THE IMPACT OF MUSCLE PHYSIOLOGY ON MEAT RESEARCH

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The final and by far the most important judge of meat quality is the ultimate consumer. It is his assessment of wholesomeness, tenderness, flavour, colour and texture which will determine the amount of meat he will eat and the price he will pay for it. His response, admittedly, will be less rapid, less unanimous, and perhaps less directly stated than that of the producer or processor, whose opinions will be based on quite different characteristics. But in the long term it is his views which will prevail, and his wishes which will have the greatest influence on the future demand for meat and meat products. His simple--even though far from straightforward--judgement of meat quality is thus much more than a mere guide allowing us to pander to the likes and dislikes of the individual. His opinions, magnified many million fold, will determine the future of meat and animal production, the agricultural policies of governments, and the economic well-being and stability of nations.

Our average consumer eats many foods other than meat, and uses many facilities and materials other than foods. In the twentieth century, and more particularly during the past twenty years, he has become accustomed to continuing rises in his standard of living, to increasing ranges of labour-saving devices, to wider interests filling more leisure hours, and to frequent upward quality changes in many of his foodstuffs; constant improvement is now the accepted norm, and the manufacturer knows all too well that to stand still is to move backward.

It is more than a little surprising, therefore, that the consumer has not demanded a comparable rate of obvious upgrading in his meat. Granted, there have been many desirable changes. New processes have added more variety to his intake, new packs have introduced more eye-appeal, new selling methods have simplified purchasing operations. But if shelf-life is increased, it is to the benefit of the processor and distributor rather than of the consumer. If the incidence of food-poisoning organisms is reduced, it will not register as a positive advantage to the meat-eater, who will consider (if he considers it at all) that he would almost certainly have escaped infection in any case. If a smaller weight loss is obtained by more rapid and earlier post-mortem freezing methods, the change would be an advantage only to the meat operator, and would pass quite unnoticed by the ultimate consumer were it not frequently accompanied by the production of a new degree of toughness--in which case the innovation is very much to his disadvantage. So far as the basic quality criteria are concerned, he detects no improved texture in his pork, no greater uniformity in his beef, no enhanced tenderness in his lamb. He may, indeed, claim to observe a deterioration in these attributes--and which of us would dare to contradict him?

Within the past few years the consumer has become much more vocal, more organized, and more belligerent, and has turned an embarrassing spotlight on a wide range of goods and services. As consumers ourselves, we must applaud the efforts and successes of these groups, but as meat scientists, we must hope fervently that meat quality does not attract their concentrated attention. Could we state truthfully that the enjoyment derived from eating meat has increased during recent years to parallel the enhanced pleasures given by other commodities? And if we could not, is it because we consider meat to be so near to perfection that it is beyond improvement?

Until the last year or two, the asking of such questions would have been without point or significance, except in reference to the relative merits of competing meat products. Now, however, the development of so called synthetic meats is well advanced, and in a very few years will offer the consumer an attractive and probably economical alternative to meat as we understand the word at present. The rivalry will then be of a much more serious kind and on a quite different scale, with not just a chain of packing houses, but an international industry at stake. Within the next decade, the meat scientist may be fighting

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for his product in a struggle every bit as fierce as that being waged by his brethren in the industries based on wool.

Several powerful incentives exist, therefore, to prompt us to greater and more productive effort, apart from the more obvious ones of pride in our chosen profession and a benign concern for the health and happiness of the meat-eating public. There is the growing awareness by the consumer that, in an era of change and (for the most part) improvement, meat remains basically unchanged and unimproved. There is the increasing powerful voice of organized consumerism, demanding a bigger or cheaper or safer or better product for its money. There is the very real threat that acceptable meat substitutes will be readily available in the comparatively near future, offering strong and direct competition to meat for the first time. Clearly, the time has come for a drastic reappraisal of our own attitude toward meat, its properties and its investigation.

There are a few primary quality factors which determine the acceptability of meat and of all products made from it, just as there are a few primary colours which determine the acceptability for a particular situation of a paint or a printing ink. What do we know of these factors, and--more to the point--of their control, their modification, their accentuation or suppression? How familiar are we with the interactions of these factors? How certain can we be that we are not causing a major deterioration in one particular attribute if we vary the conditions to encourage another? If we recommend a treatment which will accelerate throughput or reduce labour costs in a processing plant, can we be quite confident it will not produce a drastic decline in one or other of the primary factors sought by the ultimate consumer? If such a catastrophe did occur, how quickly would we detect it and take the necessary corrective action? And would we, indeed, know of an appropriate corrective action to take?

For far too long we have used the complexity of meat as our excuse for doing little or nothing to affect the primary quality factors. For too many years we have deluded ourselves into thinking that the best we can hope to do is to make meat and its products more hygienic, more attractive to the eye, more resistant to storage deterioration, but that anything improving the basic eating quality of meat is so complicated as to be entirely beyond man's power and ingenuity. For how much longer can we afford to shelter from the winds of change behind a wall of ignorance, built by our own reluctance and timidity to investigate, to understand, to explain?

If my use of the word "ignorance" appears ill-advised or over-strong, I suggest you might like to perform a simple, inexpensive and very instructive experiment when you return to your own laboratories. Take a length of sterno-mandibularis or neck muscle from a freshly killed beef animal--slaughtered, say, within the previous hour--and divide it into three pieces. The first should be dropped into already boiling water as soon as possible after excision, and cooked for fifteen minutes. The second should be left at a temperature of 15-20°C for 24 hours, transferred to a refrigerator (0-5°C) until 48 hours post-mortem, and then cooked as before. The third should be placed, within three or four hours post-mortem, in a refrigerator or cold room operating at 0-5°C and left there until 48 hours post-mortem, when it too should be cooked in the same way. When each of the three samples has been cooked and cooled, it should be assessed for tenderness--preferably by shear apparatus or tenderometer, so that results can be compared directly.

You will find that the sample cooked in a pre-rigor condition is, by normal standards, exceptionally tender, even though this muscle has a well-merited reputation for toughness. The second sample, cooked after rigor onset at room temperature and a further 24 hours chilled storage will have a shearing resistance of 2-3 times this value. The third sample (which will have shortened very appreciably during rigor onset at chiller temperature) will require a force application of 2-3 times this latter value, or perhaps eight times that of the sample cooked in a pre-rigor condition, depending on the extent of the shortening which occurred during the early post-mortem cold treatment.

When you have observed these effects, several questions will suggest themselves. There are the obvious ones: Why has the toughness increased so much from the first to the second and third treatments? Why, in fact, has it increased at all? Why did the third sample shorten by 30, 40, or perhaps even more than 50% of its initial excised length? Why did a 40% cooking-shortening in the first treatment result in very tender meat, whereas a comparable cold-plus cooking-shortening in the third treatment caused toughening to far beyond the point of edibility? Could the results of our third treatment--excessive toughness following the fairly rapid chilling of meat in a pre-rigor state--be paralleled when a freshly killed carcass is transferred to an efficient chiller?

And then there are the less obvious but rather more disturbing questions: Why do we know so little about these obviously major effects on meat tenderness? Why did this cold-shortening effect remain both unpredicted and undiscovered until a mere eight years ago? Why is it that, even now, no entirely satisfactory explanation of the effect has been offered? Has our desire to control bacterial growth by early refrigeration now gone too far, producing a toughness far exceeding that caused by any other factor? Are we so ignorant of meat and muscle that we cannot at the same time limit the development of microorganisms and prevent cold shortening with its associated toughening?

I have no doubt that a similar and perhaps even more embarrassing questionaire could be devised after an equally simple experiment in any of several fields of meat investigation, for the student of tenderness has no monopoly on ignorance.

Let us take the self-examination one stage further. In many underdeveloped parts of Asia and Africa, where refrigeration is lacking or (more probably) nonexistent, it is customary for meat to be distributed to the waiting customers and cooked by them within an hour or so of slaughter. I am assured by people from these lands that the product is delectably tender and that even our much maligned bovine neck muscles are highly acceptable--as indeed the experiment suggested earlier will soon establish. Most probably the same procedure has been used for countless generations and it is likely that early man, thousands of years ago, did the same thing after trapping or spearing his prey. We thus have the very ludicrous situation that millions of backward people today share with our primitive ancestors a crude technique giving them meat which is vastly more tender (and, as a bonus, far near to sterility) than anything available to the consumer living in our own sophisticated lands.

Now, of course, the argument has been taken much too far. Clearly, I cannot support a case for village slaughter of livestock, for the rejection of refrigeration, for meat on the menu only when the local slaughterman decides to kill an animal, and for long queues of housewives waiting to purchase the still-twitching muscle. But this is not the point; rather, I am asking why, in this scientific age, we cannot recover the eating quality of meat as it was consumed in the far distant past while retaining the obvious advantages of modern slaughter, processing and distribution facilities. Obviously in modern society we must chill and maybe freeze our meat; obviously we must store it for far longer than the few hours needed for rigor onset. But why must this necessarily result in meat several times tougher than that eaten by the Arab tribesman or African villager? Do the advantages of storage and preservation necessarily eliminate the advantage of tenderness? Are extreme tenderness, near sterility, and long-term keeping necessarily incompatible?

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I ask you to consider as an analogy the development of the automobile. The number of incompatibilities in the car of sixty years ago must have been great; if one wanted speed of a sort, one sacrificed comfort, and if safety was of paramount importance, economy declined. I can imagine our reaction, a mere half century or so later, if we were told that the car we were about to purchase could have only two of the features we considered indispensable for comfortable, economical, safe, reliable and fast driving; that we could choose the combination of desired characteristics, but that whatever our selections, they would be quite incompatible with those unchosen. Yet this situation resembles far too closely for our peace of mind the state of affairs in meat purchasing--save that we do not offer the buyer the choice of qualities he considers most important.

Here again, of course, the argument has been taken much too far. We are all well enough aware of why the automobile has been improved so much since the beginning of this century, and why meat has not. The car, from the very start, has been a man-made object, initiated, developed and controlled by man, and fully understood by him so that, if anything went wrong, if any feature required improvement, if any defect needed elimination, then the necessary alteration could be made smoothly and quickly and certainly. By contrast, meat is not man-made. It was not initiated or developed by him, and to a very large extent still cannot be controlled by him. And most of all it is not understood by him, so that defects cannot be eliminated and features cannot be improved.

If a machine is not understood and its mechanism is not comprehended, we are forced to adopt empirical methods to control or modify its behaviour. There is nothing wrong with such a try-it-and-see approach if the problem is a minor one. Clearly, it is worth cleaning the spark plugs before reboring the cylinders. But what would we think of a car mechanic who relied solely on this approach because he lacked all but a scanty knowledge of the internal combustion engine? The plain, sad fact is that we in meat science are usually forced to adopt the same form of attack on the problems we encounter, and for the same reason: we are unskilled mechanics who have not yet acquired sufficient knowledge of the biological machine we work with to control or correct its performance. Again, there is nothing inherently wrong with this approach, which will no doubt continue to serve us as well in the future as it has done in the past. At best, it may result in the rapid solution of a problem, and even at worst it may provide sufficient data to form the basis of a later and more thorough investigation. The danger is that we have become so habituated to its use through sheer necessity that we have great difficulty in seeing any other way despite the knowledge that many current problems are absolutely refractory to our present attacks. There is, in addition, another danger in the exclusive use of the empirical approach: the procedure or treatment devised after a "try-it-and-see" form of investigation may not necessarily be the best, the simplest, or the most economical in operation. It may not even be entirely reproducible under all the conditions which may be encountered in practice. In these circumstances, all we can be sure of is that the new treatment gives a better result than the old. But it may still be far from the optimum. It may cause another attribute to deteriorate. It may fail entirely under certain abnormal conditions of stress or feeding routine, of temperature or humidity.

Let us return to the relationship between muscle shortening and meat toughness which I mentioned earlier. Although the subject is fairly general interest, it is not for this reason that I wish to reintroduce it at this point. Rather, my aim is to use the work of the New Zealand group to illustrate a few fairly general principles--aspects which could have been drawn equally well from any of several current research projects elsewhere, and which could be applied equally well to most of them.

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The principal conclusions are simply enough stated. The extent of muscle shortening which occurs before rigor completion, at least in beef and lamb, has a very considerable effect on the tenderness of the cooked meat. The toughening caused by appreciable shortening far outweighs that due to any other factor. Thaw shortening and cold shortening are the two most potent toughening agents, and the possibility of their occurrence must be eliminated entirely if tender meat is to be produced. The shortening-induced form of toughening is almost certainly due to changes in the extent of interaction between the principal contractile proteins actin and myosin, and appears to be unrelated to the amount or nature of the connective tissue present.

The first point to be made is the intimate relationship revealed in this investigation between the very practical subject of meat toughness and the very academic subject of muscular contraction. It would be no exaggeration at all to say that meat tenderness depends more on the extent of actin-myosin overlap in rigor than on any other factor or combination of factors--surely a result far from the minds of Hanson and Huxley when they first formulated their sliding-filament theory of muscular contraction some fifteen years ago.

Second, the project illustrates the importance of acquiring sufficient background knowledge <u>before</u> the precipitation of a crisis. A major developing market for lamb closed its doors tightly and without warning on the grounds of excessive toughness, but reopened them within weeks on receiving assurances that the problem was at least partly understood and that remedial steps could and would be taken immediately. I am well aware that in some areas of meat science the crisis is already with us, giving yet further urgency to the need for basic information on which to base a curative treatment. But other critical situations, unsuspected at present, will arise in the future as a result of increased production, changed consumer demands, altered standards or improved breeding programmes. The acquisition of background knowledge, even if it appears only minimally or marginally relevant to (at this stage) a merely hypothetical problem still beyond the horizon, is by far the best insurance against future difficulties.

Third, the shortening toughening project reveals in retrospect an interesting cominbation of empirical and basic approaches. When the problem of excessive toughness first arose, it became necessary as a preliminary step to test a number of reasonable guesses of the causative agent: weight, grade, age, sex, slaughter method, freezing rate and delay before freezing; and all but the last were rejected. It was then possible to relate this observation to the newly discovered cold-shortening effect of Locker and Hagyard, and to Locker's suggestion four years earlier that a shortened muscle is tougher than one which remains unshortened. It was then argued that shortening would not be able to occur if cold application was delayed until cross-bridges between actin and myosin filaments had formed with rigor onset. Thanks to the now classical studies of rigor mortis by Bate-Smith and Bendall over twenty years ago, and to subsequent studies of rigor in other species which their pioneer work inspired, it became a relatively simple matter to calculate and then verify in practice the post-mortem time required to "lock" the primary filaments to an immovable configuration. This result, with safeguards added to prevent excessive desiccation and explosive bacterial development, became the basis of the specification which is now in widespread use in New Zealand.

My fourth general point from the investigation is this: that although some sort of knowledge has yielded some sort of a solution, very much more information will be required before a really satisfactory answer is available. The present process is safe, it produces an entirely satisfactory degree of tenderness, and it will not fail under any set of circumstances; but it is also space-

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wasting, time-consuming and expensive. In consequence, the product is available only to those markets prepared to pay for the additional processing costs, and before its output can be extended greatly, a technique must be found to abbreviate it. This will be done only with a greatly increased basic knowledge of the tissue and its properties.

Finally, it is worthy of note that the shortening/toughening relationship demonstrates as well as any, and perhaps better than most, current meat problems the essentially dynamic nature of meat. Merely by temperature adjustment we can toughen alternating samples of a single beef neck muscle to three times the value of the segments in between. We can elevate th shearing resistance of a lamb longissimus muscle to four or five times that of the sister muscle of the same carcass. We can cause one strip of a muscle to shorten to little more than one-third of the length of an adjacent strip. We can produce these effects only when the muscle is in the still living, still essentially functional, pre-rigor condition, and so can be left with no shadow of doubt concerning the dynamic nature both of the tissue and of the problem we have encountered.

This situation is far from unique in current meat science. The watery-pork problem, which is of much greater importance and urgency to most of you than lamb or beef toughness, is every bit as dynamic in its nature. The colour of beef is influenced very strongly by the conditions applying before slaughter. The water-binding capacity of meat is at least partly determined by the extent of both the physical and chemical changes which occur during rigor onset, after the death of the animal but before the death of its musculature. In these and other areas, quality will not be improved if we wait until the final, relatively static state has been reached, for in that condition meat is a very intractable material. Neither additions nor subtractions can be made without sacrificing the very structural features on which the demand for meat largely relies. If changes for the better are to be made to the ultimate material, therefore, they must be introduced by a more subtle process, using the animals own metabolic system to influence muscle composition during life, or the muscles own contractile and glycolytic systems to produce alterations in microstructure shortly after death, when the musculature is still vulnerable. still amenable to applied external influences.

The time has come at last to introduce the key-word in the title of this address-physiology. I have avoided its use to the present because I felt it necessary first to convince you of the present and future hazards of restricting our vision to our own immediate neighborhood of problems, and of failing to look around us for guidance or inspiration. In any case, my intentional omission of the term has not prevented a liberal use of words like living, movement, and function; and in doing so, I have in fact been talking muscle physiology for some time. These words are at the very core of the subject, and it would be virtually impossible to offer a definition without their use.

The primary function of muscle is to move; the primary function of meat is to nourish. Between these two (at present) very different fields of interest there lies the pre-rigor phase during which the properties related to the first function merge into those of the second, a relatively brief interval of a few hours--sometimes only a few minutes--when the rundown of several biochemical processes causes a transition from a living, contractile tissue to a relatively inert foodstuff. This is the period which all too often appears as an impenetrable barrier separating not only muscle from meat, but also the muscle biologist from the meat scientist; in fact, it should be the one zone of mutual contact to which both groups have immediate and ready access.

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We on our side of the barrier should be well enough aware by now of the enormous significance of this pre-rigor period to meat quality. We know that the rate of energy production may soar suddenly and unaccountably at the start of this phase in porcine muscle. We know that cold shortening occurs only in this phase in bovine and ovine muscles. We know that meat frozen during this phase may display extreme shortening when it is thawed, regardless of species. We know the influence on water-binding of rapid glycolysis in this phase. And we know only too well the drastic effects on meat quality, on the several primary attributes we discussed at the beginning, of these pre-rigor phenomena.

They--the muscle physiologists on the other side of the barrier--are also fully aware of the importance of the post-mortem but pre-rigor state, for this is the source of their experimental material, and indeed of almost all knowledge about muscle structure and function. In this condition the tissue provided the basis for Galvani's work two centuries ago, just as it is the basis of virtually all research in muscle physiology today.

If we are to learn anything at all from the physiologist, if we are to gain access to the great stock-pile of information which has already accumulated, if we are to acquire such a knowledge that we shall one day control the quality of the meat we eat, then it is in the early post-mortem phase that we must start. This is as far as the muscle physiologist will come to meet us; and if we are not prepared to meet him in this area of common ground, we shall deservedly remain unskilled mechanics servicing a machine of which we have no real comprehension. The way was indicated to us by Bate-Smith and Bendall almost a quarter century ago, and I am sure you are very much aware of the continuing--indeed, still-growing--significance of their project, and of the great influence it has exerted on the course of meat research for more than two decades.

It is not inappropriate at this time to inquire why, from all the work of the post-war years, no better example of meat-orientated physiological research comes readily to mind. Perhaps too many of us are so close to the industry we serve that we are over-occupied with its short-term demands and frequent crises. Perhaps too many of us are so conscious of the immediate needs and hopes of our research students that we fail to see the necessity for a long-term integrated programme. Perhaps too many of us are so engaged with our regulatory function that neither time nor energy remains for forward research planning. Whatever the reason, the sad fact emerges that the great bulk of physiological results applicable to meat science has been obtained by investigators with no more interest in meat than that of the ultimate consumer we met earlier.

You will all be familiar with recent examples of this, and we only need to consider current basic studies of biological energy release and control, of muscular contraction, and of protein configuration to find information of potential applicability, now or in the future, within the meat field. But other instances of fundamental observations and their later practical significance can be found in the scientific literature of long ago. One such study comes readily to mind this year, for it is exactly a century since Walker reported the great shortening which accompanies the thawing of muscle previously frozen early post-mortem. Seventy-seven years elapsed before this observation had any practical implications within the field of meat quality. In 1948 it was invoked to explain and reduce the great release of fluid when frozen whale meat was thawed. A further fifteen years were to pass before Walker's study became of very real meat workers' significance in the shortening-induced toughening of lamb and beef. A hundred-year old observation by a scientist entirely lacking any specialized interest in meat has thus become of great significance in three of the primary quality areas: fluid retention, appearance, and tenderness.

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My plea for a physiological approach to meat science is thus not solely an argument for more meat-orientated physiological research, though this is clearly part of it. If we are to acquire the ability to standardize and control the properties of meat, then we must first acquire an understanding of the structure and function of muscle. If we are to learn how to modify and improve the qualities of meat, then we must first stop paying mere lip-service to the concept that meat is muscle. If we are to apply the results of past, present, and future physiological studies to the improvement of meat, then we must first develop a dynamic, a physiological, approach to the science of meat. The cultivation of such a mental attitude on our part may well determine the future of muscle as a food.