EARLY INVESTIGATIONS ON THE ACCELERATION OF POST-MORTEM TENDERIZATION OF MEAT BY ELECTRICAL STIMULATION

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This review of early work on electrical stimulation of meat animals at slaughter might properly begin with the classical studies on muscle by Luigi Galvani in 1791 (1) . In 1749 Benjamin Franklin killed turkeys by a single electrical discharge as a rather sporting demonstration of the marvels of electricity and indicated he believed that the meat was more tender (2) . He even proposed such discharges as a means of dispatching other meat animals but, not infrequently, animals recovered from the shock if not dressed immediately. Nothing seems to have been reported on electrical stimulation of meat animals at slaughter until 1951 when Albert Harsham, Harvey Rentschler and myself proposed the process as a means of promoting tenderness of meat (3, 4) . I mentioned this work at a symposium at the 75th celebration of the American Chemical Society in 1951 and also the next year at the Reciprocal Meat Conference of what is now the American Meat Association (5) .

World War II presented the U. S. A. with a great multiplicity of new food problems. As a young researcher suddenly immersed in these problems I was bewildered but soon realized that answers to many food problems might be found in the biochemistry and physiology of organisms from which our food comes. This is certainly true of meat as the Low Temperature Group at Cambridge so effectively demonstrated in the 1920's and 1930's.

In the 1930's the Kroger Co. and Westinghouse Electric Corp. independently investigated the aging of meat at elevated temperatures. This led to interference in patent applications and the two companies cooperated in a research venture at the Mellon Institute. The result was a patent to James in 1939 (6) . The process, initiated commercially in the late 1930's, was essentially slaughtering animals and chilling the carcasses in the conventional way and then warming the carcasses in a controlled humidity room in the presence of ultraviolet light to control surface bacteria. When the desired tenderization had been achieved the carcasses were chilled and marketed under the "Tenderay" trademark.

As with any new commercial process further developmental work was necessary. Walter Reiman and his coworkers were primarily responsible. The most efficient application of the James process was essentially as follows: Animals were slaughtered and dressed in the usual manner. The sides were chilled to 13-15^0 C internal temperature which usually required 20-24 hours. The sides were then placed for 40-44 hours in a room equipped with ultraviolet lights and circulating air at 20^0 C and approximated 75% relative humidity. The carcasses were then chilled below 4^0 C for marketing.

Reiman and coworkers studied a large number of animals comparing the tenderness of matched sides of beef--one chilled out conventionally and the other held at varying conditions of time, ultraviolet light, temperature, humidity and air flow. These studies established that an economically objectionable number of sides would develop deep spoilage if the sides were not chilled out to 15^0 C or below within 20-24 hours of slaughter. This limited options for aging meat at elevated temperatures. Another observation was that tenderness did not seem to improve significantly if the carcasses were held 48 to 60 hours at 20^0 C. Holding sides at 20^0 C beyond 60 hours was not desirable. These and other observations revealed that we needed to know much more about the nature of tenderness and the process of post-mortem tenderization. Albert Harsham and I became involved because of our biochemical and physiological orientation. The work of W. A. Engelhardt, A. and A. G. Szent-Gyorgyi, H. H. Weber, their colleagues and many others provided a wealth of new knowledge on the biochemistry and physiology of skeletal muscle--meat.

In order to study the nature of the tenderization process it was necessary to determine the reproducibility of our method for measuring tenderness. We found that the paired organoleptic test for tenderness that was being used was far more reliable than any mechanical device then proposed or which we ourselves had designed (7) .

Next we needed to know how tenderness changed with aging time. It was found (8) that tenderness was not a uniformly increasing function with aging time at 1^0 C. Beef aged for 17 days was as tender as beef held for 24 days, Fig. 2. This explains why meat aged 44 hours at 20^0 C is as tender as meat aged 60 hours at that temperature.

From data available to us on aging at elevated temperature it was possible to make some estimates of the temperature coefficient of the tenderization process. Cooling curves were plotted for conventionally chilled and aged carcasses and those aged at elevated temperatures. By measuring the areas under the curves it was possible to estimate the energy units contributing to the tenderization process. It was clear that arithmetic plots did not agree with observations on tenderness. The best agreement was with temperatures plotted so as to give temperature coefficients, Q_{10}, in the range of 2. 0-2. 5, the range of values for most thermochemical processes of physiological significance. To illustrate within the area available here, Figure 3 has been prepared with some license in that the exaggerated temperature scale is plotted to begin at 10^0 C rather than 0^0 C and with Q_{10} = 2. 5. The simple temperature scale is with smaller numbers and narrower lines while the Q_{10} = 2. 5 temperature scale is with larger numbers and broader lines. If the tenderization for conventional beef begins at the minimum pH at 24 hours, then the area under curve AA extended to 17 days does not approximate the area under AC for beef at 4 days which had been subjected to the elevated temperature process even though

the tenderness values of the matched sides for the two processes are comparable. The areas from 24 hours under BB for 17 days and BC for 4 days are more nearly equal. If the onset of the tenderization process (minimum pH) could be advanced from 24 hours to 5 or less hours, then the areas under BB from 5 hours and BD from 24 hours would be comparable.

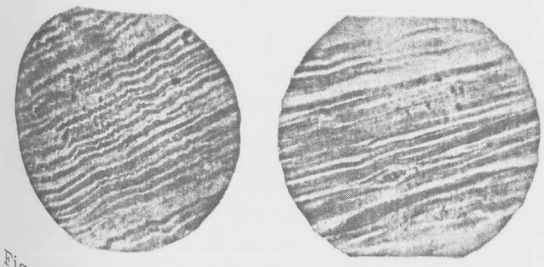

Fig. 1. Microscopic sections of normal (left) and electrically stimulated (right) beef muscle. Reproduced from Ref. (3).

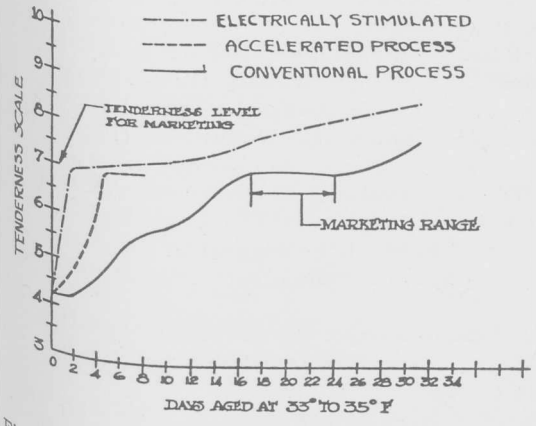

Fig. 2. Changes in tenderness of beef normally aged at 1-2° C, aged at elevated temperature, and electrically stimulated. From Ref. (3).

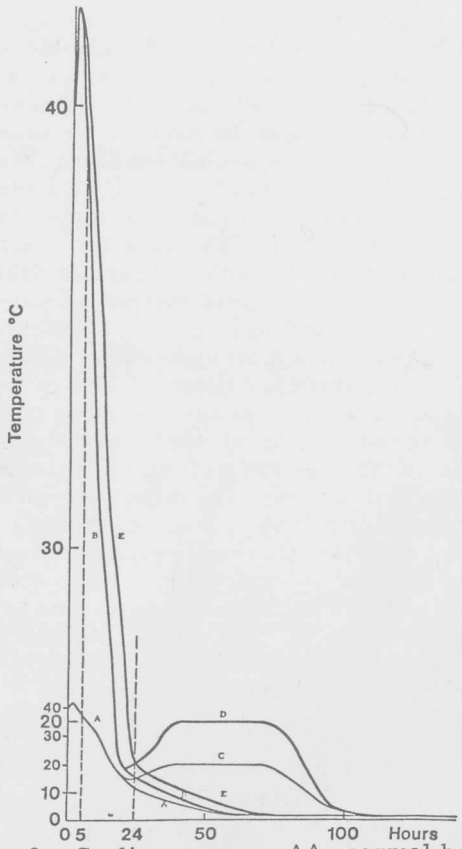

Fig. 3. Cooling curves. AA, normal beef AC, elevated temperature aging, arithmetic scale, BB and BD same curves on scale Q_{10}=2.5 from 10° C. EE slightly slower cooling rate.

Harsham studied muscle histologically as it aged. His slides were similar to those available in the literature--some fibers straight with contracture nodes and most others crinkled in apparent passive shortening. As muscle aged, he observed that the straightened fibers appeared to become disorganized faster and to take stains less readily than wavy fibers. We interpreted this to mean that the straight fibers were changing more rapidly than the others. Could we put all the fibers in the straighter or contracture mode? If so, the tenderization process might be promoted. Having had experience with didactic exercises on the irritability and contraction of muscle, it was logical to try electrical stimulation. Our first experiments were with rabbits. The animals were stunned, bled, and then stimulated to exhaustion using 60 hertz, 115 volt house current. Muscle pH dropped rapidly. Histological study confirmed our hypothesis that electrical stimulation would put the muscle fibers in a straightened mode. These results suggested another hypothesis--that the process of post-mortem tenderization does not begin until after the latent energy of stored ATP and glycogen had been expended. If we assumed that the onset of post-mortem tenderization coincided with the time when muscle reached its minimum pH, it was at once apparent that conventional beef carcasses were largely chilled out before tenderization would begin. Since minimum pH values are reached from 18-24 hours as the carcass temperature is decreasing, the processes of tenderization would occur at a much slower rate than if they were to begin at body temperature at slaughter.

Our initial experiments on cattle were done comparing stimulated with unstimulated sides of conventionally dressed beef. Stimulation was done by using 60 hertz, 115 volt house line. The ground was attached to the rail and the charged wire was attached to a metal lawn leaf rake with flexible tynes attached to a wooden handle. The sides were stroked over the entire length until contraction essentially ceased. The pH of the stimulated sides dropped quickly and rigor mortis rapidly set in. Histological studies (Fig. 2) confirmed the rabbit studies and tenderization was unmistakable.

The Director of Research of Westinghouse Lamp Division, Harvey Rentschler, was fascinated by our work and personally collaborated in a series of experiments studying electrical parameters of voltage, frequency, wave form, electrodes, etc. for the most effective stimulation. On numerous occasions he joined us in the packing plant experiments. We did many experiments over a year's time--using 8 or 16 animals per experiment almost on a weekly basis. USDA Meat Inspectors were cooperative at this stage. All of these tests indicated a reasonable latitude of voltage and wave form was permissible so long as the frequency was in the same

order of magnitude as the physiological frequency producing a normal tetanus contraction. However it became obvious that for packing house practicality, stimulation would be more effective and easier to apply immediately after bleeding and before dressing out. At this point inspection officials became less cooperative. Kroger sold its packing plant to Swift and Co., but we arranged to continue our work in a much larger plant in a different USDA district. We explained our research program and summarized our results to the inspection supervisor of the new district. He was fascinated and even before we had a chance to ask permission to stimulate carcasses immediately after stunning and bleeding, but before dressing, the supervisor himself proposed this approach that the previous supervisor would not allow us to study. We received excellent cooperation from local USDA inspectors for another year as we concluded that we had sufficient information to begin commercialization of the electrical stimulation process. Sadly, the cooperative USDA official suffered professionally for helping us. Such was the mood of the time.

With information we had accumulated, the process operated preferably as follows: Immediately after stunning, bleeding, and head removal, electrodes were attached at the neck and bared foreshanks. The ground terminal was the suspending shackle chain and hanging rail. Contact was assured by having the hind legs wet by water or salt solution. The stimulation was accomplished by using 60 pulses per second at voltages in the range of 2000-2500 volts with low current density. Stimulation was continued until contraction essentially ceased. The frequency approximated normal physiological stimulation frequencies and the current density was kept low to prevent localized heating at electrodes since high current densities are unnecessary for stimulation. The voltage was a bit higher than we wished but it was necessary because of carcass length and because we wanted to get sufficient potential differences throughout the carcass to cause contraction of all muscles. The process and equipment are described in detail in the patents (3, 4) .

When we made comparisons of electrically stimulated beef which had been rapidly chilled out with conventional aging at 17 days and with aging at elevated temperature, we found that the electrically stimulated beef was slightly less tender. The difference seemed to us not to be of significance for marketing meat. Nevertheless, we found that by slowing the chilling rate all three processes gave comparable tenderness, Figure 3, The slower chill rate was accomplished merely by placing the carcasses in a 20^0 cooling chamber for a few hours and then transferring them to the customary cooler at 1^0 C. This observation and others seemed to indicate that perhaps the actual tenderization process did not begin at full rate at the point of minimum pH drop but a short time after. The delayed process is shown by curve EE Fig. 2 in which we suggest by the dotted line that tenderization process might be fully underway at 5 hours and 24 hours for the electrically stimulated and conventional carcasses respectively.

We had hoped that rapid drop in pH of electrically stimulated beef might obviate the necessity of chilling carcasses internally to below 15^0 C in 24 hours to prevent deep spoilage. Experiments showed that this was not the case. The pH of lymph nodes did not decrease as did muscle tissue.

A fair number, but not all, carcasses went into rigor mortis rapidly, even before skinning. We were concerned that workmen would object to skinning such carcasses. They did not, but USDA inspectors were a bit uneasy. A number of carcasses regained some irritability within a half hour of initial stimulation. Also we observed that following electrical stimulation it was not uncommon to find carcass temperatures slightly higher than conventional carcasses. This is indicated in a slightly exaggerated manner in Figure 3. This elevation in carcass temperature might be expected because the essence of the process is the rapid dissipation of stored energy in muscle. Another observation confirmed the correctness of the then newer theory that rigor mortis was a result of the reaction of contractile proteins rather than stiffening due to low pH. I well remember two very dark cutters, pH 6.6 and 6.8, which went into rigor shortly after stimulation.

As word about our experiments spread among the packing house workers the sausage makers became interested. They readily tried hot-boned electrically stimulated meat and found it satisfactory whereas they did not like hot-boned conventional meat. However these trials were not well controlled.

We made preliminary studies comparing refrigeration costs. They were considerably less than for conventionally aged beef or for beef aged at elevated temperature. This was a time of cheap energy costs in the USA and so this aspect of the new process was less attractive than it is now.

Currently in the USA much attention is being given to improved color of rapidly chilled stimulated beef in comparison to the color of conventional beef. In our work we did not attach too much significance to this because beef aged at elevated temperatures offered no color problems.

World War II ended. Kroger decided to go out of the meat packing business and to renew its emphasis on retail merchandising. In the decade before the war, the company had pioneered in developing strong and effective programs of market and consumer research and quality control. Kroger's interest in meat tenderness evolved from this approach to marketing. Contributing to this decision was USDA's ultra conservative status quo attitude regarding any modernization of the meat industry which not only related to electrical stimulation but to other processes as well. We had also been involved with processes to upgrade the quality of lard (9) only to be blocked by staid USDA policies. As Kroger left the meat packing industry, they decided to curtail their research program. Westinghouse being a research oriented company, wanted to go ahead, but they decided not to pursue the program further because of their unfamiliarity with the meat processing industry and because of the prevailing attitudes of the large meat packers. Though large in size, the major packers had almost miniscule research programs on fresh meat and were reluctant to consider any new venture not their own, particularly when government approval would have to have been expensively negotiated.

As with most research ventures, more unanswered questions arose than could be studied. This was so with the work just summarized. It was, of course, impossible for me to continue work on the electrical stimulation process when I returned to the University. I wanted so much to do some more work on the process when the perceptive research of J. Wismer-Pederson on watery (PSE) pork appeared. It raised some questions about electrical stimulation that needed clarification even though in our work we had not observed a similar condition in beef due to rapid drop in pH caused by electrical stimulation. Many ideas spawned by our

work lead directly to much of the later work on meat by my colleagues, students and myself relating to the etiology of deep spoilage; vascular processing; the relationship of feeding management, breed and sex to meat quality; water holding capacity and chemical changes during processing.

It is a privilege to participate in this session. But let there be no illusions, this session is a direct result of the creative and thorough work at the Meat Industry Research Institute of New Zealand. We are all aware of their research on thaw rigor and cold shortening as they studied the nature of tenderness and its opposite toughness which was related to rapid and efficient chilling of carcasses. These workers independently recognized that hastening the natural post-mortem changes before chilling and freezing might solve their difficulties. They found that electrical stimulation was a workable solution and they persevered and put it into commercial operation. Their work stimulated research in other laboratories, particularly in England and Australia. The group at Texas A and M University has brought the process more directly to the attention of the meat industry in the USA. Clearly our work was ahead of its time. The patents covering the concepts and principles of the electrical stimulation process and the equipment for carrying it out expired over 12 years ago. All of us who had a hand in the earlier work are happy that electrical stimulation at slaughter is coming into its own. Not just for the process itself but its acceptance and application indicates a more progressive attitude by industry and by government regulators. For me personally, I am pleased and happy to read the many contributions in the area and reflect back to see how new information and ideas of so many investigators fit our own observations of a third of a century ago.

For this group it is fitting to add an anecdotal postscript for not just a few at this Congress were suffering greatly while we were involved in our work in 1944-46. I was a young biochemically oriented scientist who found himself working with one of this country's highly respected and honored physicists and industrial scientific administrators, Harvey C. Rentschler, who was approaching retirement. He was of Pennsylvania Dutch descent and a generous, warm, calm, mild mannered and cultured scholar who took every opportunity to open new vistas to a young fellow. After all he had been a university professor for more than a decade before he joined Westinghouse in World War I. He often took an overnight train to come to work with us for a day or two even though we knew that he was responsible for war-time projects, the nature of which we did not know. He and I had just completed a 10-hour session of experiments in a hot, humid packing house on a fateful day in August 1945. While dressing for dinner the Hiroshima bomb was announced. As we met for dinner in a fine restaurant, Dr. Rentschler was a man transformed. Always a man who enjoyed excellent food, he ate almost nothing. Always an excellent conversationalist, he would not talk much. Obviously in preoccupied thought, he would mumble a bit, and then make non-informative exclamations about the momentous event. Finally he pulled himself together and said "Excuse me for being poor company but I know more about this (bomb) than I can tell you. Maybe later." Indeed he did. On a visit to his home almost two years later, he showed me a 1/2 x 1 x 1 inch piece of very pure uranium, the model for use in the first atomic pile. He was responsible for producing the uranium for the atomic bomb program. Shortly after World War I, Dr. Rentschler had prepared pure uranium, learned how to work it and investigated its potential as a filament for lamps and vacuum tubes. In 20 years he had prepared only a few grams of uranium of such purity as a research service to chemists and physicists. Suddenly in World War II he was asked to secretly produce uranium in tonnage quantities in his research laboratories in New Jersey. He did. And this was his responsibility while doing experiments on the electrical stimulation of beef.

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