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AN OVERVIEW OF THE ROLE OF FAT IN NUTRITION AND FORMULATION AND ITS MEASUREMENT IN THE LIVE ANIMAL, MEAT CARCASS AND PROCESSED MEAT PRODUCTS

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Abstract

The role of fat in nutrition and health is complex but one about which consumers have only recently become aware. As a consequence of changing consumer attitudes and because fat affects many physical attributes in food, raw material suppliers and food manufacturers have attempted to improve the range and nutritional composition of available foodstuffs. However, with a substantial price difference between fat and lean, and ever-increasing demands for improved throughputs and operational cost performance, producer and manufacturing sectors require rapid, accurate methods of fat measurement suitable for commercial application. These are only just beginning to become available but should ultimately result in more consistent product quality. This paper provides an overview of the role of fat in nutrition and formulation and the technological advances made in providing for its measurement in both raw materials and finished products.

Key Words: Carcass, fat, food, manufacture, measurement, nutrition, processing.

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Introduction

Man has always eaten meat as part of his omnivorous diet. For most of his time on this planet, it has been eaten raw or cooked or preserved in a cured state. However, in the last decade there has been a radical change in the industry in an attempt to accommodate changes in lifestyles, diets, and attitudes to eating meat. In addition, a steady rise in both raw material and production costs has led to the development of alternative ways of manufacturing meat and processed meat products. This review examines the technology and techniques in fat measuring and monitoring that have been adopted by the various sectors of the meat industry. First, the many factors that have influenced the development of these technologies are briefly reviewed.

The Role of Fat in the Human Diet

In recent years, medical journals and the popular press have devoted considerable space to the effects of excessive fat and cholesterol in the human diet. A wide range of clinical disorders have been implicated with excessive fat intake, these include: coronary heart disease, stroke, atherosclerosis, thrombosis, hypertension, obesity, diabetes (type 2), gallstones, bowel disease, and certain cancers (Sinclair and O'Dea, 1990).

The diet of the developed western world has a high calorific content compared with its mass. Lack of sufficient or adequate carbohydrate, fiber or other bulking materials results in excess calorie intake before a feeling of sufficiency is felt. The diet is also characterized by a fat content, often exceeding 40% of the total energy intake. With fat providing 9 calories per gram, twice as many as for an equivalent weight of protein, relatively small levels of intake become important constituents in the overall diet.

Half of the fat intake is in the form of saturated fats. Although meat, particularly red meat and its products, is a major contributor to total saturated fat intake, dairy products and hydrogenated vegetable oils are other principle sources. Saturated fats have been implicated in the increase of plasma cholesterol levels. Keys *et al.*

(1986) showed that while total fat levels were important indicators, the ratio of unsaturated to saturated fats in the diet was inversely related to the incidence of coronary heart disease. This was lowest in countries where red meat, particularly in its processed forms, constituted a very low proportion of the diet, such as Japan, or where the level of fat intake in the unsaturated form was high, e.g., the mediterranean countries of Europe. It was at its highest, where refined and convenience foods formed the greatest part of the diet such as the USA and parts of Northern Europe, with Scotland having the highest levels. The form, type and degree of saturation in fats display significant differences in their cholesterol forming or cholesterol lowering capabilities (Grundy, 1986, 1987; Horrobin and Huang, 1987).

Dietary fat in human nutrition is important, particularly in the synthesis of the essential fatty acids, linoleic and linolenic acids (Burr and Burr, 1929) and of the fat soluble vitamins. There is also evidence to suggest that fat is essential in the synthesis of a number of hormones and in the function of human prostaglandins (Thomas, 1975; Willis, 1981; Meade *et al.*, 1986). Insufficient fat intake or absence of certain fatty acids contribute to a variety of physiological symptoms including: reduced growth, poor food conversion, increased metabolic rate, scaly skin, hair loss, dandruff, infertility (in both sexes), increased water loss through the skin, liver deficiencies, etc. (Hansen, 1963, 1986; Holman *et al.*, 1964; Holman, 1970; Sinclair and O'Dea, 1990).

With the role of certain essential fatty acids now becoming clear, the minimum and maximum levels of intake need to be established. However, there is already a wide diversity of opinion: Holman (1970) suggests that their intake needs to be 2% of total energy consumption, whilst Vergroessen (1977) recommends 15%. Perhaps a good indicator of requirement is the fat content of mammalian milk samples, including human milk where Crawford *et al.* (1978) showed that essential fatty acids comprised 7-11% of the total energy availability.

The Consumer Attitude Toward Fat

There are three major consumer dislikes of fat in the diet, namely health, waste and taste. Many recent food and marketing company surveys indicate that meat consumption is declining. In the U.K., around 2.5% of the population does not eat meat. Woodward (1988) found that more than 50% of interviewees gave health and cost as the main reasons for their reduced meat intake. Consumers are now much more aware that processed meat products generally contain higher levels of fat than the raw or cooked whole meat. Fat content and cost are the most frequently quoted reason for the decline in overall meat consumption. In a recent survey, more than 70% of meat eaters questioned declared they would eat more meat if it was less expensive (Newman, unpublished). This, therefore, suggests that although the number of non-meat eaters continues to rise slowly for several reasons including animal health and welfare, diet and fashion, meat consumption could increase if the price was right and the composition of products more 'healthy'. Overall demand for meat continues to grow as more developing nations improve the health and welfare of their general population.

The concept that fat is wasteful is linked to health, taste and cost. Few consumers like the taste of fat on its own. Many people will remove the fat before eating. With the high cost of meat, this is considered wasteful by the consumer. However, in certain forms, such as 'crackling' from pork (the crisp fat adhering to the skin after roasting or flame grilling), or cooked, salted and spiced, fat has actually generated new markets as snack food products.

The amount of fat tolerated by consumers in the meat they buy has also changed with time. A U.K. survey showed that whilst the young meat eater prefers the leanest cuts possible, older consumers still regard a moderate amount of fat as both attractive and essential for good flavor (Dransfield, 1983). As part of the same survey, with data being compared to a similar survey undertaken by Pomeroy (1956), choices were broken down by region and occupation. Interestingly, the group that showed the smallest change in opinion about fat was butchers where almost twice as many preferred a much greater level of fat in their meat.

Fat Deposition in the Live Animal and Methods for its Control

Until the last decade, producers of livestock for human consumption gave little regard to the production of excess fat because of the historical belief that fat, particularly intermuscular fat was an important precursor to good flavor. They had little or no concern for health issues and rapid weight gain was easily achieved through the *ad lib* feeding of cheap readily available animal feeds.

In the wild, animals generally have to scavenge for their food, most of which is converted into protein; there is little fat deposition and overall live weight gains are slow. When the same animals are moved into a situation of plentiful food, their metabolism changes, live weight gains become much greater and total meat weight increases, but the ratio of fat/lean distribution decreases (Mersmann, 1990). Where feed intake is controlled, the amount of fat accumulating at all the major fat depots is reduced (Smith *et al.*, 1977) and the efficiency of lean mass greatly improves (Lister, 1976; Prior *et al.*, 1977), although pasture fed ruminants do not show similar effects.

Table 1. Fat levels in raw meat cuts.
(Sources: Fisher, 1990; Newman, 1987a, 1992a).

Species	Cut	% Fat in Untrimmed Cut	% Fat in Trimmed Cut
Beef	Topside	6.7	2.1
	Rump	13.3	3.0
	Sirloin	17.7	2.7
	Brisket	32.0	14.2
Pork	Belly	42.0	28.0
	Loin	14.0	2.2
	Ham	27.8	9.0
Lamb	Loin	5.2	1.9
	Leg	18.0	7.4
	Chop	32.0	1.9*
Chicken	Breast	11.1**	1.7
	Leg	18.3**	9.7

*Eye muscle; **Skin on.

As mammals mature, there is a major shift in the partitioning of feed components and the amount of each directed to energy provision, the accumulation of fat and lean mass and site specificity. This effect is well demonstrated by the varying fat contents of raw meat cuts (Table 1). Generally, with increasing age a greater proportion of reserves is deposited as fat rather than lean mass (Byers, 1982). Where dietary intake is restricted and/or energy requirements remain high, fat growth is minimized (Etherton and Walton, 1986). Thus, in animal production, many feeding regimes lead to an uneconomic growth of fat in preference to lean mass (Mersmann, 1987). The ability to measure both the rate of growth and fat/lean distribution within individual animals would be of great economic importance (this topic will be covered in greater detail later). An understanding of the mechanism controlling this metabolic shift would also greatly help to improve the effectiveness and efficiency of animal feeding regimes.

Rate of accumulation of lean mass is also affected by a number of physiological components including hormones (well reviewed by Mersmann, 1987), especially sex hormones in ruminants, although their effect in pigs is very limited (Roche and Quirke, 1986). The growth hormone *somatotropin* improves increase in muscle mass, reduces the rate of fat deposition when applied exogenously and improves the efficiency of daily live weight gain. The physiological and physical effects are both extensive and complex (Sillence and Etherton, 1987; Petitclerc *et al.*, 1987; Campbell *et al.*, 1988), with the effects most noticeable in pig production regimes. Increased insulin levels will reduce the amount of fat deposited and the size of the internal fat depots (Romsos *et al.*, 1971). Other adrenergic agonists such as epinephrine and dopamine will also reduce overall fat depots by increasing their associated metabolic pathways (Lafontan and Berlan, 1985).

Sex hormones (both natural and artificial) have been used to promote faster growth. In general, increasing male hormones tends to improve live weight gain and protein deposition but has little effect on fat levels. Reducing male hormones (e.g., castration) lowers daily weight gain and the protein to fat ratio. Increasing female hormones decreases fat deposition in all meat species (Bass *et al.*, 1987). However, practices which use sex hormones are now banned to animal producers in the European Community (EC). Only the USA and Australasia still permit the use of growth promoters, but are under increasing pressure from vocal consumer lobbies to end the practice. The use of uncastrated males is still possible although some consumers claim they can detect an unacceptable 'taint' in the meat of some of these animals (Wood, 1990).

Control of food intake has a measurable effect on fat deposition; energy dense foods will generate higher daily weight gains. However, once protein ceases to be limiting, carcass fatness tends to increase (Campbell *et al.*, 1983), irrespective of carcass weight. Therefore, *ad lib* feeding regimes contribute significantly to the amount of fat in the carcass. Campbell *et al.* (1984) have shown that leaner pigs are produced if the level of protein in the diet is progressively reduced as the animal matures, compared with pigs of similar weight fed on a high protein diet for the whole of its growth cycle. This effect is much more difficult to induce in ruminants where initial protein intakes tend to be low (Bass *et al.*, 1987). However, reducing feed intake reduces weight gain; slaughtering at lighter weight reduces both overall fat levels and meat/bone ratios. Unfortunately the farmer's profits are also decreased because, with few exceptions, leaner animals do not as yet produce the necessary financial rewards in the marketplace.

The foregoing suggests that there are several routes available to the producer which enable him to bring animals to the marketplace and fit both processor requirements and consumer demands. In the longer term, only control of food intake and genetic selection techniques will be acceptable methods of reducing fat in farm animals. But until the payment system reflects these benefits, changes will be very slow.

In pig and poultry carcasses, a significant proportion of the total fat is deposited as subcutaneous fat (70% or more of the total fat); in beef and sheep it is much less [(30-50%, Butler-Hogg (1982); Fisher, 1990)]. Generally during carcass dressing and boning operations, the skin remains on both pig and poultry carcasses, but is removed from beef and sheep. There are four other major fat depots: intermuscular (between the muscles), intramuscular (within the muscles), those surrounding the kidneys. and the main body channel fat (within the cavity containing the soft alimentary tissues). Although these last two are removed during carcass dressing, they find considerable use in meat cut presentation and other culinary uses because of their firm texture.

Intermuscular fat levels are low in pigs (around 20%) and lower still in poultry. In ruminants, they can be as high as 40%. Intramuscular fat levels are usually below 10% and can be as low as 1% in selected lean tissues in all species. Subcutaneous fat is laid down at a faster rate than intermuscular fat in all species as weight increases (Wood, 1990).

The Role of Fat in Food

The effects of fat in food are complex and there is extensive interaction with other components. In general fat contributes to tenderness, juiciness and flavor, as well as physical appearance particularly in processed and fabricated products where its contribution to overall 'meat quality' attributes is significant (Jones *et al.*, 1989). It is much less so in whole meat cuts (Dransfield *et al.*, 1984).

The role fat plays in tenderness differs between whole meat and processed meat products. In the former, the connective tissue content and the physical condition of the muscle proteins will make the major contribution to overall tenderness. The more mature the meat, the tougher the connective tissue and the more resistant it is to heat denaturation. Toughening of the muscle proteins usually occurs as a result of poor conditioning and refrigeration. It has long been thought that the presence of additional fat during the conditioning/refrigeration phase protects the muscles from rapid temperature fall (Smith *et al.*, 1976). It may also perform a similar protective function during cooking (Dikeman, 1987), although it has no effect on connective tissue toughness. The presence of higher levels of fat within and between the muscles may also give rise to improved tenderness because of easier disruption of muscle fibers during chewing (Purslow, 1985).

The lipid/moisture ratio is also very different in subcutaneous and intermuscular fat. In the former, total lipid levels in excess of 83% are normal in beef (Newman, 1987a) and pork (Newman, 1992a). Intermuscular fat usually has a lipid content of 73-77%. This may be a physical rather than chemical phenomenon as it has been shown that if fat depots are sampled and analyzed immediately after slaughter, lipid and moisture levels are similar (Fisher and Bayntun, 1983). However, subcutaneous fat is more likely to suffer water loss due to evaporation during the chilling and boning processes, because of its closeness to the surface of the carcass.

Juiciness and tenderness are often correlated (Ashgar and Pearson, 1980). In the absence of extractable juice, meat with low fat will often feel 'dry' in the mouth, and thus will be scored as tougher. Flavor is not only related to the taste of the product but also to the 'anticipation factor'. It has been shown that 'beef aroma volatiles' could be produced from meat where only the phospholipid fraction of the fat remained (Mottram and Edwards, 1983). As this is often only 1-2% of total lipid, the claim for high levels of fat to produce flavor is debatable.

During the cooking of meat, the 'Maillard' reaction, the interaction between sugars and amino acids, is an important factor in the generation of flavor (Hurrell, 1982). It has been shown that if fresh meat or cured product, such as bacon, are cooked devoid of all visible fat, then overall acceptability scores are reduced. This has been attributed to the role that fat plays in producing flavor volatiles and generating other flavor pre-cursors which generate saliva flow in the taster. It may also reduce moisture loss during the cooking process (Dikeman, 1987).

Visual appearance and material cohesiveness are two other attributes to which fat contributes. In almost all consumer trials, cuts which display minimal fat within the lean (marbling) are most highly rated by consumers (Kempster *et al.*, 1986). Other problems in the leanest cuts, often detected by 'professionals' (butchers, trained panelists, etc.), include soft fat, wet meat (excessive drip) and poor color.

Experimental work has shown that flavor profiles of meat from animals fed almost entirely on feedstuffs containing unsaturated fat are quite different and the taste of this meat very much less acceptable to consumers; it also changes firmness. Part of the difference in attributes can be explained through composition. When pigs are fed with feed compounds containing higher levels of linoleic acid the amount of (C18:2) compounds in the fat increases with a consequent drop in fat firmness (Wood, 1984). The effect is most marked where the fat thickness levels are minimal. This effect has also been noted in beef carcasses (Campion *et al.*, 1975).

The role of intramuscular fat in food acceptability is well covered by Wood (1990) in his review. Many lean cuts in both red and white meat contain levels of lipid well below 2% (Newman, 1987a). In a wide range of taste panel tests applicable to all meat species (Larmond and Moran, 1983; Bejerholm and Barton-Gade, 1986; Dikeman, 1987; Seidemann *et al.*, 1987; De Vol *et al.*, 1988; Meat and Livestock Comm., 1989), a minimum level of 3% extractable lipid in the lean tissue was necessary to produce acceptable juiciness scores from taste panelists.

The role of fat in processed meat products is somewhat different from that in the whole muscle cuts described. Permitted levels of fat are considerably higher than one would find in most fatty raw materials. Hams usually contain 10-15% fat, belly bacon up to 60-65%, sausage products 25-50% and most spreadable products often contain 50-60% fat by weight. The role of fat in flavor production is similar to that of raw meat.

Most meat products are usually quite acceptable in terms of tenderness. Where additional 'bite' is required, it is usually provided by other constituents such as collagen or added fiber (animal and/or vegetable). Incorporating a wide range of different fats itself can provide a considerable variation in meat product textural characteristics. In drier product, such as dry sausage, harder fats are used. The smaller the particle size required, the softer the fat used (e.g., patties and emulsified sausage products).

The role of fat in the color of meat products is generally one of dilution. Being white or pale yellow, it tends to reduce color by increasing saturation and reducing intensity of any color component. Only in products such as mortadella, where discrete fat particles are expected, does its color, size and distribution effect acceptability scores.

It is difficult to be specific about the overall role of fat because of the wide variation in attitudes to it, and the different practices and preferences that occur in different countries. One example will suffice to illustrate the difficulty. The USA has a carcass grading system which positively benefits fatness. Japan pays higher prices for heavily marbled beef (Kobi beef is ranked highest of all), however they tend to consume small quantities of beef in their diets (mainly limited by very high prices). Europeans tend to wet cook meat, and when they dry cook, they do so to a much lower level of doneness than in the USA. The American approach is rapid, dry cooking to which lean meats with small levels of fat are not ideally suited. As a consequence, meat from the USA does not find great favor in Europe, generally being too fatty for the palette. Europe also has lower levels of fat in its products than the domestic USA market.

Despite a widely divergent marketplace for meat and meat products, there is a common requirement to quantitatively measure the deposition of fat in the live animal and objectively monitor the processing of the resultant materials and their products. The remaining sections of this review look at the progress of technology in these measuring and monitoring applications.

Fat Monitoring and Measurement in the Live Animal

Until fairly recently, the only method available to the farmer and the livestock buyer was skilled subjective assessment of anatomical characteristics on the live animal. However, there have been many instances where the desirable characteristics in the dressed carcass have failed to be identified by live animal classification. In their review of carcass classification methods, Kempster *et al.* (1982) provide numerous examples which highlight the need to develop technology to objectively undertake the task, thus reducing the inaccuracies and bias of current methods.

One of the major problems encountered in making quantitative measurements on the live animal is that, with the exception of external assessment of conformation (shape), most of the relevant information is subsurface. Not only is it necessary to probe under the surface, the animal must be restrained in order to take the measurement. This clearly generates a number of logistical and practical constraints on the technology. In a free range system, animals may only be collected together once a year which will be of little benefit in beef production and none at all in the raising of lambs.

There are a wide range of technologies which could find application including X-ray computer tomography (CT), nuclear magnetic resonance (NMR), positron emission tomography (PET) and photon and neutron activation analysis (PAA, NAA). These are all described in some detail by Allen (1991) in his review. All have found considerable application in the field of human clinical diagnostics. They have all demonstrated very good correlations between the attribute measured trait and actual fat/lean distribution. Groeneveld *et al.* (1984) showed that both CT and NMR, when applied to pig carcasses, gave correlations of 0.98 for these traits. However, all studies have to date been *in vitro* as clinical equipment has had to be used *in situ* and no suitable portable equipment has yet become available. All these techniques are time consuming, ranging from many seconds for NMR to several hours for PET; they involve very expensive, heavy and immobile equipment and require a willing passive participant.

These characteristics are opposite to that required for field or farm use, where the equipment must be robust, easily portable and simple to use by a single operator with minimal training. It should also be rapid in its data acquisition, inexpensive to buy, cheap to run and easy to maintain. From a logistics standpoint, it needs to be non-invasive and require no special treatment of the animal, either in the form of immobilization of the animal or the removal of any outer tissues. At present, none of the methods satisfy these criteria.

Two other technologies, namely ultrasound and electrical conductivity, do have the potential to work within the above-mentioned restrictions. The latter has given good results in predicting human body composition (Presta, 1983), but data obtained using the electrical conductivity on both mobile and anaesthetized animals were poorly correlated and showed low repeatability (Stiffler *et al.*, 1976; Mersmann *et al.*, 1984). If the prediction equations contained factors for both feeding system and housing type, then predictors of lean mass became better correlated (Joyal *et al.*, 1987). In a practical environment, such information is often unknown and its application unrealistic. Ultrasound techniques have been used in a number of farm applications for some years, particularly to confirm the pregnancy status of ewes to predict dietary requirements.

Two basic formats are available for practical use. The first, pulse-echo, looks at the echo signal amplitude relative to time. These basic one-dimensional scanners provide information on linear fat depth. A second generation, using the same principle but using an array of transducers, can produce two-dimensional data which enables them to measure or calculate eye muscle and fat depot areas (Miles *et al.*, 1983). The second technique is velocity of ultrasound (VOS). This makes use of the fact that sound waves travel at different constant speeds through defined materials. If the test site is devoid of skeletal impedance and there is no temperature difference, measurement between a known distance is able to differentiate between the proportions of fat and lean at that site. If the site is representative of the whole animal then predictions of total fat and lean can be calculated (Miles *et al.*, 1990).

Pulse echo fat measurement techniques have been widely used in pigs. All machines, irrespective of complexity, give good predictabilities of fat depth with RSDs (residual standard deviation) in the region of 2.5% and correlations greater than 0.8. However, predictions of carcass traits, such as lean depth and lean area, from live animal measurements, or percentage lean values, show much greater errors and lower correlations (0.14-0.59; Thwaites, 1984). Again, the addition of data, such as live weight, daily live weight gain, and food intake, significantly improve the prediction equations (Molenaar, 1984, 1985). In cattle, the range of correlations for the same traits has been shown to be even greater than for pigs (summarized by Allen, 1991). In sheep, the results have been more variable, probably due to the fact that there is greater variability in the ratio and distribution of subcutaneous and intramuscular fat depots. The use of VOS has been shown to be accurate and repeatable in cattle (Miles *et al.*, 1983). But when compared to assessments of trained visual graders, it showed lower correlations and greater RSDs for prediction of lean, total fat and saleable meat. Much of the variability in the results can be attributed to selection of different measuring sites, the differing skill levels of operators and the need to make and maintain good physical contact while the readings are being taken (with sheep, this often requires the removal of a strip of fleece). With little repeatable improvement over current manual subjective techniques, ultrasound techniques have not, as yet, achieved much commercial success. Until such benefits can be achieved, producers will be unwilling to buy or use the technology.

Fat Monitoring and Measurement in the Carcass

This area has received considerable investigation in the last decade because it is generally considered to be the point at which the most tangible financial benefits can be obtained. Measurements in the processing area are important for both quality control and quality assurance. However, at this point in the operation, the raw materials have already been selected and purchased. Objective measurements of carcass fatness and conformation should be the goal for the industry. With such information, the meat buyer will be able to purchase only the meat he requires and the producer will get a payment which accurately reflects the value of each carcass.

However, there is considerable political and economic interference in obtaining these objectives. Abattoirs have shown themselves to be unwilling to change current practices unless forced to by legislation. One of the reasons is the perception that they will have to bear the cost of the technology and its running costs while receiving little financial benefit. They also believe that they will lose financially from the increased accuracy of the quantitative technology. It has been shown in a number of open (Kempster *et al.*, 1982) and closed trials (Newman, unpublished data) that abattoirs generally underestimate leanness and overestimate fatness. Consequently, their current rate of return would fall, and that benefit would pass to the meat buyers and the producers. However, where the abattoir is part of a raw material supply and conversion facility, considerable financial gain could be accrued from the early selection of carcass types of specific applications. It is this approach that is receiving the greatest interest. As a consequence, the application of objective techniques to the measurement of carcass fatness has been the subject of a number of detailed reviews, the latest being those of Newman (1992b) and Fisher (1990). The available techniques are basically those already mentioned for the live animal with a number of additions including optical probes, image analysis and electrical conductance.

For animals such as pigs and poultry, the high percentage of total fat deposited subcutaneously makes it

Table 2. Precision (in residual standard deviations) of electronic probes* in predicting percentage lean in pigs (source: Kempster *et al.*, 1985).

	Site	HGP	FOMOP
Carcass Wt	6.19	6.19	6.19
Wt + Last Rib	4.06	3.71	3.08
Wt + 3/4F	3.66	3.14	3.08
Wt + 3/4F + 3/4M	3.59	2.91	----

HGP = Hennessy grading probe; FOM = Fat-O-Meter; OP = optical probe.

Table 3. Improvement in precision of pig % lean prediction with quantitative confirmation score (source: Newman and Wood, 1989).

Measurement	Correlation Coefficient (r^2)
Probe Fat Depth	0.53
Probe Fat Depth + Carcass Wt	0.58
VOS	0.61
VOS + Carcass Wt	0.65
VOS + Carcass Wt + VIA Conformation Score	0.72
(Sample standard deviation = 6.97)	

possible to obtain a considerable amount of information on overall carcass fatness from sub-surface backfat measurements. Consequently, probes, which measure this trait, have become particularly popular in pig carcass assessment. The original probe devices were little more than an illuminated tip linked to a mirror system to observe the interface between fat and lean at the chosen site and a graduated scale to enable a reading to be taken. All operations were manual and the determination of the fat/lean interface subjective. A variant of this system, the optical probe, is still used within the U.K. pork industry. These have been generally superseded by a range of reflectance probes which utilize the fact that lean and fat have different reflectance capabilities, so with the incorporation of an automatic depth measurement system, the unit can accurately determine the interface of the various tissues. They can also measure the minor axis of the loin 'eye muscle' (the major lean tissue underlying the backfat). From these measurements, predictions of carcass percent lean can be calculated.

Within the EC, objective grading of pigs is now a statutory requirement and a number of these probes including Hennessey (Hennessey, Auckland, New Zealand), Fat-O-Meter, (SKF, Soborg, Denmark), Destron (Anitech Inc., Markham, Ontario, Canada) have reached the necessary standard, i.e., a correlation coefficient (r) of 0.8 between prediction and actual percentage lean in a cross-sectional population and a residual standard deviation (RSD) of less than 2.5%. A wide range of studies and trials have been undertaken to compare both the performance of the probes and their respective precision in predicting percentage lean (Kempster *et al.*, 1979; Fortin *et al.*, 1984; Cooke *et al.*, 1989; Diestre *et al.*, 1989). Table 2 summarizes some of the performance data obtained. The manually operated, optical probe performed better than the electronic devices in several of these trials. This can be for a variety of reasons, but both operator efficiency and the ability to accurately differentiate the tissue boundaries play an important part in finding the correct location. Inaccuracies and errors generated by imprecise site location have recently been quantified by Forrest *et al.* (1990).

In the other major red meat species, cattle and sheep, there is much more variable fat partitioning and with the inability to find a representative site, probes are much less accurate in predicting lean meat percentage. Chadwick and Kempster (1983) found that probe measurements on cattle were less accurate than subjective visual assessment. Johnson and Ball (1988) also concluded that fat site measurements were poor predictors of beef carcass meat yield. Similarly, Chadwick *et al.* (1986) found that subjective scoring outperformed tissue depth measurements in predicting lean content in lambs. It has been suggested by Kempster *et al.* (1982), Dumont (1989), and others that adding some measurement of conformation (carcass muscularity) to fat depth measurements improves the precision of percentage lean predictions. This has lead to development of another new technology, video image analysis (VIA).

VIA technology has previously been developed to measure fat in the processing environment (Newman, 1984a, 1987a). This has now been adapted to undertake carcass measurements. A recent independent trial using the technique for lamb carcass evaluation (Meat Livestock Commission, U.K., unpublished report) showed that VIA was significantly better than both ultrasound and subjective visual grading. Adding an objective conformation score to the fat depth probe data improves the accuracy of the meat prediction in pigs (see Table 3), particularly the more muscular carcasses which tend to be consistently under-predicted by the probes (Newman and Wood, 1989). Extended commercial VIA trials will shortly commence for all three red meat species.

The relatively widespread adoption of probes in pig carcass classification has tended to limit the application of ultrasound to beef and lamb, although some commercial use of the technique in pigs is reported (e.g., Branscheid *et al.*, 1989). The VOS technique of Miles *et al.* (1983), described earlier, has shown itself to be more accurate than visual appraisal in determining percentage lean, but less accurate in determining percentage subcutaneous fat in beef. In all instances, the addition of some measurement of conformation significantly reduced sample RSDs (Table 4). Similarly, a number of electro-mechanical devices such as the SKG II (Giralda GmbH, Aichach, Germany), Porkitron and ZP (Zimmermann Technik, Bahlingen, Germany), which has achieved some recognition in Germany for pig carcass grading, add conformation data to fat depth data to achieve improved predictions of percentage lean (Walstra, 1989; Casteels *et al.*, 1984).

Early results using the electro-magnetic measuring equipment (EMME) to predict percentage lean in carcasses were not good. However, recent results from Forrest *et al.* (1990) have been much better. The technique shows a good correlation between lean mass and predictive measurements, but this is significantly lower for percentage lean predictions as variations in fat/bone ratios within the component parts will show considerable variation. Addition of carcass weight to the predictive model reduces this error.

The results discussed here suggest that a combination of more than one technology is needed to accurately express both muscle and fat composition and distribution. There is also a need to replace manually operated techniques with automated ones, not only to improve reliability and repeatability of measurement, but also to remove operator costs and overheads. While objective measurements would improve the method of producer payment and would undoubtedly aid meat buying, the ability to predict tissue distribution of primals or some of the more highly priced cuts within the carcass would generate considerable improvements in cost benefit particularly to the meat processor.

Table 4. Precision of ultrasound, fat depth measurements and visual scoring in predicting beef % lean (source: Miles *et al.*, 1990).

Measurement	% Lean (RSD)	Subcut Fat (RSD)	Intermuscular Fat (RSD)
Sample SD	4.50	2.50	2.20
VOS (3 sites)	1.89	1.21	1.10
VOS + Conformation Score	1.58		
Probe Fat Depth	3.46	1.71	1.82
Probe + Conformation Score	2.92		
Visual Fat Score	2.39	0.91	1.30
Visual Fat + Conformation Score	2.05		

Table 5. Fat content range in a number of common processed meat products (sources: Hudson *et al.*, 1986; Jones *et al.*, 1989; Newman, 1987b; Souci *et al.*, 1981).

Product	Range of % Fat
Cooked Ham	5.6 - 23.0
Country-Style Ham	25.0 - 40.0
Blockwurst	42.0 - 50.0
Liver Sausage	36.5 - 46.0
Spreadable Sausage	43.7 - 64.9
Fresh Sausage	21.0 - 45.0
British Sausage	10.3 - 30.0
Smoked Country Hams	22.4 - 42.5
Wieners	20.8 - 25.0
Mince (Ground) Meat	5.3 - 31.3

Fat Monitoring and Measurement in Manufacturing

Continuous 'on-line' monitoring and measuring of fat is certainly the area of operation which can produce the biggest cost benefit and cost performance improvements. During this stage of the manufacturing process, excess fat can either be removed by trimming if a raw cut such as a joint or chop, or an intermediate product such as uncured bacon or ham is being produced, or by the addition of lean if it is a processed product. Excess fat is a low value material and may even generate a disposal cost unless it can be utilized elsewhere. Therefore, considering the importance of monitoring and measuring fat levels in the processing environment and the wide range of fat levels encountered within every product category (Table 5), it is surprising that few continuous techniques have been developed. Traditionally, sample coring and chemical extraction techniques have been used. These are slow and relatively inaccurate with large-scale unblended materials (Newman, 1984a). Mixing errors in formulations and blends can result in the necessity for expensive remedial action, such reworking also affects overall meat quality.

A number of developments have automated some or all of the fat sample measurements [Fosslet (Foss-Electric, Hillerod, Denmark); and CEM (CEM Corp., Indian Trail, NC, USA)], however, they still require that the sample be blended before measurement as well as only working on discrete samples. The Anal Ray (Anal Ray Corp, Davenport, Iowa) system has been the *de facto* fat measuring technique adopted within the factory environment for the past 15 years. This technique operates on the principle that when exposed to a

Table 6. Comparison of fat measurement in commercial ground pork samples using two commercial methods (source: Newman, 1992c).

Method 1. batch sampling using Anal-Ray.

i) Single Samples (combined from 5 sampling locations - conventional commercial practice).

	Before Mixing			After Mixing		
	Batch 1	Batch 2	Batch 3	Batch 1	Batch 2	Batch 3
	24.7	24.1	28.3	21.0	23.7	24.1

ii) Random sampling of whole batch (15 x 10 lb samples).

	Batch 1	Batch 2	Batch 3
	23.0	23.8	28.5
	22.8	25.8	28.8
	21.9	23.8	25.2
	24.7	25.2	24.0
	22.1	24.8	28.3
	23.4	24.9	27.2
	22.3	26.1	23.5
	24.7	25.0	23.8
	21.6	24.8	24.3
	22.5	26.2	22.9
	20.4	26.7	23.0
	22.1	26.7	24.4
	21.2	25.9	23.9
	23.6	26.8	23.2
	22.5	26.4	27.4
Sample Mean	22.4	25.35	25.33
Sample S.D.	± 1.09	± 1.01	± 2.14
Sample Range	20.04 - 24.7	23.8 - 26.8	22.9 - 28.8

Method 2. Continuous 'on-line' sampling (sampling 25 times per second, total samples 11,250).

	Batch 1	Batch 2	Batch 3
Sample Mean	22.69	25.07	25.14
Sample S.D.	± 0.46	± 0.39	± 0.44

known low level dose of X-rays, fat and lean absorb different amounts of X-rays. It uses larger samples than the chemical techniques (a few kilograms as opposed to a few grams), but these are still small compared with overall production volumes which will often exceed 1000 kg per batch. The work of Palmer (1978), Newman (1984a) and others has shown that for most applications, a minimum of 10% of the batch needs to be sampled to accurately reflect total sample fat content and accommodate product variability; this rises to more than 25% for large pieces of meat trim, materials of high fat variability or where the resultant material arises from more than one source. While the Anal-Ray technique is a great improvement over chemical methods for many commercial applications, considerable errors can still be generated. Sample size, the presence of material other than fat and lean such as skin, connective tissue and bone, fat source, the presence of air voids in the sample and poor sampling techniques can all compound to produce wide sample variability. In a survey covering a wide range of manufacturing environments, variability of fat levels have often exceeded 10% in the fat measurement of trimmings, 5% in intermediate mixes and 2% in final blends (Table 6; Newman, 1992c). This has resulted in the usual commercial practice of 'overleaning' to ensure that all product meets customer specifications. With a price ratio of 10:1 in the relative values of fat and lean, this practice is expensive to the meat processors.

Thus, there is a considerable need to develop continuous on-line fat measuring techniques. Two such instruments have been developed that have met with varying degrees of commercial acceptance. The principle of the EMME system has already been discussed. Two versions of the technology have been developed, one to measure lean in meat cuts and primals, the other to monitor fat content in boxed meat. In the former, good results have been found for boneless cuts, although the presence of bone and skin increase predictive errors (Gwartney and Forrest., 1992). Eustace and Thornton (1991) have shown that EMME techniques can be used effectively on cartonned meat provided the carton is filled to a standard fill, the pieces of meat are not large and the meat temperature, box type and box orientation are not changed during the course of the batch. Their results showed that individual boxes can vary by 3% but that the overall error decreased as the batch size increased. Unfortunately, the technique is unable to accommodate a continuous flow of random sized trimmings and therefore in its present configuration is not practical in any continuous product monitoring and control application such as trim blending, sausage or burger formulations. For this type of application, VIA technology is more suited.

VIA has been used in a wide variety of process and constituent monitoring applications using fresh or frozen, sliced, diced or minced meats. Because it is also able to compensate of materials for different fat type, it has very high correlation with actual lipid content (Newman, 1984a,b; 1987a,b). VIA has also been successful in its process control capabilities where in conjunction with a 'least cost formulation' program, it can closely monitor and mix meat materials with a wide range of differing fat levels, while maintaining tight control of overall fat content ($\pm$ 1.0% against fat, $\pm$ 1.5% against chemical lipid). However, VIA alone has limitations. It relies on representative sampling, so the measurement of large pieces of meat displaying surface characteristics unrepresentative of the whole batch can lead to large errors in prediction. Also, as with the EMME system, very small samples, i.e., a single carton, can generate larger sampling errors.

A recent advance (Newman, 1992c) using VIA combined with two other technologies, X-ray and line scan image acquisition, has successfully overcome all of these problems so that the manufacturer of processed meats can continuously monitor his production process. The provision of images generated by X-ray enables three-dimensional rather than two-dimensional data to be collected; line-scan image generation techniques allows data capture, processing and display to be continuously undertaken at production rates. The result is a very accurate, automatic continuous fat measurement system which also functions as a total mixing/blending process controller (Table 6). This system, which has recently become commercially available, can also be integrated with technology used to detect food contaminants such as bone, glass, and stones, thus providing a total but flexible quality assurance and control capability to the manufacturer.

The Future

In the absence of evidence to the contrary, there will be a continuing need for a reduction in the fat content both in meat products and the diet in general. Consumers will demand tighter control of fat in the products they buy and an accurate declaration of the fat content on the product label. Processors will continue to refine their techniques to improve both quality assurance and quality control. By becoming more efficient in their ability to monitor fat levels in raw materials, they in turn, will become more demanding of their suppliers, the abattoirs. At the other end of the production cycle, producers will integrate technology with changes in animal husbandry practices and genetic selection enabling them to supply the market with the lower fat, better quality raw materials demanded. Using technology to monitor the rate of deposition and the distribution of fat and lean in their livestock, will allow them to continuously fine tune their operations. But they will demand higher prices, or prices which better reflect the differential between lean and fatter carcasses.

So where does this leave the abattoir? Within the EC, objective grading legislation for all three red meat species will probably be introduced during this decade. Such legislation will oblige abattoirs to have the technology installed and in operation. They, in turn, will be capable of greater selection in the purchasing of animals from the producers, but the increased differential they will have to pay will be passed on the processors. Ultimately, the consumer will pay, but in return they will get better quality, healthier, lower fat meat and meat products.

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Editor's Note: All of the reviewer's concerns were appropriately addressed by text changes, hence there is no **Discussion with Reviewers**.