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Effect of the direction of *m. psoas major* fibres on the results of tensile test - can we model meat as a material?

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Abstract. The aim of this study was to examine the possibility of tensile-test application at three strain rates (0.01/s and 0.001/s and 0.001/s) on suitable samples of grilled pork meat (*musculus psoas major*). Differences in the stress-strain curves were observed between the two directions of the muscle fibres (i.e. strain parallel to and transverse to the fibres). However, the strain rate of 0.001/s resulted in the most linear stress-strain curves for strain in both muscle fibre directions. Also, results confirmed that specimens tested transversally to the muscle fibre direction required less stress to fracture. We also concluded that specimens stretch more in the direction transverse to the muscle fibre direction for strain rates of 0.01/s and 0.001/s. Gaining knowledge from different methods of empirical mechanical testing of meat should enhance the possibility of forming material constitutive laws to be used as input to finite element simulations of industrial processes of meat such as cutting or of human oral processing.

1. Introduction

Oral processing from the moment of the first bite to the moment of swallowing includes mechanical changes of food structure during mastication, chemical changes related to oral enzymatic digestion, and temperature-associated transitions such as melting [1, 2]. Starting from the first bite to the moment of swallowing, food changes are caused by rhythmic motor activity of the jaw controlled by the central nervous system, and transportation of the food pile in the oral cavity by the tongue movements [1, 3]. The pathway of nonliquid food structure changes during mastication includes mechanical structure failure, further grinding of food particles, saliva incorporation, particle agglomeration, and bolus formation [4, 5].

The mechanical characteristics of food determine its behaviour as a material during oral processing, which means they determine such parameters as particle size distribution, eating rate, number of chews per gram, etc. Besides that, palatability of the food can affect food digestion, absorption of nutrients and the occurrence of disorders such as obesity or dyspepsia [4, 6]. Some authors have confirmed that denture wearers do not have the same patterns of meat mastication compared to fully dentate masticators [7].

Although the mechanical characteristics of food can be of great importance, there are not many studies that deal with the mechanical testing of meat. One of the reasons for this is that meat has a complex structure and so is considered as a composite and anisotropic material [8], which means that, for mechanical testing, it is hard to obtain appropriate samples consisting just of muscle tissue [9]. Also, we must bear in mind that other materials such as connective and adipose tissues are present in the meat as well. An additional factor that can affect the results of mechanical testing is the direction of the muscle fibres [8, 9]. Besides that, other factors such as: breed, feeding regime, sex, age, animal treatment before slaughter and carcass management can have an influence on meat toughness [8].

In the case of meat, Honikel [10] suggested the tensile test, Warner-Bratzler shear test and penetrometer measurements as appropriate methods of meat tenderness evaluation. Lepetit and Culioli [9] pointed out the suitability of the following mechanical methods for meat toughness examinations: Warner-Bratzler test, compression test, tensile test, penetrometry, multi-blade shearing, and bite test.

One of the latest trends in food science and engineering is mechanical characterization and modelling of food materials [11, 12]. Data obtained from these types of mechanical tests are needed for the definition of the material constitutive laws and can be inputs for further modelling of the material. In this study, the possibilities for mechanical testing of grilled pork meat (*musculus psoas major*) were investigated in terms of tensile tests. The working hypothesis was that results differ depending on the direction of muscle fibres.

2. Materials and methods

Pork meat used for this study (*musculus psoas major*) was commercially purchased at a London market. Preliminary tests were conducted on raw meat. Even though Honikel [10] considered it possible to conduct a tensile test on raw meat, our preliminary trials for this study showed it is hard to obtain uniform geometry and dimensions of tensile test specimens of raw meat. Therefore, in order to produce samples with adequate geometry, the meat was grilled. Figure 1 shows the dumbbell shape of the specimens for uniaxial tension, denoting dimensions. Dimensions were chosen according to recommendations provided in the literature [10].

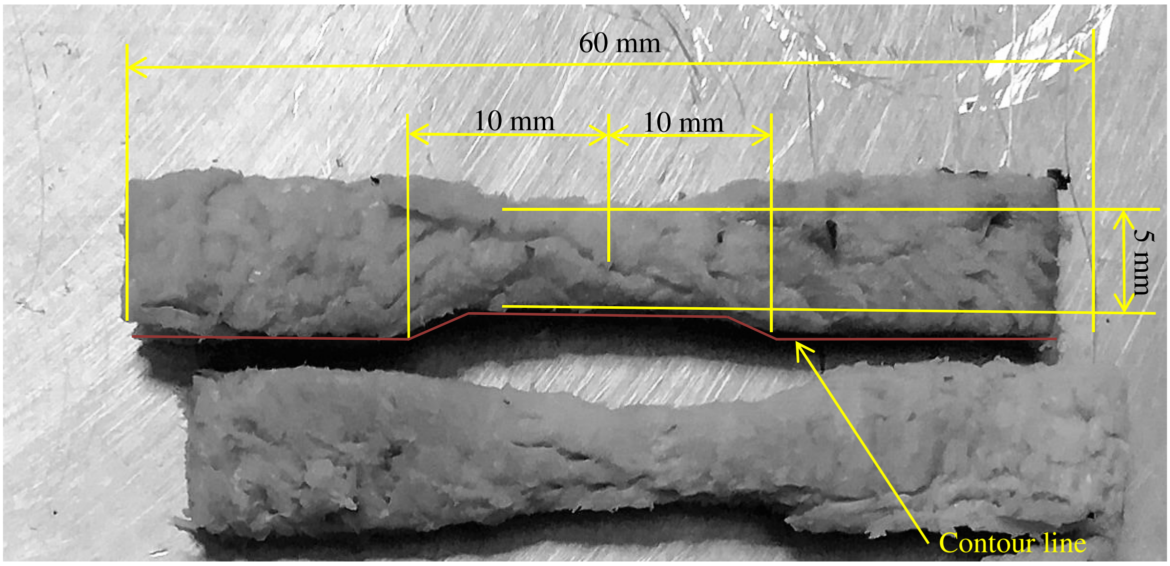

Figure 1. Dumbbell-shaped specimens for uniaxial tension test, parallel to the muscle fibre direction

Meat (3 mm thick slices) was grilled then cut with a razor blade in order to gain specimens as shown in Figure 1. Specimens were cut from the grilled meat with a metal cutting template parallel to the direction of muscle fibres and transverse to the direction of muscle fibres. Hence, two types of specimens were obtained for the tensile tests.

Before tensile testing, the dimensions of all grilled meat specimens were measured with a digital Vernier caliper of 0.1 mm accuracy. Specimen measurements were as follows: height: 19.00±1.50; width: 4.91±0.74; thickness 3.49±0.77. They were labelled with a marker at three points along the gauge length in order to track uniformity of specimen deformation during the test. For this purpose, all tests were video recorded (Figure 2).

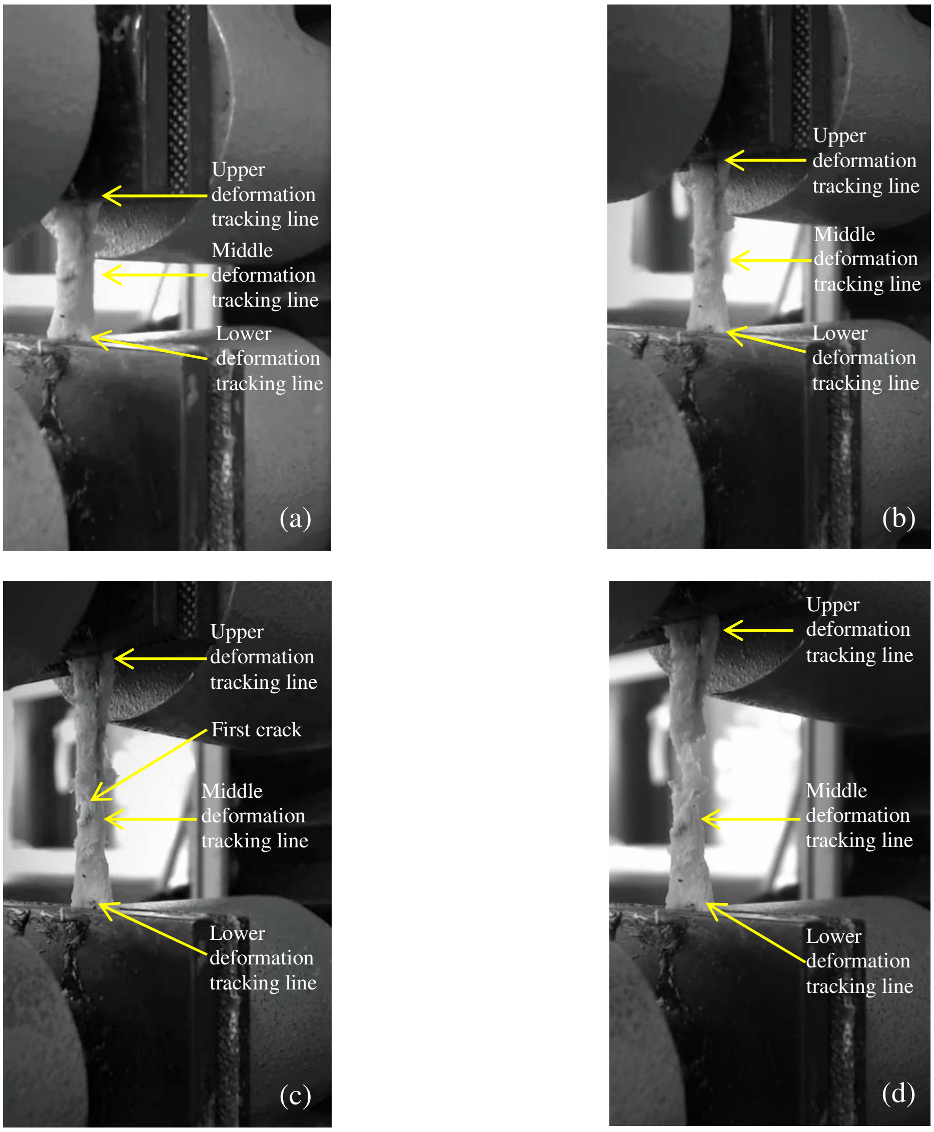

Figure 2. Specimen deformation during the tensile test, parallel to the muscle fibre direction, 0.1/s constant strain rate; (a) specimen before the beginning of the test; (b) tension of the specimen; (c) first crack of the specimen; (d) specimen material failure

Tensile tests were conducted on an Instron machine 2530. All tests were performed with the 10 kN load cell. The strain rate dependency was assessed via monotonic tests at three constant true strain rates: 0.001/s, 0.01/s, and 0.1/s. For each of the two different muscle fibre directions and each of three strain rates, five replicates were conducted. All data are shown below as mean values, using standard deviation as error bars. The true (Cauchy) stress, σ, *versus* true (Hencky) strain, ε, were calculated using the following equations:

$$\begin{aligned} &(a) \qquad \sigma = F/A_i \\ &(b) \qquad \varepsilon = \ln(H_i/H_o) \end{aligned} \tag{1}$$

where A_i is the instantaneous cross-sectional area of the specimen, F is the corresponding force applied and H_o is an original reference dimension of the specimen (gauge length in tension) together with its deformed value, H_i.

Tests were performed in a laboratory maintained at 23°C and 50% relative humidity.

3. Results and discussion

Tensile tests resulted in six stress-strain diagrams, three for each of the muscle fibre directions. For both of the directions, three tensile tests were conducted at 0.1/s, 0.01/s, and 0.001/s constant strain rate (Figure 3). Even though video analysis of the testing was employed, with the aim of excluding unsatisfactory data from further data analysis, the diagrams show significant variability in the stress-strain data. Still, differences in the stress-strain curves can be noted between the two directions of the muscle fibres.

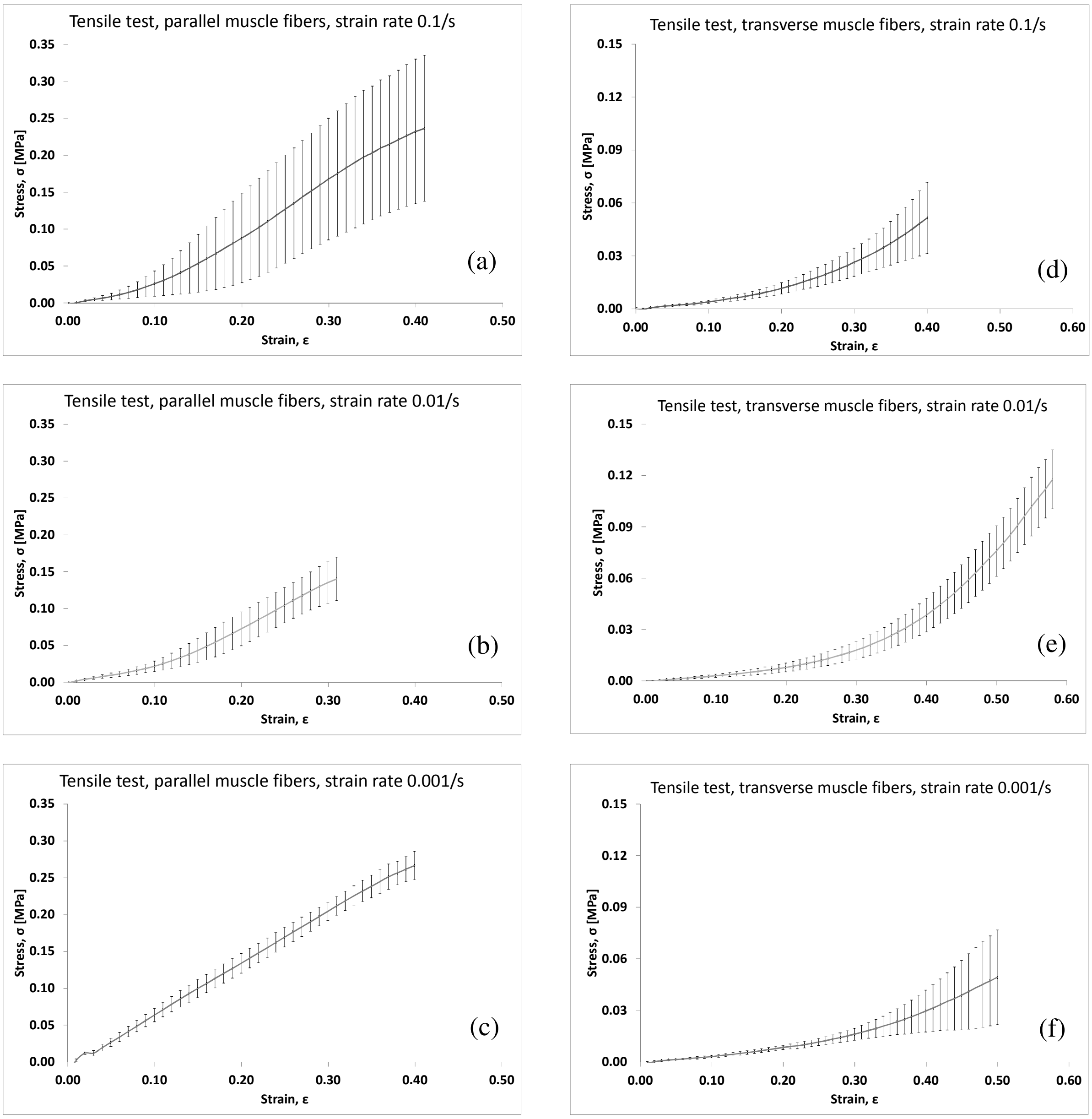

Figure 3. Stress-strain curves; (a) monotonic tension, 0.1/s strain rate, parallel to the direction of the muscle fibres; (b) monotonic tension, 0.01/s strain rate, parallel to the direction of the muscle fibres; (c) monotonic tension, 0.001/s strain rate, parallel to the direction of the muscle fibres; (d) monotonic tension, 0.1/s strain rate, transverse to the direction of the muscle fibres; (e) monotonic tension, 0.01/s

strain rate, transverse to the direction of the muscle fibres; (f) monotonic tension, 0.001/s strain rate, transverse to the direction of the muscle fibres

Comparing the diagrams, it appears the strain rate of 0.001/s resulted in the most linear stress-strain curves for both muscle fibre directions. From Figure 3, it can be concluded that specimens tested transversally to the muscle fibre direction required less stress to fracture. On the other hand, by considering Figures 3b, 3c, 3e and 3f, for the strain rates of 0.01/s and 0.001/s, it appears the specimens of grilled meat stretched more in the case of the transverse muscle fibre direction.

Grilling the meat improved the shape and uniformity of the specimens' dimensions, but further enhancements are still needed. Because of the material cracking between the muscle fibres when the specimens were cut from the grilled meat, future testing should reconsider the replacement of metal cutting templates with a suitable manual press. Also, the drying of the specimens during the tests should be considered.

3.1. Future modelling of the results

There are two basic approaches in modelling meat as a material. The first is reproducing food separation patterns under strain tests, which could resemble boundary conditions applied when modelling the chewing of meat using finite element analysis [11, 12]. This should allow information on the mechanical behaviour of meat to be obtained. Such information could enhance better our understanding of the structural changes of meat during oral processing.

The second approach is introducing mechanical characteristics of meat as oral processing parameters in order to model specific quality parameters, using quality function deployment [13], or quality index models [14]. This type of modelling can enable quality improvement aimed at satisfying the consumers as well as translating the consumer's oral processing demands into meat quality targets.

Recent research conducted by Dekkers et al. [15] deals with structuring of meat analogues. It can be assumed that better understanding of meat's mechanical properties would improve the structure of meat analogues. Some recent studies are introducing novel technologies in the area of food science and engineering, such as 3D food printing. Most of these studies are investigating the applicability for 3D printing of plant origin materials such as potato starch [16], pectin [17] or xanthan gum [18]. Gaining knowledge of meat mechanics and related structure characteristics should lead to future progress in the design of foods through 3D food printing, which is a promising area in the field of food engineering.

4. Conclusion

Literature findings point to the possible difficulties regarding mechanical testing of meat. Although some authors maintain it should be possible to conduct mechanical tests on raw meat, preliminary studies for the present research revealed this type of testing as inappropriate. On the other hand, limited scientific findings analysed mechanical testing of grilled meat.

With the aim of examining the uniaxial tension of grilled pork meat, monotonic tensile tests with constant strain rates were performed for two different muscle fibre directions and three different strain rates. This research revealed differences in the stress-strain curves between the two directions of the muscle fibres. The strain rate of 0.001/s resulted in the most linear stress-strain curves for both muscle fibre directions examined. Also, this study showed that the strain testing transversally to the muscle fibre direction required less stress for the muscle fibres to fracture.

This study highlights the need for understanding various breakdown mechanisms during chewing of meat as one of the most complex food materials. Modelling should try to utilize food disintegration and bolus breakdown and its relation with the original mechanical and physical properties of meat. Further research could cover various types of meat and chemical changes that occur due to saliva incorporation or enzymatic gastric conditions. Meat structure and related mechanical characteristics are required as inputs to novel food engineering methods such as 3D printing of food.

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