ELECTROMYOGRAPHY OF MASTICATORY MUSCLES APPLIED TO MEAT TEXTURE ASSESSMENT

MATHEVON E., MIOCHE L., CULIOLI J.

Station de Recherches sur la Viande, INRA, Theix, Saint-Genès Champanelle, FRANCE

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SUMMARY

Variations in beef texture, induced by six different cooking temperatures (45° to 80°C), were studied using three different approaches: rheology, sensory assessment and masticatory muscle electromyography (EMG). Mechanical behaviour of meat, from the two *Semimembranosus* muscles of the same animal was studied by compression and shear tests in destructive or non-destructive conditions. Electromyographs from the masticatory muscles were recorded during mastication of the meat samples in fourteen trained subjects, who had to assess five descriptors of texture at the end of each masticatory sequence. The increase in the cooking temperature induced an overall increase in mechanical parameters, sensory hardness and total muscle work developed during mastication. However, these parameters did not vary linearly with cooking temperature. For each assessor, good correlations were obtained between sensory assessments and mechanical measurements. Moreover, sensory assessment were very well correlated with EMG parameters. EMG of the masticatory muscles appeared to be a good objective method to analyse variations in texture of meat induced by cooking.

Introduction

Traditionally the way to determine the most appropriate methods for objective assessment of texture has been to correlate mechanical measurements with sensory evaluation of the same products (Boyd & Sherman, 1975 ; Szczesniak, 1987 ; Touraille, 1988). However, optimal fitting between sensory and mechanical values is limited by various factors. Indeed, to determine the relevant mechanical properties would necessitate the knowledge of conditions of deformation, the masticatory forces and mandibular jaw movements which are dependant of the texture of food (Michael *et al*; 1990 ; Bishop *et al.* 1990). However, the relationships between sensory assessment of food texture and the physiological answers from which they are derived are largely unknown. Texture assessment depend on individual capabilities of subjects in analysing and translating their perception.

A new insight into texture perception may be expected from examination of the modifications induced in motor components of the masticatory pattern, arising from mastication of foods differing in texture properties. Information about the masticatory pattern can be obtained by electromyographic recordings which allow a direct measurement of the muscular activity without disruption of the masticatory process. A large number of parameters can be derived from the pattern of electrical activity of the main elevator muscles of mandible, the *Masseter* and the *Temporalis* (Brown, 1994).

The complex mechanical behaviour of meat products makes texture analysis particularly difficult. In this context, EMG recordings may bring a new insight into the understanding of the texture properties. The present study sought to determine the relative contribution of mechanical and psychophysiological measurements (including sensory analysis and EMG recording) to assess the variation in texture properties of beef, induced by different cooking temperatures (45° to 80°C).

Material and methods

Preparation of meat samples

Both mechanical and sensory tests were performed on the right and left *Semimembranosus* muscles of a seven years Montbeliard cull cow. The muscles were excised 24 hours *post-mortem* and then stored at +2°C. Slices (15 x 5 x 2.5 cm) were cut 48 hours *post-mortem*, the largest dimension being parallel to the fibre axis. They were individually vacuum-packed and stored 18 days at +4°C for ageing. Cooking was performed by immersion for 30 min of slices in their individual plastic bag in a water bath maintained at different temperatures (45, 55, 60, 65, 70, 80°C). After cooling under a 15°C water rinse, the slices were frozen by immersion for 3 hours in an alcohol bath at -20°C. 24 cooked slices (4 of each cooking temperature) were randomly chosen for sensory tests, and cut frozen into samples of identical size (2 x 1.5 x 1 cm). Long-term conservation was obtained by keeping the samples at -18°C. Slices for mechanical measurements were cut into samples (2 x 1 x 1 cm, the largest dimension being parallel to the fibre axis) for shear and compression tests. Cylindrical samples of meat (diameter 2 cm, height 1cm) were cut with a punch for viscoelastic measurements.

Rheological measurements

Compression tests: Tests were performed, at room temperature, with the Food Texture Analysis System (FTAS) as developed by Salé *et al.* (1984). Meat samples underwent compression perpendicular to the fibres axis in a cell equipped with two lateral walls limiting the free deformation to only one direction. Two configurations were used: parallel (longitudinal configuration) and perpendicular (transverse configuration) at room temperature. Samples from each slice were compressed in the conditions defined by Kamoun and Culioli (1988) up to 20 or 80% of deformation, corresponding to ''non-destructive'' and ''destructive'' tests respectively. From the stress-strain curves two parameters were determined: maximum stress (N/cm^2) and compression modulus (N/cm^2).

Shear tests: These tests were carried out using the shearing cell, devised by Salé (1971), attached to an Universal Testing Machine. Samples from each cooked slice were sheared at room temperature. The displacement (60 mm/min) of the shear blade was perpendicular to the fibres and two configurations were used: a longitudinal (shear plan parallel to the fibre axis) and a transverse (shear plan perpendicular to the fibre axis) one. Maximal force (N) and energy (J) were calculated from the force-displacement diagrams.

Viscoelasticity measurements: The rheological behaviour was analysed using a controlled-stress rheometer (Carri-med CSL 100) in the oscillatory mode. The cylindrical samples were coated with a cyanoacrylate glue. All measurements were performed in transverse (fibres parallel to the plates) or axial (fibres perpendicular to the plates) configurations. Samples were pre-strained in compression (5%) and the surface of meat was oiled to prevent evaporation. Measurements were performed at a frequency of 0.1 Hz and a maximal strain of 0.5%, conditions under which is was previously ascertained that meat exhibited a linear viscoelastic behaviour. From sinusoidal strain and stress curves three parameters were calculated: storage (G') and loss (G'') moduli which indicate elasticity and viscosity respectively, and phase angle (δ) which is the ratio G''/G'.

Psychophysiological experiments

Subjects

14 subjects (7 female and 7 male, age range 20-49 years), were selected after a dental examination made at the dental faculty of Clermont-Ferrand, to select subjects free of severe dysfunctions. Subjects were trained for sensory assessment of texture of different solid foods, during the two months prior the experiment (one hour twice a week).

Electromyography recordings

EMG recordings were obtained using bipolar electrodes, located on both left and right *masseter* and *temporalis* muscles of each subject. Muscles were identified by palpation when subjects clenched their teeth. The signal was filtered and amplified. After rectification of the EMG signals, three parameters were analysed with the pooled muscles from the complete sequence of the mastication (starting at the food intake and ending at the swallowing): Chewing time (total duration before swallowing), average duration of a single burst of muscle activity and sum of the areas of the EMG curves of individual bursts (duration x mean voltage of each burst, expressed in V.s). The same analysis was performed for all subjects.

Sensory analysis

The subjects had to assess 18 meat samples randomised (3 replicates of the 6 different temperatures). The samples were given to eat at room temperature. Texture assessment was performed at the end of each chewing sequence. Five descriptors (hardness, fibrous texture, juiciness, ease of chewing and duration in the mouth), associated to a non-anchored scale of ten centimetre, were assessed simultaneously.

Results

Influence of cooking treatment on mechanical properties of meat

Increase in cooking temperature from 45° to 80°C produced an overall increase in all the mechanical parameters, except phase angle. Under all test conditions, the increase in the mechanical resistance with cooking temperature was non-linear. Indeed, a drop of resistance was found at 60°C with the shear test whatever the configuration and with the transverse compression tests used in destructive conditions and at 70°C in the other conditions of compression tests (Figure 1). Viscoelastic properties also showed non-linear variation with cooking temperature. Both storage (G') and loss (G") moduli increased between 45° and 80°C, with a slight diminution above 55°C and at 70°C. Because of these different rates of increase, the phase angle i.e. the G"/G' ratio decreased nearly linearly with the cooking temperature which corresponds to an increase in the sample elasticity.

Influence of cooking treatment on the EMG recordings

All the parameters were analysed from the mean values of the group of subjects. The chewing time lengthens with the cooking temperature from 19. 3 to 29.2 seconds. However, a slight shortening (non significant) occurred for samples cooked at 60°C. The average burst duration of one burst varied in the 0.2-0.3 ms range and increased with cooking temperature. The sum area of all the bursts within one sequence could be considered as the muscle work necessary to prepare the food bolus to be swallowed. This parameter increased with the cooking temperature but a plateau is observed in the 55°-60°C range. It discriminated 4 groups of products with the highest F value (33).

Influence of cooking treatment on the sensory assessments

All the descriptors were significantly ($P < 0.001$) affected by the cooking treatment. Intensity of hardness, fibrous properties and duration in the mouth increased with cooking temperature. However, as already noticed with the mechanical measurements and EMG recordings, no strict linear relationship was observed between these descriptors of texture and the cooking temperature, there being a slight decrease in the 60°C samples. Hardness was the most discriminating descriptor (5 groups, $F = 69.7$). Ease of chewing and juiciness values varied inversely with temperature with the exception of a slight deflection of the curve for the 60°C samples. Juiciness continuously decrease from 45°C to 80°C.

Relationship between the three different approaches

The sensory hardness, the sum area of the complete chewing sequence (respectively the most discriminant sensory descriptor and EMG parameter) and the three mechanical tests (only those presenting the best correlations) have been correlated each others for each subject (Table 1). It appears that the best correlations between mechanical properties and hardness or sum area were always obtained for a given subject with the same mechanical test condition (destructive or non-destructive). Most of the coefficients of correlation were significant and often very high (up to 0.93). Excellent linear relation was obtained between sensory hardness and sum area (Figure 2). A higher SEM was obtained for sum area than for hardness.

Discussion

In the present study, the cooking temperature was studied as a unique factor of variation in texture, by three different approaches on the two *Semimembranosus* muscles of a single animal. With such a protocol, the mechanical parameters were highly correlated to psychophysiological parameters. The variations of these parameters with cooking temperature followed different patterns according to the test considered, with a local decrease either at 60°C or at 70°C. It seems reasonable that some mechanical tests are more sensitive to variations in the myofibrilar structure while others reflect modifications in the connective tissue, more particularly in the collagen network. However, this interpretation is not straightforward and not easy to generalise (Kamoun & Culioli, 1989). A decrease in mechanical properties at 60°C has been shown by several authors (Bouton *et al.*, 1981 ; Bouton & Harris, 1981). This decrease may be due to the modification of connective tissue. Indeed, at 60°C, collagen is denatured (Martens *et al.*, 1982) and its strength decreases from this temperature (Lewis & Purslow, 1990). However the decrease in resistance observed at 70°C is more difficult to interpret.

A regular increase in rigidity between 45°C and 80°C had also been observed by Bohlin *et al.* (1987). However, these results are not in accordance with those of Tornberg & Persson (1988) who found a maximal rigidity at 60°C.

Influence of cooking temperature on sensory properties of meat has also been studied by Martens *et al.* (1982) and Tornberg & Persson (1988). They observed a decrease in hardness when temperature increased from 55° to 60°-65°C which is in accordance with the present results. However, these authors found that the toughest meat was obtained for meat cooked at low temperatures (<55°C) which is contradictory to our results. Differences in collagen content, thermal stability of collagen and ageing state of muscles could be put forward to explain the discrepancy between these studies. But in the present study the mechanical, sensory and EMG results vary in the same direction, *i.e.* meat cooked at low temperature presented the lowest mechanical resistance, was considered as most tender and was chewed with the lowest muscle activity.

EMG measurements offer an objective texture analysis which is independent of the sensory knowledge of the subjects (Brown, *et al.*, 1994). This study suggested that individuals may analyse their muscle work in order to quantify sensory hardness. However, as subjects assessed the sensory descriptors without particular recommendation about the way to masticate food samples, they could have used their different oral conditions of deformation in order to obtain the best texture perception. Moreover, EMG recordings allow to quantify texture variations in a continuous way instead of only discrete discrimination as for sensory assessments.

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