Meat. Structural aspects of cooking
A micro X-ray tomography study

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***Abstract* -The present paper presents tomographic images of meat pieces obtained by x-Ray micro-CT. Besides introducing the micro CT technology in meat research, it attempts to give some insights into clarifying the 3D structure of meat fibers in the raw meat and in meat after different cooking methods, as well as discussing the role of the spatial architecture of meat fibers in the tenderness of meat.**

Meat pieces were analyzed with high resolution micro CT after minimal preparation. The micro CT method is currently used for exploring the full 3D structure of mineralized tissues such as bones, tendons and ligaments, as well as for studying the structure of soft tissues after heavy metal staining. For the first time this method is used for studying the meat structure. Raw pieces of meat were partially dried in the fridge for 36 hours, whereas cooked meat was scanned without any preparation following cooking.

For the first time, I show in this paper the 3D structure of raw meat at room temperature and without any preparation (no chemical fixation, no extensive drying and no freezing). Meats of different origin (mainly chicken and beef) are compared. The structures of raw and cooked meat are also compared. It is shown in this work that the internal structure of different kinds of meats is different and it is implied that this structure may be an important factor in determining meat tenderness.

I. INTRODUCTION

Animal muscle becomes meat after *rigor mortis* (post mortem rigidity) is installed. The organoleptic properties of meat are extremely hard to estimate, since historic, educational and religious background of each consumer is involved, but its texture and tenderness are relatively easy to estimate, either by laboratory techniques (1-3) or by simple tasting.

Animal muscle is made of huge cells called muscle fibers that include the actin/myosin/sarcoplasmic reticulum apparatus that allow muscle contraction (4). The size of those fibers increases with the age of the animal and depends of the cut of the meat (5,6). The muscle fibers are surrounded by fibrous connective tissue mainly made of collagen fibers and of elastin (4). The amount and type of collagen, mainly of type I and III, which depends on the degree of activity of each muscle (7,8) is supposed to be the central element inducing meat rigidity while its solubility and its cross-linking are supposed to be of a secondary importance (6). Also the presence and amount of elastin and proteoglycans in the fibrous connective tissue (9) is considered to be a factor of a lesser importance in determining the meat tenderness. Ideally, the problem of meat texture and its rigidity can be addressed by visualizing the complex structure of the fibers and their surrounding tissue in different types of muscle. Several studies attempted (since the beginning of the 20-th century) to visualize and measure some muscular structures, such as the fiber size, but they aimed at resolving the puzzle of muscle contraction, not the meat structure. In fact, there is a lot of work done on chemistry and genetics of meat and meat animals as opposed to the scarce structural effort (see however 10-12). Mainly because there were no adequate experimental methods to address the complex 3D architecture of meat fibers, the prevalent opinion is that the spatial structure of meat fibers is either not important in meat tenderness or is destroyed before cooking (see 11). The result is that structural knowledge of meat is scarce. Actually we know more on the structure of collagen fibers in the connective tissue than on the spatial architecture of fibers in different cuts of meat.

Different traditional techniques of meat cooking were developed in order to reduce meat rigidity, some of them being more efficient than others, and each of them adapted to certain cuts of meat. With the exception of hanging, which is designed to apparently lengthen the postrigor sarcomere length and decrease the fiber diameter (13), the reduction of thoughness induced by *rigor mortis* is done by cooking, marinating, and conditioning meat. This attempts at affecting the collagen matrix either by "melting" it into fat (broiling or grilling) or by destroying it by maintaining the meat for longtime at temperatures close to 100^{o} C (boiling or stewing). Until this paper, we didn't know how the 3D structural arrangement of meat fibers is affected by different cooking methods.

The present paper presents tomographic images obtained by x-Ray micro-CT of meat pieces. It addresses both unresolved questions raised above: the 3D structure of meat fibers in the raw meat and the structure of the meat after cooking. Apparently, until now, nobody realized that one can study meat by x-ray. It is probably the high Ca++ ions around the myofibrils that absorb a certain amount of x-ray which renders them visible in any piece of meat that was treated to remove some of the water background. I show in this paper tomographic images of both raw and cooked (grilled and micro waved) meat of beef and chicken origin and discuss structural differences between different cuts of beef. Aside from introducing the micro CT use in food research, the paper discusses the possible implications of the 3D structures in the rigidity of meat.

II. MATERIALS AND METHODS

1x1 cm of different pieces of meat (chicken breast and beef tenderloin, rib eye steak and chuck steak) was used. The meat was not treated with salt or chemicals, but different cuts of beef were not from the same animal. Also, since the meat was purchased on the free market, post mortem storage period is unknown to the author.

The center of the meat piece, a parallelepiped 1 cm high and with an almost square section of 1.5x1.5 mm was isolated and immobilized by applying a slight pressure into a standard 0.2 ml empty pipette tip. The pipette and tip containing samples were examined in a micro CT instrument (Mxct 400, XRadia, USA) under 40KV and 200 mA. The typical magnification was 4x. No x-ray source filter was used. The results were obtained with a pixel size of 5.08 mm.

III. RESULTS and DISCUSSION

I am still puzzled by the fact that one can actually visualize unstained meat in the X- ray. I have no clear explanation of this. Fig 1 shows snapshots (2D rendering) of the volume image of a piece of raw chicken breast meat dried for two days in the fridge compared to the image a similarly conditioned piece of beef chuck steak. It is easy to observe the random architecture of the muscle fibers in the chicken meat as opposed to the parallel fibers seen in the beef (see arrows). Although the image does not have the contrast to reveal individual fibers, their overall spatial arrangement is clearly visible. There is no need of sophisticated analyses to be sure that the chicken breast meat is tenderer than the beef. It may be that the clear difference in the 3D order of the fibers which is probably the result of less collagen in the chicken than in the beef, is not the only cause of the difference of texture, but it should be an important one.

The difference is amplified by different cooking methods. Fig 2 shows two pieces of the same meats after 4 minutes of pan grilling showing a mostly oriented matrix of fibers in the beef (fig2C) versus an unordered bunch of chicken breast fibers (fig 2A) in which some have been affected by Maillard reaction and look brighter in the image.1.5 minute microwaving at 750W induce a drier state of the samples and allows us to actually observe individual fibers in the beef sample (fig2D). In the beef piece they are almost parallel to each other while the chicken breast is only slightly domain oriented (fig 2B). Even slow industrial meat processing leading to chicken pastrami (see fig 2E) keeps the unordered structure of the meat fibers.

IV. CONCLUSIONS

The tenderness of meat depends of many factors, such as the quality and quantity of the collagen fibers, the amount of elastin, the thickness and length of muscle fibers, and so on. The paper shows that those factors induce slight but observable different 3D structure in different kind of meats, both of different origin and of different position and activity of the muscle from which it is derived. It appears that the less ordered is the architecture of the fiber matrix of the meat, the tender it is.

It may be possible that the old alchemistic-like dream of meat producers to transform bad cuts of meat into a very high quality product will never be fulfilled, but it becomes clear from this work that, in order to improve the quality of lower class meat cuts without recurring to expensive elevation techniques for animals, or to genetic modifications and chemicals, one should strive to alter the organization of the fibers inside the meat.

REFERENCES

1. Smith, G. C., Z. L. Carpenter, and G. T. King.. ***Considerations for beef tenderness evaluations.*** J. Food Sci. 34 (612–618) 1969
2. Smith, G. C., C. W. Spaeth, Z. L. Carpenter, G. T. King, and K. E.Hoke.. ***The effects of freezing, frozen storage conditions, and degree of doneness on lamb palatability characteristics***. J.Food Sci. 33(19–24) 1968
3. Shanks B. C., Wulf D. M. and Maddock R. J. ***Technical note: The effect of freezing on Warner-Bratzler shear force values of beef longissimus steaks across several postmortem aging periods*** J. Anim. Sci.. 80(2122–2125) 2002
4. Hertzman, C., U. Olsson, and E. Tornberg, ***Principles of meat science****, 3rd* ed., Kendall/Hunt Publishing Company, Dubuque, Iowa. (1993)
5. Hammond J. ***Growth and the developpement of mutton qualities in sheep***, Oliver and Boyd London 1932
6. Hiner,R.L Hanxins O.G, Sloane H.S, Fellers G.R and Anderson E.E ***Fiber diameter in relation with tenderness of beef muscle***, Food Res. 18 (363), 1953
7. Bayley A.J and Light N.D, ***Connective Tissue in meat and meat products*** Elsevier, London-New York (1-355) 1989
8. Brendall, J.R. ***The elastin content in various muscles of beef animals*** J.Sci. Food and Agriculture 18 (553-558) 1967
9. Locker, R.L. ***Degree of muscular contraction as a factor in tenderness of beef,*** Food Research 35 (304) 1960
10. Nishimura, T ***The role of intramuscular connective tissue in meat texture*** Animal Science Journal **81 (** 21–27) 2010
11. Lepetit, J. ***Collagen contribution to meat toughness : Theoretical aspects*** Meat Science 80 (960-967) 2008
12. Jones S.B, Carroll R.J and Cavanaugh J.R ***Structural changes in heated bovine muscle : A scanning electron microscopy study*** J.Food Sci. 42 (125-131) 1977
13. Herring H. K., Cassens R. G., and Briskey E. J. ***Further Studies on Bovine Muscle Tenderness as Influenced by Carcass Position, Sarcomere Length, and Fiber Diameter*** J. Food Sci 30 (1049-1054) 1965

FIGURE

Insets show typical 2D slices inside the volume limited by the marked area, not merely enlarged image of the surface.

Fig 1 **The 3D Structure of raw meat** from (A) chicken breast and (B) chuck steak dried in the fridge for two days (40 hours).

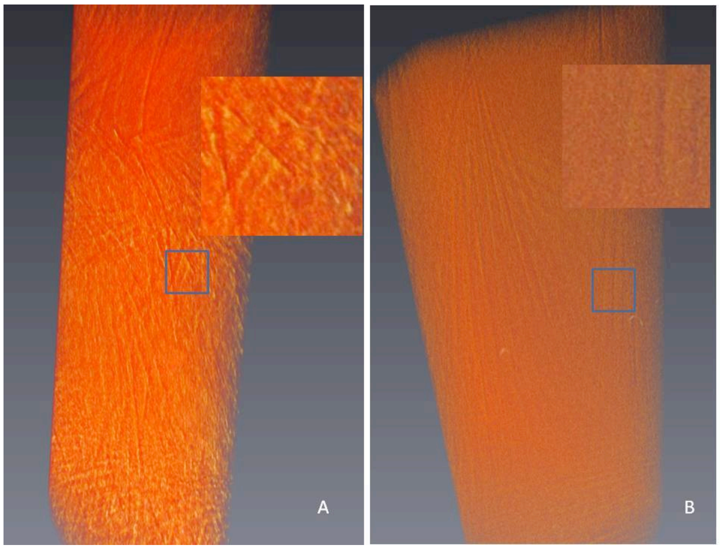

Fig2 **Tomographs of cooked meat of different origin** (A) and (B) show grilled and respectively microwaved chicken breast meat, while (C) an (D) are images of beef under the same conditions. All pieces of meat were cooked together. Image (F) shows a tomogram of a piece of chicken pastrami.