table 1. The mean values of A, B and c and the variance $s^2$ for each temperature.

Figure 1. Modelled shortening versus time and temperature for *M. semimembranosus.*

Figure 2. Modelled and actual shortening versus time for slow chilling of *M. semimembranosus.*

Figure 3. Modelled and actual shortening versus time for fast chilling of M. semimembranosus.