# ANALYSIS OF MUSCLE DEFORMATION AND NaCl HOMOGENIZATION IN BRINE INJECTION AND TUMBLING

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**Abstract – Homogenization of salt content in meat is known to be a key factor for quality of tumbled meat products, like cooked ham. However no spatial salt distribution were found during tumbling after brine injection. In addition, deformation of meat cuts in tumblers which enhances salt migration was unknown. First, both kinetics and rates of deformation were estimated from slow-motion films (1000 frames/s) of two types of ham muscles falling. Duration and rate of muscle deformation varied from 20 to 120 ms and from a few % to 40%, respectively. Then, such deformations were applied to *Semimembranosus* pork muscles after brine injection (25 % NaCl content and injection rate 10 % w/w ) thanks to a new laboratory tumbling simulator. NaCl content spatial distributions were assessed from 39 samples in each muscle. The distribution was logically very uneven a few minutes after injection. After 2500 deformations at 30% deformation rate it roughly followed a Gauss like curve, centred on the expected mean NaCl content value but was still inhomogeneous.**

**Key Words – mechanical treatment, meat deformation, mass transfer.**

## I. INTRODUCTION

After brine injection in meat, tumbling is performed before cooking in baffled rotating drums that have diameters ranging from 0.5 to 2 m. Processing time (2 to 12 h) and rotational speed (4 to 12 rpm) are recipe-dependent, changing with pre-treatment, meat type, piece size, final product properties, and so on.. The mechanical energy which is transmitted to meat pieces due to falling and striking against the baffles leads to meat deformation. Studies show that meat tumbling modifies meat tissue structure [1, 2] and enhances salt diffusion [2,3]. However, no data are available to relate NaCl homogenization speed to the mechanical action.

Our aim was to analyze meat falls using slow-motion films, to reproduce and characterize such mechanical treatments in a laboratory device and to assess NaCl homogenization *versus* treatment intensity and time in pork *Semimembranosus* (SM) and *Rectus femoris* (RF) muscles after brine injection.

## II. MATERIALS AND METHODS

*Brine injection control*

Brine (25 % NaCl w/w) was injected at a rate of about 10 % of muscle weight using a laboratory multi-needle prototype that enable to control injection pressure (250 kPa). Distances between two needles were 2.7 and 2.0 cm in two orthogonal directions.

*Deformation analysis from slow motion films*

A trial consisted in dropping a muscle on a stiff surface. Heights of fall were 25, 50, 75 and 100 cm so as to cover those existing in industrial tumblers of various diameters. Black-and-white slow-motion films were recorded with a high-speed camera (HighSpeedStar 4G, Lavision ®) equipped with a 105-mm lens, at a speed of 1000 frames/s, with an image resolution of 1024×1024 pixels. Actual spatial resolution in the images was 0.34 mm. Each case (muscle type × fall height) was repeated 3 times. For each image, a mean deformation rate, or instantaneous compression rate (Cri), was calculated as the mean of the compression rates at time t estimated for 3 cross-sections that separate the muscle into 4 parts of equal length along the main muscle axis (see photographs in Figure 2). Compression rate was defined as the ratio of vertical height to height of the same section at rest.

*Reproduction and measurement of the mechanical treatment*

Massaging was controlled using a new lab-scale tumbling simulator [4] that can reproduce mechanical treatments occurring in real-world tumblers: hundreds of rapid deformations (controlled compression orthogonally to muscle main length and lateral free extension) are applied to one muscle to simulate the successive falls promoted by tumbler drum rotation. The maximum compression rate (Cr) is controlled and the dissipated strain energy of each deformation (E) is calculated from force *versus* strain recordings. The muscles were rotated at 8 rpm in the simulator tank to vary muscle position from compression to compression. Two massaging conditions were tested: 350 compressions at Cr 10% and 2500 compressions at Cr 30%.

*Distribution of NaCl in the brined muscle:*

A part of each muscle was cut in 39 samples (0.5 × 0.5 × 2 cm), the main length being parallel to injection holes. Then, $Na^+$ concentration was measured by ion-exchange chromatography (Metrohm, 930 IC Flex) after sample mincing in deionized water and centrifugation (20 min, 14 000 rpm). Since it was shown [5] that $Na^+$ and $Cl^-$ ions transfers in meat are identical, NaCl content was derived from $Na^+$ concentration.

## III. RESULTS AND DISCUSSION

*Muscle deformation analysis*

Figure 1 shows a typical succession of cross-section images from a film recorded with a cut RF muscle at the end of a fall from 25-cm height. The muscle height decreased rapidly, reached a minimum and then increased until reaching the same thickness as observed at rest. Muscle volume should stay constant, since meat tissue is an incompressible material. Thus, as the muscle stretched horizontally, the minimum of vertical compression always corresponded to the maximum of horizontal extension.

The time–course of mean instantaneous compression ratio calculated for 3 repetitions with one RF muscle is shown in Figure 2 for the lowest and highest fall heights. The maximum compression ratio (Cr) was achieved after about ⅓ of the total deformation time. It is not proportional to fall height, whereas initial potential energy is theoretically proportional to fall height. This behaviour can be explained by the rheological properties of the meat tissue which is not a pure elastic material but a viscoelastic one, with the viscous component partially absorbing the impact.

Figure 1: Four images of the cross-section of a cut RF at the end of a 25 cm fall. The cross-section was manually highlighted in white.

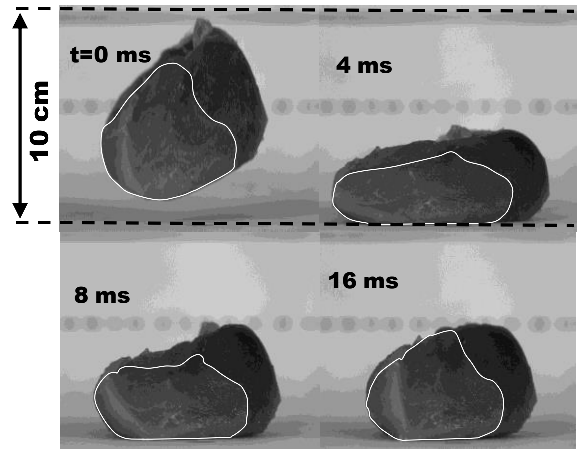
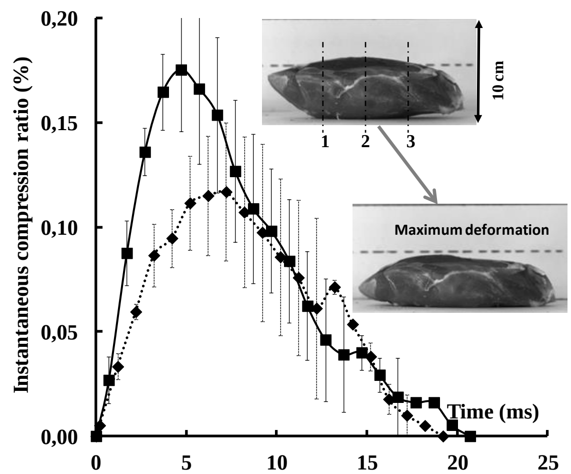
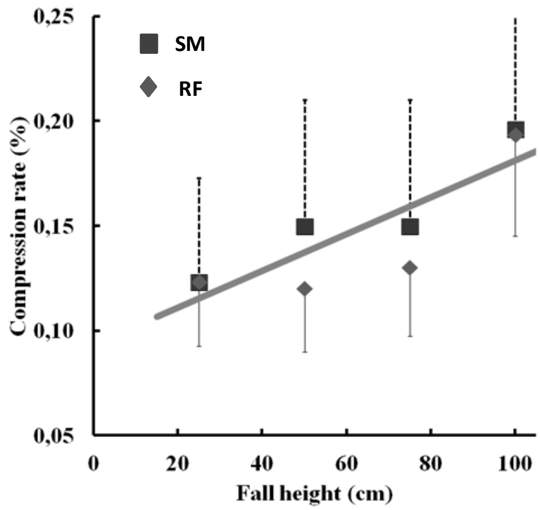



Figure 2:. Deformation kinetics of a *Rectus femoris* muscle for two fall heights: 25 cm (diamonds) and 100 cm (squares). Bars indicate standard deviation over 3 repetitions.




Min–max Cr values were 3% and 42%, with no significant difference between the means calculated for two types of muscle, i.e. 15 ± 8% for SM and 14 ± 5% for RF. All the Cr values are reported in Figure 3 as a function of fall height. Note that the standard deviations are particularly high. This is likely due to the fact that muscles fell into different positions leading to great variability. However, notwithstanding this variability, Figure 3 shows that after pooling all the measures with both SM and RF muscles, we found a rough linear correlation between Cr and fall height ($r^2 = 0.72$).

Figure 3: Compression rate versus fall height for the two muscles (RF, diamonds; SM, squares). Bars indicate standard deviation over 3 repetitions. Solid line is the linear regression calculated with all the data.




The above deformation rates can be considered as values found in industrial tumblers since tumbler diameters vary in the 50-200 cm range and since RF and SM muscles represent meat cuts of extreme properties according to the 2 parameters that determine deformation: (i) RF and SM weights are equal to about 0.45 and 1.4 kg, and (ii) their elasticities are equal to 0.38 and 0.45, respectively, while pork muscle elasticity varies in the range 0.34–0.45 [6]. As a conservative measure, we considered a larger range and selected two target compression rates, i.e. 10% and 30%, for the massaging tests with our laboratory tumbling simulator [4].

Figures 4 to 6 shows the Nacl content distribution in *Semimembranosus* muscles in a slice orthogonal to the injection hole direction: 2 cm in thickness and covering a surface of about 6 injection holes.

Figure 4 shows an example of the distribution a few minutes after brine injection. This initial distribution was always very uneven: the samples taken in the neighbourhood of injection holes had logically the highest salt contents while some samples could have no salt since ions diffusion over a few millimetres needs hours [5]. This initial distribution varied a lot from muscle to muscle; sometimes a great number of samples had a salt content below 0.5 % and sometimes the bins with salt content higher than 4 % were much more important than in Figure 4. This initial distribution variability can be explained by preferential infiltration ways that depend on meat macroscopic structure; a much greater sampling would be necessary to stabilize the measured histogram.

Figure 4: NaCl content distribution in SM muscle just after brine injection

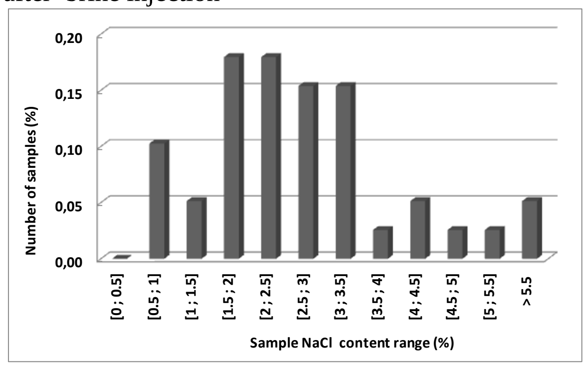



Figure 5: NaCl content distribution in SM muscle after 350 deformations at Cr 10%.

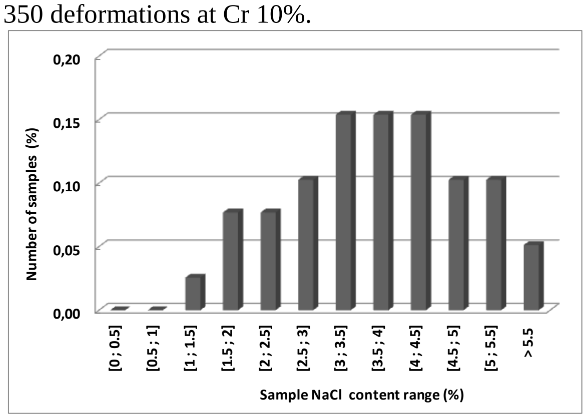



Figure 6: NaCl content distribution in SM muscle after 2500 deformations at Cr 30%

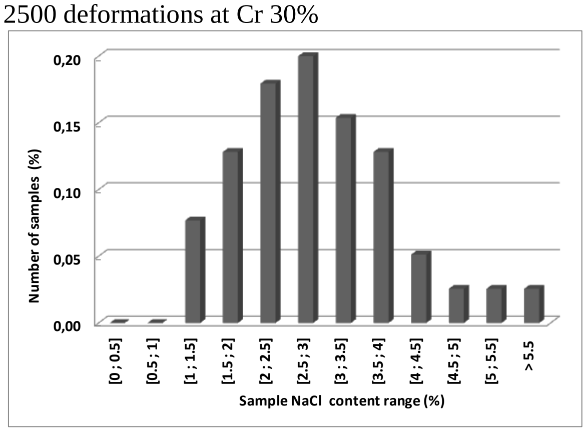


Figure 5 corresponded to massaging for 45 minutes in a small tumbler rotating at 8 rpm (350 compressions at Cr 10 %). The average deformation energy (E) of each deformation was equal to 100 mJ The measured salt content distribution is unimodal and approximately symmetric around the mean value but the measured NaCl contents stretched from 1 to 5.5 %. Figure 6 corresponded to 5 hours of massaging in a large tumbler rotating at 8 rpm (2 500 compressions at Cr 30 %). In this case E was 5 times higher than in the previous case: 570 mJ. The histogram roughly follows a Gauss like curve, centred on the expected mean value. However, the NaCl distribution was surprisingly still inhomogeneous. Since salt homogenization is also promoted by ions diffusion longer treatments should be tested using the same number of deformations to evaluate the respective incidences of diffusion and muscle deformations. Our present results suggest that salt could carry on with homogenizing during cooking, cooling and storage. Thus, it would be interesting to measure protein solubility which depends on salt content and affects meat product texture after cooking.

## IV. CONCLUSION

Meat pieces falling in tumblers experience significant and brief deformations. The compression rate in one direction roughly corresponds to an equivalent extension rate in the orthogonal direction. The deformation rate roughly vary linearly with fall height and therefore with tumbler diameter and yield.

For the first time the spatial distribution of salt content was measured in muscles during massaging after brine injection. Massaging was controlled using a lab-scale tumbling simulator and two extreme deformation rates were tested. Even after a mechanical treatment that corresponded to usual massaging condition in large industrial tumblers salt distribution was not homogeneous.

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