4:1

RELATIONSHIPS BETWEEN MECHANICAL PROPERTIES OF RAW MEAT AND CHARACTERISTICS OF CONNECTIVE TISSUE

ABUSTAM E., BORDES P., CULIOLI J.

Station de Recherches sur la Viande, I.N.R.A.
Theix F-63122 Ceyrat, France

SUMMARY

The relationships between mechanical parameters, measured with sinusoidal compression, and connective tissue characteristics, such as collagen content and solubility, collagen network organization, have been studied on four muscles (Longissimus dorsi, Semitendinosus, Pectoralis profundus and Triceps brachii caput lateralae) from ten animals (young bulls, cull cows). Compression tests under low strain do not provide any information on connective tissue characteristics. But, 66 % of the variations in collagen content can be assessed with a destructive compression test. No relationship between mechanical parameters and collagen solubility could be found. A critical value of the compression ratio (K = 0.3-0.4) has been defined ; it corresponds to the start of a significant correlation between collagen content and meat strength. To characterize collagen fibre strength, the connective network has to be put under tension, first. On this basis, the suitability of a non-destructive mechanical test to evaluate collagen characteristics has been discussed.

MATERIALS AND METHODS

Muscle sampling

Experiments have been carried out on 4 muscles : Longissimus dorsi (LD), Semitendinosus (ST), Pectoralis profundus (PP) and Triceps brachii caput lateralae (TB).

Six Friesian cull cows and four young Friesian bulls were used in these experiments. After slaughter, carcasses were conditionned at 15°C for 6 h and then cooled at 2°C for 2 days. Selected muscles were excised 2 days post-mortem, vacuum packed and stored at 2°C. All measurements were carried out 8 days post-mortem on a 2 cm slice taken on each muscle, perpendicularly to the myofibres.

Analysis

Linear density of the main perimysium network was measured on an enlarged photograph of the slice. The main axis of the slice, defined as the largest dimension, was determined. The total number of crossings between this axis and the main perimysium network was calculated (Dumont, 1983). The number of crossings per length unit along this main axis was considered to be the linear density (LD1).

Collagen content was estimated, after perchloric acid hydrolysis, by the amount of total hydroxyproline (x7.5) titrated according to the method of Bergmann and Loxley (1963). Hydrolysis was performed by heating 3 g of muscle at 100°C for 4 h, in 15 ml of 70% perchloric acid.

Collagen solubility was determined after heating 3 g of minced muscle at 90°C for 4 h in the following buffer: Tris HCl 0.02 M, pH 7.4. After filtration, the unsolubilized part of the samples were hydrolysed and collagen was determined, under the same conditions. The solubility percentage was calculated according to the following expression:

$$\text{solubility}(\%) = \frac{\text{Total collagen} - \text{insoluble collagen}}{\text{Total collagen}} \times 100$$

Sarcomere length was determined by diffraction of a laser beam according to the method of Cross et al. (1980, 1981).

Mechanical measurements

The mechanical measurements were carried out with the Food Texture Analysis System (F.T.A.S.) set up by Salé et al. (1984). Meat samples (3 cm x 1 cm x 1 cm) were compressed by a 1cm2 probe perpendicularly to the myofibres in a cell equipped with 2 lateral walls. In these conditions the free deformation of the samples was limited to only one direction, either perpendicular (transversal configuration) or parallel (longitudinal configuration) to the myofibres (fig. 1). The compression ratio varied within a large range, $0.2 \leq K \leq 0.8$.

From the stress-strain curves obtained during one sinusoidal compression cycle (period: 0.1s), the following parameters were determined:

σm (N/cm2) : maximum stress reached during the compression

rt : elasticity factor which was the ratio of the energy almost instantaneously released by the sample during the upward movement of the probe, over the total energy given to it during compression.

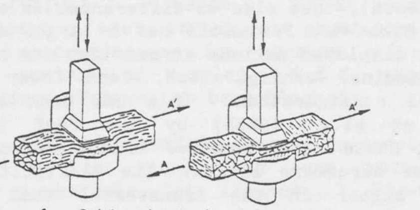

Figure 1 - Schématic design of the compression cell with a meat sample in the longitudinal (L) and transversal (T) configurations

RESULTS

The characteristics of connective tissue and the sarcomere lengths of the different muscles are indicated in table 1. Large variations in collagen content (5.8-11.6 mg/g fresh tissue), solubility (30.3-36.3 %), linear density (1.85-2.90 cm^{-1}) and sarcomere length (2.0-2.7μ) were observed, due to muscle factor. Animal influence was reflected in the standard deviations that accounted for 22 %, 36 %,25 % and 20 % of the respective mean values. The LD muscle had the lowest collagen content and linear density, but the highest solubility whilst the ST muscle had the lowest solubility. The PP muscle had the highest sarcomere length and linear density.

Table 1. Mean values of connective tissue characteristics (collagen content COL,solubility SOL, linear density (LD1) and sarcomere length (SL) for different muscles.Standard deviations in brackets.

	LD	ST	PP	TB
COL (mg/g)	5.8 (0.5)	10.8 (1.2)	11.3 (2.1)	11.6 (2.5)
SOL (%)	36.3 (8.7)	30.3 (7.7)	31.3 (11.3)	34.9 (9.6)
LD1 (cm^{-1})	1.85 (0.30)	2.48 (0.60)	2.90 (0.45)	2.60 (0.50)
SL (μ)	2.00 (0.4)	2.06 (0.2)	2.7 (0.3)	2.2 (0.2)

Table 2. Mean values of maximum stresses (N/cm2) and elasticity factor (%) for different muscles, at 2 compression ratios (K= 0.2 and K= 0.8) and in the longitudinal (L) and transversal (T) configuration (standard deviations in brackets)

Compression ratio	Configuration	LD σ_m	LD rt	ST σ_m	ST rt	PP σ_m	PP rt	TB σ_m	TB rt
0.2	L	9.8 (2.7)	24.5 (4.1)	9.5 (2.5)	23.2 (5.3)	17.3 (6.6)	30.5 (7.7)	15.0 (4.0)	23.2 (3.8)
	T	6.9 (2.9)	44.5 (4.7)	7.3 (4.5)	40.8 (10.0)	4.4 (1.5)	33.8 (7.2)	8.0 (3.0)	46.8 (5.6)
0.8	L	47.1 (15.0)	15.0 (2.4)	108.0 (22.0)	20.9 (1.8)	96.6 (18.0)	19.3 (2.4)	84.0 (27.0)	18.2 (2.9)
	T	42.5 (11.0)	15.1 (2.9)	71.0 (9.2)	14.7 (3.5)	83.0 (24.0)	21.5 (3.5)	87.0 (26.0)	18.4 (4.3)

Large standard deviations were also observed for the maximum stresses obtained in various conditions table 2. At a 0.2 compression ratio, the differences between muscles in the longitudinal configuration may be due not only to variations in ageing rates (Lepetit et al., 1986a), but also to differences in sarcomere lengths. Since the PP muscle has a larger sarcomere length, it displayed maximum stress that was higher in the longitudinal configuration, and lower in the transversal configuration. This has been explained (Lepetit et al., 1986b) by the fact that the stretching state of connective tissue network is a function of sarcomere length. The elasticity factor was much higher in the transversal than in the longitudinal configuration, because the myofibre viscous component was not displayed when the free lateral strain was perpendicular to the myofibre axis (Lepetit and Culioli, 1985). Sarcomere length may also have an influence on the rt values, as the PP muscle was more elastic than the other muscles in longitudinal configuration, and less elastic in transversal configuration. At a 0.8 compression ratio, the lowest maximum stresses were obtained with the LD muscles ($\sim$45N/cm2), whilst ST, PP and TB muscles had displayed small differences (83 N/cm2 $\leqslant \sigma_m \leqslant$ 108 N/cm2). The gap between transversal and longitudinal values would depend on the muscle. Because of destructive conditions, the elasticity factor was lower than previously and was not influenced by configuration or muscle.

In the non-destructive test (K=0.2), the correlation coefficients between the mechanical parameters (maximum stress and elasticity) determined on raw meat and the collagen content, the solubility or the linear density of connective tissue were fairly low ($r \leqslant 0.37$) and in most cases non-significant (table 3).

Table 3. Correlation coefficients (r) between the connective tissue characteristics (collagen content COL, solubility SOL, linear density LD1) and the various mechanical parameters determined at 2 compression ratios (K=0.2, K=0.8) in longitudinal (L) and transversal (T) configurations.

	K = 0.2 σ_m L	K = 0.2 σ_m T	K = 0.2 rt L	K = 0.2 rt T	K = 0.8 σ_m L	K = 0.8 σ_m T	K = 0.8 rt L	K = 0.8 rt T
COL	0.31	-0.17	-0.01	-0.09	0.71	0.82	0.58	0.49
SOL	0.29	0.05	0.37	0.24	-0.17	-0.14	-0.27	0.03
LD1	0.18	-0.11	0.46	-0.05	0.49	0.38	0.38	0.26

r values greater than 0.3 are significant at a $P < 0.05$ level

Still, there was a better correlation between collagen content and mechanical parameters when the test was destructive (K=0.8). Thus, variations in collagen content explained 67 % (r=0.82) of the variations in mechanical resistance measured in the transversal configuration (fig. 2). The relationship between collagen content and elasticity was, however, not as close ($0.5 \leqslant r \leqslant 0.6$).

The correlation coefficient between the linear density of the primary perimysium network and collagen content was nearly 0.5. Yet, the information on collagen content given by mechanical measurements was not improved when linear density was taken into consideration in a multiple regression. This is probably due to the fact that LD1 and maximum stress were not independent variables (table 3) and that only the perimysial network was taken into account and not all the perimisyal network, as in the studies of Dumont (1983).

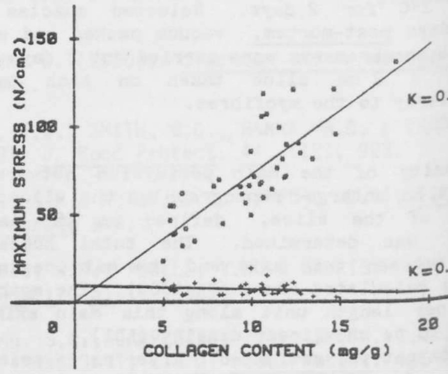

Figure 2 - Variations in maximum stress with collagen content, at 2 compression ratio + K = 0.2 ; ⁎ K = 0.8, and in transversal configuration

When the compression ratio increased, the correlation between collagen content and maximum stress increased following a sigmoidal curve with a point of inflexion at around K=0.4 (fig. 3). The configuration did not influence either the shape of the curve noticeably, or the correlation coefficient values.

Collagen solubility, which is an important component of cooked meat tenderness, did not correlate very well with the different mechanical parameters determined on raw meat ($r \leqslant 0.37$).

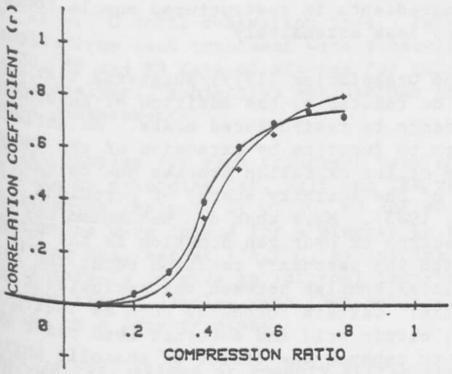

Figure 3 - Influence of compression ratio on the correlation coefficient between maximum stress and collagen content
+ transversal, o longitudinal configurations

DISCUSSION - CONCLUSION

Although Compression tests performed on raw meat at low stress (⩽20 %) allows a good evaluation of myofibrillar properties (Lepetit et al., 1986), they did not provide any information on connective tissue characteristics, or collagen content and solubility, or on network linear density. But destructive compression tests can give good estimate of the intramuscular collagen contents. However collagen solubility cannot be evaluated. These results confirm those of Kopp and Bonnet (1982) who obtained good correlations between collagen content and maximum shear force measured on raw meat, whatever the collagen solubility.

At low compression ratios (⩽20 %), the meshes in the connective tissue are deformed, but the wavy collagen fibres are not directly strained. To characterize the resistance of these fibres, the network has to undergo tension first. This can be achieved only when compression is around 30 %, which does not induce any apparent breaking in samples. So, a non-destructive mechanical test should be used in this range of compression. The application of such a test to the entire muscle meets with additional problems in connection with myofibre orientation and deformation characterization.

REFERENCES

BERGMAN I., LöXLEY R. (1963). Two improved and simplified methods for the spectrophotometric determination of hydroxyproline. Anal. Chem., 35, 1961-1963.

CROSS M.R., WEST R.L., DUTSON T.R. (1980-81). Comparison of methods for measuring sarcomere length in beef Semitendinosus muscle. Meat Sci., 5, 261-266.

DUMONT B.L. (1983). Densité linéaire de la trame périmysiale et dureté de la viande bovine. Viandes et Produits Carnés, n° spécial, 88.

DUMONT B.L., LEFREVRE J., SCHMITT O., BARBU L. (1977). Relations entre les caractères de la trame conjonctive et la dureté de la viande. 23rd Eur. Meet. Meat Res. Workers, Moscow, F4-244.

LEPETIT J., CULIOLI J. (1985). Analysis of the rheological properties of raw meat. Prospects of application to the industrial control of muscles. In: Accelerated Processing. CEE Workshop, Roma, Italy (to be published).

LEPETIT J., CULIOLI J., ABUSTAM E., BORDES P. (1986b). Relations between meat structural organization and rheological properties at low strains. In: Non-destructive control of muscles, C.E.E. Workshop, Clermont-Ferrand, France (to be published).

LEPETIT J., SALE P. (1985). Analyse du comportement rhéologique de la viande par une méthode de compression sinusoïdale. Sci. Aliments, 5, 521-540.

LEPETIT J., SALE P., OUALI A. (1986a). Post mortem evolution of rheological properties of the myofibrillar structure. Meat Sci., 16, 161-174.

KOPP J., BONNET M. (1982). Dureté de la viande et résistance au cisaillement des fibres de collagène. Sci. Aliments, 2 (hors série II), 127-132.

SALE P., NOEL Y., OLEON C., LASTEYRAS A. (1984). A sinusoidal compression system to study rheological properties of food in transient state. J. of Texture Studies, 5, 283-297.