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Review

Healthier meat and meat products: their role as functional foods

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Abstract

This review deals with the implications of meat and meat products for human health. It analyses the effect of the presence or absence of various factors: fat, fatty acid composition, cholesterol, calorific value, salt, nitrite or lipid oxidation products that can cause health problems. Bearing in mind these considerations, it then describes the strategies used in animal production, treatment of meat raw material and reformulation of meat products to obtain healthier meat and meat products. Functional ingredients are responsible for making functional foods work, and this review therefore discusses the scope of current meat technology to favour the presence of various active-food components, and provide an additional physiological benefit beyond that of meeting basic nutritional needs. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

In rich societies, consumers increasingly attach importance to all those aspects that improve their quality of life. Diet is not the only factor that affects well-being and health, but it is one of the most important. The aim is to have balanced, varied diets containing even safer and even healthier foods still with a pleasant mouthfeel. Factors that have fostered this development include the tremendous current impact on public opinion of the media on the relationship between diet and health, the growing life-expectancy of the population (consumers have a high purchasing power and greater health problems and they are very eager to take part in any initiative to keep healthy), more concern with disease prevention, etc.

It is this complex situation that lies behind the spectacular growth in the development of "healthier" products. Such products must possess one of the following characteristics: modified composition and/or processing conditions to prevent or limit the presence of certain potentially harmful compounds, and/or the possibility of including certain desirable substances, either naturally or by addition, with the subsequent added benefits to health. The concept of "healthier" products includes what are known as "functional foods". These are defined as foods that are used to prevent and treat certain disorders and diseases, in addition to their nutritional value per se. In fact, this is not a new idea, for centuries mankind has been exploiting the properties of certain foods to treat, mitigate or prevent diseases. However, the large amount of scientific evidence available on the relationship between food intake and the incidence of disease has led to a burgeoning interest in foods that provide additional physiological benefits.

There are three basic requirements for a food to be regarded as functional (Goldberg, 1994): (1) it is a food (not capsules, tablets, or powder) derived from natural occurring ingredients; (2) it can and should be consumed as a part of the daily diet; and (3) once ingested, it must regulate specific processes such as enhancing biological defence mechanisms, preventing and treating specific diseases, controlling physical and mental conditions, and delaying the ageing process.

Meat and meat products are essential components in the diets of developed countries. Their consumption is affected by various factors. The most important ones are product characteristics (sensory and nutritional properties, safety, price, convenience, etc.) and consumer and environment-related ones (psychological, health, family or educational aspects, general economic situation, climate, legislation, etc.). These factors are usually closely linked to social, economic, political and geographical aspects. The consequence of all this is that

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in rich societies one of the aspects that most affects the "image" and hence the consumption of meat is whether it is perceived as healthy. Obviously, there are some aspects that are currently causing a lack of confidence. One of them is the implication of certain meat constituents in some of the most prevalent diseases in our society (cardiovascular disease, cancer, hypertension and obesity). Another is the outbreak of bovine spongiform encephalopathy (BSE), and *Salmonella* in chicken, scandals arising from the use of clembuterol, and more recently dioxin-contaminated animal feed in Belgium. These two types of phenomenon are very different in nature, but together they help create a crisis situation which is proving highly detrimental to the industry.

Meat and meat products are important sources of proteins, vitamins and minerals, but they also contain fat, saturated fatty acids, cholesterol, salt, etc. In order to produce "healthier" meat products we need to fully understand their positive and negative effects on health. Only then shall we be able to devise suitable strategies to effectively control and adjust their characteristics to suit our needs.

2. Implication of meat for human health

Like any other food, meat and meat products contain elements which in certain circumstances and in inappropriate proportions have a negative effect on human health. Some of these are constituents (natural or otherwise) present in live animals, for instance, fat, cholesterol, residues from environmental pollution or the use of pharmaceuticals, etc. Others are added to the product during processing for technological, microbiological or sensory reasons (salt, nitrite, phosphate, etc.). There is a third group that is produced by technological treatment (including contaminants from disinfectants or detergents, toxic compounds formed during cooking, etc.). Finally, there are those that develop particularly in the storage/commercialisation phase, notably the growth of some pathogenic bacteria, the formation of certain lipid oxidation products and the migration of compounds from the packing material to the product.

Below is an analysis of several of the most important aspects of the potential health problems associated with meat consumption. Meat safety aspects like chemical residues, emerging pathogens or BSE, although of notable interest (Tarrant, 1998), are not dealt with in this review.

2.1. Fat, fatty acids, cholesterol and calorific value

The general nutritional and health implications of fats and oils is an area of research and development where the information is frequently contradictory. However, there are a number of proven facts as regards fat intake. There is evidence that fat-rich diets, as well as causing obesity, are also directly related to the risk of colon cancer. Fat and cholesterol are also associated with cardiovascular diseases. In light of these implications, various international institutions, among them the World Health Organization (WHO), have drawn up the following nutritional recommendations: fat should provide between 15 and 30% of the calories in the diet, saturated fat should not provide more than 10% of these calories, and cholesterol intake should be limited to 300 mg/day. Clearly, these limitations refer not only to the *amount of fat* but also to the *fatty acid composition* and the *cholesterol levels* in foods, of which meat and meat products constitute a major part.

All fats do not have the same metabolism, and therefore the extent to which the composition of meat and meat derivatives should be modified is closely linked to cholesterol levels and fat intake (and the fatty acid profile). Meat fat content can vary widely depending on various factors such as species, feeding, cut, degree of separation of the fat in the various handling phases (processing of the carcass, cutting, preparation of commercial cuts, removal by the consumer), cooking conditions, etc. The lipid content in edible lean meat today is less than 5% (Chizzolini, Zanardi, Dorigoni, & Ghidini, 1999), so it can no longer be considered an energy-rich food. However, this is not the case of some of the leading commercial meat products, where the percentages can be as high as 40–50% and structural disintegration is so great that the consumer cannot reduce the high fat content.

Fatty acid composition has a considerable effect on the diet/health relationship, since each fatty acid affects the plasmatic lipids differently. Meat lipids usually contain less than 50% saturated fatty acids (SFAs of which only 25–35% have atherogenic properties), and up to 70% (beef 50–52%, pork 55–57%, lamb 50–52%, chicken 70%, rabbit 62%) unsaturated fatty acids (monounsaturates, MUFAs, and polyunsaturates, PUFAs; Romans, Costello, Carlson, Greaser, & Jones, 1994). The presence of MUFAs and PUFAs in the diet reduces the level of plasma low-density lipoproteins-cholesterol, although PUFAs also depress the high density lipoproteins-cholesterol (Mattson & Grundy, 1985). Hence, it does not seem reasonable to describe meat generally as a highly saturated food, especially in comparison with some other products (e.g. some dairy products).

The amount of cholesterol in meat and meat products depends on numerous factors, but in general it is less than 75 mg/100 g, except in the case of some edible offal (heart, kidney, brains, etc.) where the concentrations are much higher (Chizzolini et al., 1999; Romans et al., 1994). From meat consumption and cholesterol content data, it has been estimated that from one-third to one-half of the daily recommended cholesterol intake (less than 300mg) is provided by meat (Chizzolini et al., 1999).

In industrialised countries, although levels are falling, some 36–40% of the total calories in the food supply come from fat (well above the recommended limit of 30%), nearly half of which is from meat intake (Byers, Turner, & Cross, 1993; Sheard, Wood, Nute, & Ball, 1998). Different dietary guidelines (Paneras, Bloukas, & Filis, 1998) offer recommendations as to the source of calorie intake: no more than 10% should come from saturated fatty acids, no more than 10% from polyunsaturated fatty acids, and 10–15% should come from monounsaturated fatty acids. Approximately 34% of the calories in the Mediterranean diet come from lipids. Of these, 10% come from saturated fatty acids, 18% from monounsaturated and 6% from omega-6 fatty acids.

The data used for fat intake (and other constituents) are generally based on the amount of meat marketed and meat composition parameters. Nevertheless, for a more realistic estimation of fat and calorie intake, we need to know the exact amount and final composition of the products consumed, information that cannot be obtained from the aforementioned data. Currently, only about 60% of meat production (after elimination of non-edible parts) is used in human food (Klurfeld, 1994). On the other hand, many foods, like meat, undergo different treatments prior to consumption (e.g. cooking), which may affect composition. In the light of these considerations, Sheard et al. (1998) have indicated that the actual amount of meat consumed in the UK is 30–40% less than that estimated by the compilers of the National Food Survey (NFS; based on the amount of meat purchased). Bearing in mind that these same authors indicate that large quantities of fat (almost 25%) are released during meat cooking, the new calculations reveal that actual fat consumption (and hence calorie content) has dropped from 18.1 (NFS estimate) to 13.6 g per person per day. This can even be as low as 10.3 where subcutaneous fat and skin are also removed (as in chicken and turkey), all without any change in meat consumption figures.

2.2. Salt

It has recently been recommended that salt intake be reduced in light of the relationship between high sodium levels and arterial hypertension. A large percentage of the population possesses a hereditary predisposition to arterial hypertension, the incidence of which is further affected by excess weight and high sodium intake. Sodium comes from a wide variety of foods, among them meat and meat derivatives.

Meat as such is relatively poor in sodium, containing only 50–90 mg of sodium per 100 g (Romans et al., 1994). However, the sodium in meat derivatives is much higher because of the salt content, which can be as much as 2% in heat-treated products (e.g. sausages) and as much as 6% in uncooked cured products, in which drying (loss of moisture) increases the proportion even further. Estimations taking eating habits into account suggest that approximately 20–30% of common salt intake comes from meat and meat derivatives (Wirth, 1991).

2.3. Toxic compounds produced during meat processing and storage

Like other complex foods, meat and meat products undergo major chemical changes during processing and commercialisation (grinding, cooking, storage, exposure to light, etc.). These changes include the formation of numerous compounds, many of which impart desirable characteristics to food. Others, however, can possess potentially harmful biological properties. The compounds that can cause disease include polycyclic aromatic hydrocarbons (PAHs), nitrosamines and lipid oxidation products (Hotchkiss & Parker, 1990).

PAHs result from the combustion of organic matter in the cooking and smoking of meat and meat products, as in many other foods. Their presence is determined by a number of factors, among them the composition of the product and the heat treatment applied. It is important to detect variable amounts of these hydrocarbons in certain meat derivatives, as some of them are carcinogenic (Hotchkiss & Parker, 1990).

Sodium nitrite used in cured meat products interacts with various constituents in the meat's complex biological systems. Thus at the end of the manufacturing process only about 10–20% of the nitrite originally added can be detected with analysis. Residual nitrite levels can drop even further during storage and distribution, and again during preparation and consumption (Cassens, 1997). Despite the technological, microbiological and sensory advantages of nitrite, its use was brought seriously into question in the 1970s because of its interaction with secondary amines to form N-nitrosamines, chemical agents with carcinogenic properties. These compounds, which are detected in a number of different foods, including heat-treated cured meat products, can form both in the product itself, depending on the heating conditions, salt and nitrite concentration, pH or ascorbate content, and also in the consumer's stomach after ingestion (Pegg & Shahidi, 1997; Shahidi, 1989). Recently, Cassens (1997) highlighted the need to review the effect on health of residual nitrite and ascorbate in meat derivatives (the latter inhibit the formation of N-nitrosamines). New scientific evidence also points to the health benefits of nitrite (and/or its reaction products).

Polyunsaturated fatty acids and cholesterol may undergo oxidation during the preparation and storage of meat and meat products. This oxidation produces numerous compounds (hydroperoxides, aldehydes, ketones, cholesterol oxides such as oxysterols, etc.), some of which are believed to have mutagenic and carcinogenic effects, and cytotoxic properties. Oxidation products are usually not abundant in foods and are well below the threshold of toxicity. The threshold of sensory detection of these compounds is also very low, which together with their unpleasant smell and taste, means that they are easily detected and the food is rejected. This is a mechanism to protect against exposure to high concentrations of these substances, but the long-term impact on health of continually consuming small amounts is not known (Hotchkiss & Parker, 1990).

3. Strategies for achieving healthier meat and meat products

As in other food sectors, in order to achieve healthier meat and meat derivatives (even with functional properties), it is necessary to avoid undesired substances (natural or otherwise) or reduce them to appropriate limits, and to increase the levels (naturally or by programmed additions) of other substances with beneficial properties (functional ingredients).

Essentially, three kinds of strategies are used to achieve this: these are associated with animal production, the handling of meat raw materials, and the reformulation of meat derivatives. The various stages through which the product passes before it is consumed (storage, transport, shelf display, etc.) are important because of their effect on meat characteristics, some of which affect human health. The consumer-dependent stages (storage at home, cooking, etc.), although primarily associated with food safety, are also of importance.

Some examples of the techniques currently being used to produce healthier meat and meat products are given below.

3.1. Modification of carcass composition

Apart from aspects relating to food safety (residues, BSE, etc.), carcass composition can be altered at the animal production stage.

The composition of the carcass, and hence also of commercial cuts, varies not only according to species, but also according to breed, age, sex, feed type, etc. A wide range of strategies is available for inducing changes in different meat constituents such as protein, lipid content, fatty acid composition, and vitamin E level, etc. These include genetic selection, nutrition and feeding management, growth-promoting and nutrient partitioning agents, immunisation of animals against target circulation hormones or releasing factors and gene manipulation techniques (Bass, Butler-Hogg, & Kirton, 1990; Byers et al., 1993; Hay & Preston, 1994).

By selecting races and genetic lines, carcass composition has been significantly altered. This has led to a substantial reduction in fattiness and a higher percentage of unsaturated fatty acids (Hay & Preston, 1994; Morrissey, Sheeny, Galvin, Kerry, & Buckley, 1998).

The ratio of fat to lean in pig and cattle carcasses is affected by the diet composition and feeding levels, particularly the energy and protein intake. In pigs, restricting the energy intake will reduce carcass fat, and feeding excess protein will result in a higher proportion of lean to fat (Hay & Preston, 1994). Dietary fatty acid composition is an extremely important part of the fatty acid profiles of monogastric animals (pigs, poultry) and is less important in ruminants (cattle) where desirable combinations of fatty acids are to be obtained for human consumption (Byers et al., 1993) with less saturated and more mono- and polyunsaturated fatty acids. Increasing the amount of unsaturated fatty acids in meat means that there is a greater possibility of oxidation, a process that has undesirable sensory or health effects. There are several ways of minimising lipid oxidation and some of them are associated with animal feeding (Decker & Xu, 1998; Morrissey et al., 1998). A vitamin E-supplemented diet in poultry, pigs and cattle prolongs the shelf-life of these products. The antioxidant activity reduces rancidity and helps the meat retain its colour (Pszczola, 1998). Feeding strategies have been successfully used to produce eggs, beef and chicken with up to 20 times the normal level of DHA (docosahexaenoic acid, 22:6 n-3), 7 times the normal level of vitamin E and 6 times the normal omega-3 content of their traditional counterparts (Sloan, 2000).

By using partitioning agents like anabolisers, growth hormones, etc., or immunisation strategies, it is possible to alter those metabolic processes that regulate the use of nutrients during growth, thus promoting protein synthesis and reducing fat deposition (Bass et al., 1990; Beermann, 1994; Byers et al., 1993). For example, the administration of somatotropin to pigs can lead to a 60% reduction in carcass fat, a 70% increase in carcass protein content and 27% less lipid content in lean tissues containing as much as 40 and 37% less of SFAs and MUFAs, respectively, and no differences in PUFAs (Solomon, 1994). Strategies for reducing carcass fat content include elimination of castration, level of maturity, and so forth (Bass et al., 1990).

3.2. Manipulation of meat raw materials

It is possible to intervene at any stage in the process of transformation of muscle into meat and in the various different stages of raw material preparation to alter the meat composition and thereby achieve healthier products.

The desire to limit the fat content of commercial cuts has encouraged the development of several procedures designed to separate and/or extract both visible fat and fat located in less accessible parts of the muscle tissue where it is more difficult to remove. The most immediate system consists of extensive trimming to remove external and internal fat from the carcass; further trimming is done on primal cuts and, where necessary, the defatting is completed on retail cuts. However, this is sometimes not feasible or desirable because of lower yields, costs and other considerations. Depending on the type of meat raw materials and the required fat content, fairly complex physicochemical techniques have been applied, generally consisting of reducing the meat particle size before preparing (modifying the pH, ionic strength of the medium, etc.) and then proceeding to the actual extraction or separation processes based on cryoconcentration, centrifugation, decantation, etc.

3.3. *Reformulation of meat products*

Depending on the product type (composed of identifiable pieces of meat, coarsely or finely ground, emulsions, cooked, cured, etc.), one of the best moments at which to alter the composition of foods is perhaps during one of the preparation stages. At this stage reformulation is used as far as possible to develop a range of derivatives with custom-designed composition and properties. For this there are two possible types of complementary intervention. The first involves reducing some compounds normally present in these foods to appropriate amounts, for example, fat, SFAs, salt, nitrites and so on. The second is to incorporate ingredients that are potentially health-enhancing (functional), for example, fibre, certain types of vegetable protein, MUFAs and PUFAs, antioxidants, etc.

There are numerous aspects to be taken into account in the development of these kinds of products (Jiménez-Colmenero, 2000). The new meat derivative must have the appropriate technological, sensory and nutritional properties, and be safe and convenient for consumption, etc. Ignoring such requirements, which are demanded by the reference products if they are to be improved, not only compromises the success of the derivatives concerned but also projects a bad image of these meat derivatives and creates a lack of confidence which is difficult to surmount. Some examples of meat product reformulation processes are given below.

3.3.1. *Reduction of fat content*

Generally speaking, fat reduction is achieved by reformulation. This consists of combining pre-selected meat raw materials (leaner and of known composition) with appropriate amounts of water, fat (animal or vegetable depending on the new composition), flavourings (with modified formulation) and other ingredients (fat replacements or substitutes), which coupled with technological processes give the product certain desirable characteristics, such as improved composition, sensory and technological properties, safety, nutritional value, convenience, etc.

Consequently, the development of low-fat products means that factors associated with meat raw materials, non-meat ingredients, and manufacture and preparation procedures (Jiménez Colmenero, 1996; Keeton, 1994) together with other factors such as the characteristics of the new derivative must be taken into account. These characteristics include the class of product (patties, frankfurters, bolognas, etc.), the final composition desired (percentage and fat type, protein, salt, etc.), and the processing type required (cooking, smoking, dry-curing, etc.). All these factors affect the various quality attributes, and it is hard to determine their behaviour beforehand when such variables as composition, pH, ionic strength and some physical and chemical properties are introduced.

3.3.2. *Modification of the fatty acid profile*

There are essentially two procedures whereby meat fatty acid composition can be altered, simultaneously with fat reduction or otherwise. The first of these is to use genetic and feeding strategies (discussed earlier) to improve the degree of lipid unsaturation. Sausages containing high concentrations of monounsaturated acids have been made with meat raw materials from pigs fed on safflower, sunflower and canola oils (Sackelford, Miller, Haydon, & Reagan, 1990; St. John, Buyck, Keeton, Leu, & Smith, 1986).

The second procedure consists of replacing part of the animal fat normally present in the product with another more suited to human needs, i.e. with less saturated fatty acids and more monounsaturated (oleic) or polyunsaturated acids, and with no cholesterol. Although simple fat replacement does not reduce the caloric content, it does greatly improve the nutritional qualities of the product. Both fish oils (omega-3 polyunsaturated oil) and vegetable oils (partially hydrogenated from corn, cottonseed, palm, peanut and soybean, peanut, high-oleic acid sunflower, cottonseed, olive) have been used for this purpose in products such as patties and sausages (Liu, Huffman, & Egbert, 1991; Marquez, Ahmed, West, & Johnson, 1989; Park, Rhee, Keeton, & Rhee, 1989; Paneras et al., 1998). Depending on the kind of oil, products may present some differences (including sensory differences) from their reference products, but these differences can be readjusted by means of one or more strategies for the production of low-fat products (Jiménez Colmenero, 1996).

3.3.3. Reduction of cholesterol

In the last few decades there has been a clear drop in the fat content of carcasses, but there is no easy way of determining whether the same is also true of cholesterol content (Chizzolini et al., 1999). There are two basic reasons for this. Firstly, comparisons are difficult because analytical methods have improved so much in recent years. Secondly, the amount of intra- and intermuscular fat is not always directly related to the cholesterol level. In dry matter, the amount of cholesterol in beef, pork, lamb and poultry lean tissue may be as much as twice that present in adipose tissue, but in wet matter, the cholesterol content of lean tissues is slightly lower than that of adipose tissue (Mandigo, 1991). This goes some way to explain why the cholesterol content of meat products is not clearly related to the fat content (within wide margins: 1–35%), even after cooking has caused weight loss by eliminating water (and to a lesser extent, fat as well), and changed the composition (Hoelscher, Savell, Harris, Cross, & Rhee, 1987). The reduction of fat in beef patties (from 20 to 9.8%) and its replacement by lean meat does not lower cholesterol (Egbert, Huffman, Chen, & Dylewski, 1991). Reducing the percentage of fat in the product therefore does not seem to be a viable method for lowering cholesterol in meat derivatives. It has even been suggested that when fat is reduced by increasing the proportion of lean meat, the cholesterol level in the product may even increase (Mandigo, 1991).

Products with less cholesterol can be obtained by replacing fat and lean meat raw materials (since dietary cholesterol is strictly linked to animal cells) with other vegetable materials containing no cholesterol. A number of meat products (sausages, patties, etc.) have been reformulated by reducing and/or partially replacing animal fat with vegetable oils (peanut, canola, sunflower, olive, etc.) and adding vegetable proteins (soy, maize, oats, etc.). For example, the use of peanut oil to replace 60% of the beef fat in frankfurters containing 29% fat reduced the cholesterol content by more than 35% (Marquez et al., 1989). Paneras et al. (1998), using olive, cottonseed and soy oils, obtained frankfurters (10% fat) with up to 59% less cholesterol than normal frankfurters containing 30% animal fat.

3.3.4. Reduction of calories

In keeping with dietary recommendations, both the total caloric content and the percentage of calories from fat (also the fatty acid profile) will be the new criteria for evaluation of consumer-manipulated foods. They are therefore a key consideration in designing the new composition of any product. The calorific values (per gram) of the principal components of foods are: fat 9 kcal, proteins 4 kcal and carbohydrates 4 kcal. Calorie intake is most frequently limited by reducing the proportion of fat, where the content is more than twice that of proteins or carbohydrates, but the role of fat replacement should not be ignored.

Simple fat reduction helps limit the calorie intake from meat products, but in many cases this may not be sufficient to meet WHO's dietary recommendations. For example, in products with 10–12% protein and 25–30% fat, over 80% of the calorie intake comes from lipids. In meat derivatives containing only 6% fat, as much as 50% of the calories come from fatty compounds. It is only possible to reduce the intake of fat from lipids to 30%, either by drastically reducing fat content to around 2%, or by diluting it with fat replacements or substitutes that improve the protein/fat/carbohydrate balance (Shand, Schmidt, Mandingo, & Claus, 1990).

3.3.5. Reduction of sodium content

Sodium reduction requires partially substituting the sodium chloride added to meat derivatives by other compounds that have similar effects on sensory, technological and microbiological properties. The extent to which salt levels can be limited depends on the product type (Wirth, 1991).

A number of compounds have been used for this purpose, among them chlorides other than NaCl, such as potassium and magnesium salts. Although total substitution of NaCl does not seem possible because of sensory reasons, a combination of sodium, potassium and magnesium salts may produce satisfactory results. A case in point are certain commercial preparations used in the meat industry, which contain 43% less sodium and do not have the sensory disadvantages frequently associated with NaCl substitutes (Pszczola, 1999).

The addition of phosphates to meat products reduces the negative effect of lower salt levels by improving sensory and technological properties (e.g. fat and water-retention capacity) and it does not raise the sodium levels. Moreover, the antimicrobial and antioxidant activity of phosphates promotes product stability. The extent of these effects depends on a number of factors, including phosphate type and concentration, the product pH, the NaCl content, the presence of other inhibitors (e.g. nitrites or sorbates), the heat treatment used, etc. With phosphates, the salt normally present in a meat derivative can be reduced by as much as 50%.

In the meat industry, salt levels can be reduced by lactates, as flavour enhancers and inhibitors of microbial growth, and by collagen hydrolysates as flavour enhancers. Texture can be altered and binding properties improved by the gel-forming properties of calcium alginate (which unlike other hydrocolloids forms chemical gels at low temperatures) or the activity of transglutaminase, which aid certain protein interactions. These new methods are particularly useful to the meat industry for restructured products, since all these properties are also imparted to non-heat-treated products with little or no salt or phosphates (Pszczola, 1999).

3.3.6. Reduction of nitrites

There are two basic strategies for reducing the potential health risks of nitrites in meat products. One is to reduce or eliminate the addition of nitrite, and the other is to use N-nitrosamine inhibitors.

N-nitrosamine production depends on the residual nitrite level. Reducing this level will lower the risk of these carcinogenic compounds forming. In fact, residual nitrite has been substantially reduced (as much as 80%) in the last few years. This change has come about thanks to the addition of less nitrite, the increased use of ascorbates, improvements in manufacturing processes and changes in composition (e.g. larger proportions of ingredients; Cassens, 1997). Nevertheless, N-nitrosamine production cannot be totally eliminated while its precursors (nitrites, amines and amino acids) are still present. Alternatives must therefore be found, but this is not easy because of the numerous reactions of N-nitrosamine with the complex biological systems present in meat. Indeed, it is impossible to find any single compound capable of replacing the functions of nitrite. The solution must therefore be to combine several compounds, which together have a cumulative effect on colour, flavour, and antioxidant and antimicrobial activity.

Proposals for alternatives to the colouring effects of nitrites range from using colorants like erythrosin to forming the same pigment that occurs naturally in the cured product (mononitrosyl ferrohemochrome) outside the meat system and adding it later (Pegg & Shahidi, 1997). The flavour of cured products is associated with the cumulative effect of very small amounts of numerous compounds. The role of nitrite in flavour appears to be related to its antioxidant activity, which prevents a further build-up of these substances. To reproduce this property, there have been assays combining chemical antioxidants and chelating agents. Sorbic acid and potassium sorbate, sodium hypophosphite, fumaric acid esters, parabens and even lactic acid-producing bacteria have been used to reproduce the microbial action of nitrites (Shahidi, 1989).

Compounds like ascorbate and erythorbate help inhibit the formation of N-nitrosamines, but their solubility in adipose tissue is too slight for them to be really effective. There have been studies on the action of several liposoluble derivatives of ascorbic acid (L-ascorbyl palmitate, long-chain acetals), combinations of α-tocopherol and ascorbate, and lactic acid (Pegg & Shahidi, 1997). In recent years there has been a noticeable increase in the residual ascorbate in commercialised meat products (Cassens, 1997).

3.3.7. Incorporation of functional ingredients

The action of functional foods is based on the use of functional ingredients. The health benefits of certain substances in food have been recognised for some time now. It is however only more recently that their role in the treatment and prevention of various diseases, or their long-term impact on ageing processes, has been established. Twelve broad groups of ingredients (of animal and vegetable origin) have been identified as having potentially beneficial effects for human health (Goldberg, 1994): (1) dietary fibre; (2) oligosaccharides; (3) sugars/alcohols; (4) amino acids, peptides and proteins; (5) glucosides; (6) alcohols; (7) isoprenes and vitamins; (8) choline; (9) lactic acid bacteria; (10) minerals; (11) unsaturated fatty acids; and (12) others not included in the preceding categories (e.g. antioxidants). Many of these ingredients have been or are currently being studied, and the results obtained are very different. The effects of the habitual transformation and conservation processes on the specific activity these ingredients should also be assessed. The use of one or more of these ingredients in meat products has opened up an enormous range of possibilities, some of which have been investigated and even commercialised. Yet there is much still to be done in what will surely be one of the most important areas in the coming years. Some examples of functional ingredients in meat derivatives are given below.

Dietary fibres from oat, sugar beet, soy, apple, pea, etc., have been included in the formulation of several meat products such as patties and sausages (Cofrades, Guerra, Carballo, Fernández-Martín, & Jiménez Colmenero, 2000; Keeton, 1994; Troutt, Hunt, Johnson, Claus, Kastner, & Kropf, 1992). In many instances, these dietary fibres not only have beneficial physiological effects thanks to their resistance to hydrolysis by digestive enzymes, but they also generate important technological properties that offset the effect of fat reduction. Inulin, a polymer of fructose with health-enhancing properties extracted from chicory (Pszczola, 1998), is being used in products like sausages or cooked ham.

Protein derivatives of vegetable origin have been used in meat products for technological purposes to reduce formulation costs and they have even been used for their nutritional value. Soy and sunflower proteins, wheat and maize derivatives, and flours from cottonseed and oats, some of which contain health-enhancing substances, have all been used as fat replacements (Keeton, 1994). For example, soy has been described as useful in the prevention and treatment of cardiovascular diseases, cancer and osteoporosis, and in the relief of menopausal symptoms (Hasler, 1998). Sunflower protein is rich in L-arginine, which combined with a low L-lysine/L-arginine ratio, is extremely useful in the prevention of hypercholesterolaemia and platelet aggregation. The meat industry has not been blind to the beneficial effects (cholesterol reduction, anticancer and combating of enteric pathogens and other intestinal organisms) of some microorganisms traditionally occurring in fermentative processes. For instance, some makers are commercialising "*chorizo*" (dry fermented sausage) inoculated with "active bifidus" and "*Lactobacilus casei*" and treated in specific conditions to ensure microbial activity. This activity helps digestion by reducing the absorption of fat and cholesterol and promoting the assimilation of nutrients.

As mentioned earlier, the importance of the lipid component in food for health has prompted the emergence of various procedures (raw materials and reformulation of products) to alter their presence both quantitatively (reducing their proportion) and qualitatively (for example, promoting the presence of omega-3 fatty acids and oleic acid). In addition to these changes, the lipid material also undergoes changes during meat processing, which can be beneficial to health. Conjugated linoleic acid has recently been detected in cooked meat. This compound is useful because it is anticarcinogenic and it occurs precisely in heat-treated meat products in which some mutagenic and carcinogenic substances have been found (Hasler, 1998).

A number of strategies are being used to enhance antioxidant activity in meat systems and to reduce the formation of oxidation products with their subsequent impact on ageing, cancer and cardiovascular disease (Decker & Xu, 1998). Some are based on intervention in raw materials, for instance modification of animal diet to increase the amount of endogenous antioxidants (vitamin E, carotenoids, etc.), to reduce the amount of pro-oxidants and/or to alter the oxidisable substrate (fatty acid composition). Others improve oxidative stability by acting upon the very processing, for instance, exogenous antioxidants (nitrite, phenolic antioxidants, tocopherols, plant derivatives, chelating agents, etc.) are added and packaging technologies are used to limit the presence of oxygen. There are currently a number of vitamin C and E-enriched meat products on the market (e.g. sausage and cooked ham).

4. Final considerations and conclusions

There can be no doubt about the importance of food for human health, and also the subsequent need for control of the nutrients consumed. Meat and meat products are essential components of our diet, they contain compounds like fat, fatty acids, cholesterol, sodium, nitrite, etc., which can have an effect on health. However, the true role of meat and its derivatives can only be fully understood by determining the amount of these compounds in meat in comparison with other foods, i.e. considering the elements in our diet all together. Moreover, in many cases product preparation leads to changes in composition, which must be taken into account if we are to have a real idea of the nutrients present in food when it is consumed rather than when it is produced or sold.

Meat and its derivatives may be considered functional foods to the extent that they contain numerous compounds thought to be functional. The idea of using food for health purposes rather than for nutrition opens up a whole new field for the meat industry. In addition to traditional presentations, the meat industry can explore various possibilities, including the control of the composition of raw and processed materials to produce design foods reformulated to have specific properties, for example, fatty acid profiles, the inclusion of antioxidants, dietary fibre, probiotics, etc. In many such products it may be necessary to use new ingredients and/or methods which affect the technological, microbiological and sensory properties.

Several aspects of these products need to be considered. The continued bio-availability of many of the functional compounds should be ensured throughout the various stages of processing and commercial storage. Furthermore, the optimum levels of the biologically active components should be established in order to ensure that their effects are genuinely beneficial in the concentrations and conditions in which they are consumed (Hasler, 1998).

Knowledge, variety and moderation are the key elements of diet and nutrition. Having a balanced diet is the consumer's responsibility, but the food industry should also co-operate and provide a wide range of products in response to this need.

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TRENDS IN FOOD SCIENCE & TECHNOLOGY

Review

The changing nature of red meat: 20 years of improving nutritional quality

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Meat, a concentrated nutrient source, was traditionally considered essential for optimal growth and development. This reputation diminished as enthusiasm for the lipid hypothesis gathered pace. The meat industry has worked steadily to reduce the fat content of red meat achieving significant results. Progress continues with both total fat reduction and modifications to the fatty acid profiles.

Recent concerns over intakes of certain micronutrients in vulnerable age groups, particularly iron, zinc and vitamin D are highlighted. Is this a positive opportunity for lean meat—now a relatively low fat, natural, nutritional supplement?

This review summarizes the changes in the nutritional composition of red meat over the past 20 years, focusing on the positive nutritional opportunities, within the confines of current scientific opinion and policy on human nutritional needs.

The role of red meat in the British diet today

Is there a place for meat in the modern diet?

Traditionally meat was considered a highly nutritious food, highly valued, and associated with good health and prosperity. As such western societies gradually increased consumption with increasing affluence. This healthy image for red meat has gradually been eroded since the 1980s. The lipid hypothesis focussed attention on the fat contributed from meat. The British Government's Committee on Medical Aspects of Food and Nutrition (COMA) report on coronary heart disease (CHD) in 1984 identified meat as a major source of saturated fatty acids, contributing a quarter of UK intakes [1]. Although the multifactorial nature of CHD risk is now widely acknowledged [2,3], the health image of red meat remains tarnished due to its negative association with fat, and more recently due to non-nutritional issues including animal health concerns such as bovine spongiform encephalopathy (BSE).

Vegetarian studies have been used to explore the associations between diet and chronic 'western diseases of affluence'. Since meat intake is by definition the obvious difference between such diets, these studies have often exaggerated the health benefits of a vegetarian diet whilst reinforcing the negative health image of meat. It has been recognized for some time [4] that although vegetarianism seems to confer some protection against heart disease, it is not clear if this is due to abstinence from meat or high consumption of vegetables. Additionally vegetarians have tended to be more health conscious, such that other lifestyle factors may influence their health—they traditionally smoke less, consume less alcohol, tea, and coffee, and tend to exercise more.

The influence of physical activity is becoming a more significant factor as research consistently points to the profound importance of physical inactivity as a prime risk factor for CHD, obesity, non-insulin-dependent diabetes, hypertension and general long-term health [5–7]. Meat-eating groups typify Western society and tend to be dominated by sedentary, physically inactive subjects, with little interest in diet.

Typical Western omnivorous diets over the last 40 years have been relatively high in protein and fat with insufficient dietary fibre, and fruit and vegetables. It is just as plausible that meat intake is acting as a marker for a generally '*unhealthy*' diet, as measured by today's dietary standards [8–11].

With a limited range of foods available in primitive societies throughout history, meat was important as a concentrated source of a wide range of nutrients [12]. The significance of meat to nutrient intake depends on

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the importance given to meat in an individual's, or society's diet and culture. Where meat is excluded the nutrients it provides can be supplied from a combination of other foods and within traditional vegetarian cultures this appears at least adequate, provided the diet is not too restrictive and dependant on nutritionally inferior staples such as maize or cassava [13]. With the range and abundance of foods available to developed societies today, the nutritional significance of any one food is reduced. Nutritional adequacy of vegetarian diets is easier to achieve and indeed the vegetarian is likely to consume a wider range of foods than the meat eater. Consequently vegetarians in Europe and North America have similar energy intakes to meat eaters and greater intakes of vitamins B1, C, E, folic acid, beta carotene, potassium and fibre [13]. Vegetarianism can no longer be assumed to provide a favourable fatty acid intake. Comparative studies of vegetarian and omnivorous children surveyed from 9 to 17 years found that saturated fat intakes were no lower in the vegetarian children [14–16]. Concern arises when meat is excluded with insufficient attention given to selecting appropriate combinations of foods to ensure adequate nutrients are supplied, especially in children and adolescents. Today's busy lifestyles give rise to dietary practices that mean it is *easier* to obtain all nutrients required for health by including meat as a component of the diet. Little time is devoted to planning and preparing meals and an increasing proportion of our daily food intake is consumed outside the home, as snacks and quick meals. National Food Survey (NFS) data suggest that in 1998 28% of total expenditure on food and drink was outside the home [17]. New data on the dietary intakes and nutritional status of young people aged 4–18 yrs in Britain indicate that energy intakes of young people are now approximately 10% below estimated average requirements (EAR) for age. Growth patterns suggest such intakes are adequate and merely reflect the corresponding lower activity levels of youngsters today, which in itself is a concern. Reduced energy intakes however put greater emphasis on the need for a more nutrient dense diet, particularly in growing children. The survey has recorded intakes of iron, zinc and copper below the RNI particularly in older girls [18]. It is possible that the recorded lower meat intakes are partly responsible for this. Such trends require careful monitoring.

Although the opportunity for personal choice has never been easier in affluent countries today, the decision to become vegetarian should be accompanied by adequate nutritional information and education. Despite popular opinion, vegetarianism *per se* does not guarantee a nutritionally adequate diet. Conversely, meat eating can be enjoyed as part of a healthy lifestyle with meat's positive nutritional contribution once again recognized [19,20].

Concerns about fat

Regular consumption of red meat is associated, epidemiologically at least with increased risk of coronary heart disease, due to its fat composition. There is however a growing bank of evidence that a healthy diet which includes lean red meat can produce positive changes in lipid biochemistry [21–24]. Blood cholesterol levels are increased by inclusion of beef fat, not lean beef in an otherwise low-fat diet. Equal amounts of lean beef, chicken, and fish added to low fat, low saturated fat diets, similarly reduce plasma cholesterol and LDL-cholesterol levels in hypercholesterolaemic and normocholesterolaemic men and women.

Meat is a source of arachidonic acid (20:4n-6), both in the lean and visible fat components [25]. Assumptions that the 20:4n-6 content of meat was responsible for increasing thrombotic tendencies in Western societies are too simplistic. The presence of large amounts of linoleic acid (18:2n-6) in current diets results in plasma increases of linoleic and arachidonic acids only. However, in the absence of linoleic acid, the long chain n-6 and n-3 PUFAs present in lean meat can influence the plasma pool, increasing plasma eicosatrienoic acid (20:3n-6), 20:4n-6, and eicosapentanoic acid (20:5n-3), and probably reducing thrombotic tendencies. It is the imbalance of n-6: n-3 PUFAs in the diet, brought about by excessive 18:2n-6 that causes high tissue 20:4n-6 levels, so encouraging metabolism to eicosanoids [26,27].

Meat is associated with cholesterol, and although it is now accepted that dietary intake of cholesterol has little bearing on plasma cholesterol, for consumers this is another negative influence on meat's health image. A recent review of the cholesterol content of meat indicates surprisingly that levels of cholesterol are generally not higher in fatty meat or meat products. The cholesterol content of a meat is related to the number of muscle fibres so tends to be higher the more red the muscle. Meat contributes between one third to half of UK daily cholesterol intake [28,29].

How reductions in the fat content of red meat have been achieved

Twenty years ago red meat and meat products contributed 26.4% to total daily UK fat intake [30]. Most of the visible (subcutaneous) fat was consumed with the meat. In the early 1980s the red meat industry began to shift production systems to favour less fat, reflecting more energy efficient animal husbandary. The fat content of the carcase has reduced in Britain by over 30% for pork, making British pork virtually the leanest in the world, 15% for beef, and 10% for lamb, with further reductions anticipated for beef and lamb over the next 5–10 years. These achievements are due to 3 factors: selective breeding and feeding practices designed to increase the carcase lean to fat ratio; official carcase classification systems designed to favour leaner production; and modern butchery techniques (seaming out whole muscles, and trimming away all intermuscular fat). It is easier to appreciate the process and extent of fat reduction by looking at the changes over time for a single cut of meat such as a pork chop (Fig. 1.)

The reduction in fat for pig meat is well illustrated by the trend downwards in P_2 fat depth from 1970s–1990s (P_2 is fat depth at the position of the last rib) (Fig. 2). Since 1992 it has remained stable at around 11mm. Although updated compositional figures for British meat were published from 1986 onwards [31–34], it is only since updated supplements to the McCance and Widdowson tables were published in 1995 [35,36], that the achievement of the meat industry in reducing the fat content of meat has been more widely acknowledged [20,37]. The reduction in fat in red meat and meat products is now reflected in NFS data that shows a decreased contribution from 22 g in 1991 to 14.5 g in 1998 [38].

A fat audit for the UK to trace all fat in the human food chain provides useful information to illustrate the reduction in fat intake from meat between 1982–1992, compared with other foods [39] (Table 1). This data provides a more accurate picture than NFS data for identifying principle sources of fat in the diet. It illustrates that whereas the fat contributed by red meat reduced by nearly a third, that from fats and oils as a group increased by a third to contribute nearly half of our fat intakes. This striking picture is lost in NFS data since vegetable fats (in particular) are consumed within a broad range of end products; from chips (so hidden within the vegetables section) to meat products (so artificially inflating the apparent fat contributed by meat).

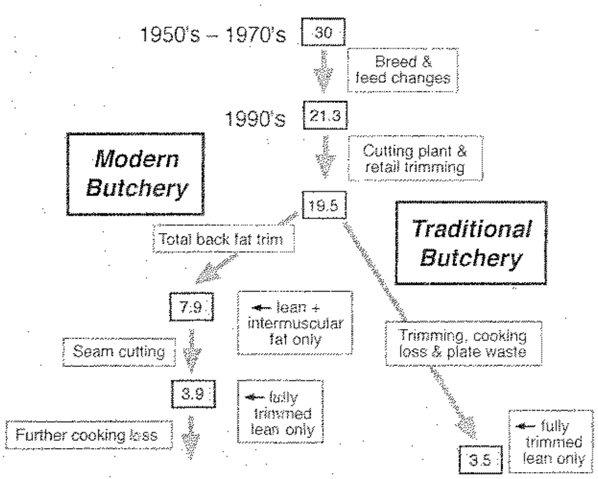

Fig. 1. Pork Loin—change in fat content of pork loin for 100 g of raw edible tissue. Revised from Higgs and Pratt [40] data sources: [34,35,98,99,100].

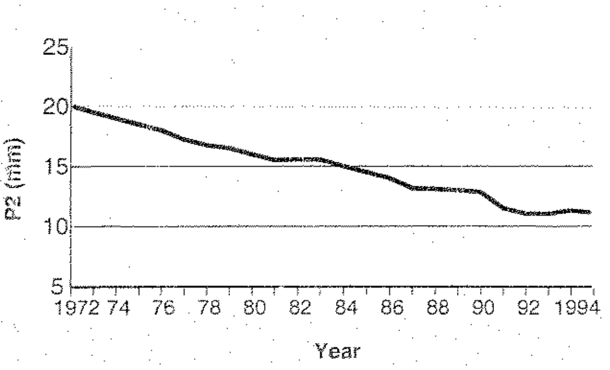

Fig. 2. Average P_2 fat depth of British slaughter pigs 1972–1995.

The fat content of meat products can vary considerably, dependent on the proportion of lean and fat from meat as well as the other ingredients [40]. Traditional types such as sausages, pastry-covered pies and salami are high in fat (up to 50%) but modern products include ready meals and prepared meats that can be low in fat (5%). The trend downwards in fat for red meat is reflected in the reduced fat content of a number of meat products, such as hams and sausages. Some reduced-fat meat products are now available although the potential for product development in this area has not been fully exploited.

Saturated fatty acid content of meat

Much of the discussion of the fat content of red meat has incorrectly focused on the saturated fat content. It is commonly assumed that all the fat in meat is saturated, yet meat contains a mixture of fatty acids, and as the fat content of red meat has reduced so the fatty acid mix has changed with% saturated fat lower than in the past. Pork and beef are less than 50% saturated, lamb is 51% saturated and poultry 30% saturated.

The main saturated fats in red meat are palmitic and stearic acid. Not all saturated fatty acids have a cholesterol elevating effect and stearic acid is neutral. Myristic acid is thought to be the most atherogenic and has four times the cholesterol raising potential of palmitic acid [41]. There are only minor amounts of myristic acid in meat.

Table 1. Total fat available for consumption (UK). Source: Ulbricht [41]

UK dietary fat per person	Kg		Percentage of Total (%)	
	1982	**1992**	**1982**	**1992**
Dairy fat	12.91[a]	11.04	25.92	22.86
Fats and oils	17.4	21.98	34.94	45.51
Red meat	9.29	6.8	18.65	14.08
Fish and fish oil	4.4	2.2	8.84	4.55
Eggs	1.56	1.09	3.13	2.26
Chocolate	1.54	1.92	3.09	3.98
Poultry meat	1.51[b]	1.88	3.03	3.89
Cereals	0.92	1.05	1.85	2.17
Nuts	0.27	0.34	0.54	0.7
Total	**49.8**	**48.3**	**100**	**100**

[a] 1983
[b] 1981

The saturated fat contributed to the diet from red meat and meat products has reduced steadily from 24% in 1979 to 17.5% in 1997 [30,38]. The reduction is more dramatic for carcase meat, now providing only 2g of saturated fat. In reality even this figure is an over-estimate, since there is a disproportionate wastage of fat in terms of trimming, cooking losses and plate waste [42].

Unsaturated fatty acid content of meat

Meat is one of the main contributors to monounsaturated fatty acids in the British diet. The principal monounsaturated fat in meat is oleic acid and 40% of the fat in meat is in this form. So replacing red meat with dairy products, as in many vegetarian diets may on balance actually worsen the fatty acid profile of the resulting diet, since dairy products contain higher amounts of myristic acid and less monounsaturates than red meat. For example average whole milk contains 1.1% monounsaturated fatty acids [43]. Beef, lamb and pork provide useful amounts of long chain polyunsaturated fatty acids, specifically 20:3*n*-6, 20:4*n*-6, 20:5*n*-3, and docosapentanoic (22:5*n*-3) [25, 44]. Richest dietary sources of 20:4*n*-6 include liver, kidney and turkey, with smaller quantities found in beef, lamb, pork, and chicken (Table 2). Significant losses occur with cooking for some fatty acids more susceptible to oxidation, particularly the more highly unsaturated C20 and C22.

Docosahexanoic acid (DHA, C22:6*n*-3) is an essential fatty acid in the development of the CNS in the new-born.

Table 2. Fatty acid composition of muscle from English beef, lamb and pork From Enser et al. [46]

Fatty acid	Percentage by weight of total fatty acids		
	Beef	Lamb	Pork
12:0 lauric	0.080±0.030	0.31±0.18	0.120±0.050
14:0 myristic	2.660±0.540	3.30±1.07	1.330±0.200
16:0 palmitic	25.000±1.770	22.2±1.56	23.200±1.460
16:1 *cis*	4.540±0.810	2.20±0.26	2.710±0.450
18:0 stearic	13.400±1.840	18.1±2.80	12.200±1.110
18:1 *trans*	2.750±1.280	4.67±1.67	ND
18:1n-9 oleic	36.100±2.870	32.5±3.25	32.800±3.910
18:1n-7 vaccenic	2.330±0.400	1.45±0.26	3.990±0.590
18:2n-6 linoleic	2.420±0.630	2.70±0.86	14.200±4.090
18:3n-6 -linolenic	ND	ND	0.060±0.030
18:3n-3 -linolenic	0.700±0.180	1.37±0.48	0.950±0.330
20:2n-6	ND	ND	0.420±0.110
20:3n-6	0.210±0.060	0.05±0.04	0.340±0.090
20:3n-3	0.007±0.011	ND	0.120±0.050
20:4n-6 arachidonic	0.630±0.210	0.64±0.23	2.210±0.730
20:4n-3	0.080±0.030	ND	0.009±0.022
20:5n-3 EPA	0.280±0.110	0.45±0.13	0.310±0.150
22:4n-6	0.040±0.020	ND	0.230±0.070
22:5n-3	0.450±0.140	0.52±0.14	0.620±0.200
22:6n-3 DHA	0.050±0.020	0.15±0.05	0.390±0.230

ND: not detected. EPA: eicosapentaenoic acid; DHA: docosahexaenoic acid.

Lower concentrations of DHA are seen in cord artery phospholipids of vegetarians and in the breast milk of vegan mothers compared to omnivorous controls. The full significance of these findings remain uncertain but abnormalities in visual and cortical functioning are seen in term and preterm infants deprived of DHA [13,44,45].

Production systems for monogastrics and ruminants will influence the fatty acid profile of the resultant meat. This is easier for monogastrics and more progress has been achieved with pigs than with ruminants. Inclusion of vegetable and fish oils in pig feeds results in significant increases in *n*-3 PUFA [46,47]. Leskanich et al. [48] has illustrated that such feeding regimes can produce pork products with nearly half the daily recommendation for 20:5*n*-3 and 20:6*n*-3 (2 pork sausages providing 81 mg). The rumen hydrogenates unsaturated dietary fat, making it more difficult to modify the fatty acid profile of ruminant meat. Nevertheless, some dietary unsaturated fat will bypass the rumen for deposition in fat stores, and feeding linseed and fish oils results in beef with increased *n*-3 PUFA levels [49]. Grass-fed animals have higher concentrations of α-linolenic acid compared with grain-fed, and beef and lamb have favourable *n*-6:*n*-3 ratios [46]. Meat along with fish provide the only significant dietary sources of C20 and C22 *n*-3 fatty acids, and for countries like Britain where fish intakes remain low, the contribution to the diet from meat is significant, despite absolute levels in meat being low relative to fish [46,50]. Further research is required to fully realize the potential for modification of the fatty acid composition of red meat to more closely match human nutritional needs. Clearly, however, it is inappropriate to class the fat from meat as 'not useful' in this respect.

Ruminant meats provide a source of *trans* fatty acids, contributing around 18% of total intakes. These are formed during biohydrogenation in the rumen. It appears from an analysis of 14 European countries that the fat content of meat does not correlate with the percentage of trans fatty acid content [51]. *Trans* fats have been highlighted as contributing to atherogenesis, although the hydrogenated fats from vegetable sources used in bakery goods and other processed foods appear to be more of a concern than the natural *trans* fats found in ruminant meat and milk fats [50]. At the levels currently consumed in the UK, (2% of dietary energy) trans fatty acids do not present a problem, whereas in the USA, where there is much greater reliance on processed foods, the consequent higher intakes (6% of dietary energy) are causing some concern.

Conjugated linoleic acid (CLA), a mixture of geometric and positional isomers of linoleic acid, is only found in useful amounts in meat (especially from ruminants) and dairy products. Seventy-six to 93% of the CLA in meat and milk is in the form of *cis*-9, *trans*-11-octadienoic acid. Interest in CLA continues to grow as it has been known for some years that small amounts

(0.1% of the diet) have anti-mutagenic activity in animal models, regardless of the amount and type of fat consumed in test diets [52,53]. The potential for human nutrition is not known and the content of CLA in human diets requires accurate confirmation. Estimates for it's content in meat, which is affected by the feed regime, range from 0.6 mg/g fat for US pork to 14.9 mg/g fat for Australian lamb [54]. Interest in the potential for CLA to increase lean body mass and reduce body fat when included in chicken and pig diets has dominated research on CLA due to the more tangible benefit to animal production. The significance of CLA in human diets and its anti-cancer properties deserves serious consideration.

But isn't fat important for meat quality?

Extensive research world-wide has shown that meat quality is influenced by a host of variables, e.g. pre- and post-slaughter handling, hanging time, age at slaughter, and that fat content is not a prime consideration until it reaches very low levels for example 2% intra-muscular fat in beef [55]. Reducing intramuscular fat levels down to 5% with perhaps greater reductions in subcutaneous and intermuscular fat levels will make a positive contribution for human nutrition without jeopardising meat quality [28]. Modern eating practices positively influence the way meat is consumed to further reduce meat fat levels. Strips for stirfrys, cubes for casseroles/kebabs, and pre-marinaded quick cook steaks all have less need for basting fat and fat as a flavour provider, and require trimming of any intermuscular fat for optimum presentation.

There is still a demand for large joints to satisfy the rapidly expanding foodservice industry, where some fat enhances the cooking, but any visible fat can still be removed by the end user. The challenge for public health nutritionists is to encourage the consumer to treat the fat on meat as they would, say, the peel on an orange, as waste. Although there is a functional requirement for some fat in our diet, there is far too much in today's food supply, relative to our sedentary lifestyles. Any excess fat from meat is unlikely to make a positive contribution to the adult diet, unlike the lean component. However individuals should have the opportunity to choose for themselves which sources of fat they include in their diet, within their ideal daily allowance.

Red meat as a source of protein and micronutrients

Meat is an important source of a wide range of micronutrients [35,36,40]. Aside from those nutrients discussed below, meat contains useful amounts of copper, magnesium, cobalt, phosphorus, chromium and nickel. The real contribution meat makes to the diet should be measured in terms of nutrient availability for some micronutrients.

Meat is a significant source of high biological value protein, contributing 28.7% to the average diet in Britain [38]. The protein density of different meats and cuts varies according to the fat content. Meat is a rich source of essential amino acids and as such it can be of particular benefit to those where muscle tissue is being rebuilt, e.g. athletes, post surgery. Meat is rich in taurine, essential in newborn infants who are less able to synthesise this amino acid from cysteine. The significance of lower levels of taurine in the breast milk of vegan mothers is unknown.

During the 1980s, the emphasis on a prudent diet for health that recommended just 11 E% [56] from protein perhaps further encouraged a disregard for the nutritional benefits offered by meat. Recent interest in the use of high protein diets (25E%) for weight reduction have utilized the higher satiating properties of protein, important for dietary compliance, and achieved significantly more weight loss over a six month dietary intervention compared with low (12E%) protein diets. These results were achieved without adverse effects on renal function [57,58].

Iron and meat

Red meat is an excellent source of iron, having 50–60% in the haem form. This is absorbed by a more efficient mechanism than the non-haem iron found in plant foods. Absorption of iron from meat is typically 15–25%, compared with 1–7% from plant sources [59]. Meat provides an assured source of iron as it is unaffected by the numerous inhibitors of iron absorption such as phytate in cereals. Meat also enhances iron absorption from plant foods, so the presence of meat in a meal can double the amount of iron absorbed from the other components of the meal. The exact mechanism for this, although not confirmed, is believed to be due to the iron-binding capacity of cysteine within peptides following proteolysis of meat muscle. Although the absolute iron content of white meats, e.g. chicken, and meat products may appear low compared with some plant food sources, this enhancing function and their better iron availability makes them useful contributors to iron intakes. Cooking in iron or steel utensils can increase the iron content of the meal due to this enhancing effect of meat.

Meat contributes about 14% of total iron intake [38]. Despite reduced red meat consumption in recent years, this figure grossly underestimates the value of meat for iron status and it remains an important influence due to it's enhancing properties. Iron deficiency anaemia is the commonest deficiency in the world [60]. Sub-optimal iron intakes in vulnerable groups within developed countries, (toddlers, adolescents and women of childbearing age) have encouraged renewed interest in meat, as an assured source of haem iron [18,59,60]. The COMA report on 'Weaning and the Weaning Diet' [61] recommends that foods containing haem iron should be incorporated into the diet of infants by 6–8 months of age. This goes against the modern trend to delay introduction. Although the iron content of vegetarian diets has been found to be little different from that of omnivores, the large differences in availability of the iron present accounts for the higher iron stores in omnivores [13]. Several studies have shown that iron deficiency is more prevalent in vegetarians than non vegetarians of child-bearing age, despite the enhanced absorption conferred by high intakes of vitamin C. Serum ferritin levels, the body's iron store, are strongly correlated with haem iron intake [64]. Lyle [65] has demonstrated that meat supplements were more effective than iron tablets in maintaining iron status during exercise in previously sedentary young women.

Zinc and meat

The best sources of zinc are meat, poultry and seafood. Bioavailability of zinc is enhanced when consumed with animal protein, and is reduced by inhibitors such as phytate and oxalate, which are found in larger amounts in vegetarian and vegan diets. This explains the finding in several studies of lower plasma zinc in vegetarians and vegan individuals, despite higher intakes [66].

In metabolic studies, zinc absorption and retention is greater on high-meat diets, compared to low-meat or zinc-supplemented diets [67]. Meat is, thus, a major influencer of zinc status. Approximately 20–40% of zinc is absorbed from meat, which is the major contributor to zinc intakes in developed countries. Sub-optimal zinc intakes in the diets of infants, children and young people have been highlighted in recent British national reports, where meat is providing up to just 25% of total zinc intakes, compared to 40% of adult intakes [18,61,68]. Concern over zinc status has prompted the Department of Health to suggest increasing meat portion sizes for weaning infants [63].

Selenium and meat

Selenium is one of the major antioxidants considered to protect against coronary heart disease and cancers. Meat provides about 10μg selenium per 100g of meat, which is about 25% of the day's requirement.

Bioavailability of selenium from plant foods was thought to be greater than that from animal foods, but recent data demonstrate that meat, raw and cooked, provides a highly bioavailable source [69].

Glutathione and meat

Meat is one of the richest natural sources of glutathione which is an important reducing agent providing a major cellular defence against a variety of toxicological and pathological processes. Glutathione is active in the intestinal tract, reducing the mutagenicity of aflatoxins and it inhibits formation of mutagens in model systems [70]. It also maintains ascorbate in a reduced and functional form. Glutathione's importance in the defence against chronic disease provides positive potential for meat and merits further research [70,71].

Vitamins

Meat is a useful source of all B vitamins except folate and biotin. Thiamin and riboflavin are found in useful amounts and pork (including its products, such as bacon and ham) is one of the richest sources of thiamin, typical servings providing the daily requirement. A single portion (100 g) of liver and kidney provide more than the daily requirement of riboflavin.

Meats also provide the richest source of niacin and vitamin B_6. Half the niacin provided by meat is derived from tryptophan, making it more readily absorbed by the body than that bound to glucose in plant sources. Per 100 g portion, veal liver provides half our daily B_6 needs, and other meats provide around a third.

Foods of animal origin provide the only dietary source of vitamin B_{12} and deficiency does occur in vegetarians, vegans being especially at risk. Thus vegetarians are recommended to take supplements since the quantity consumed from foods fortified with the vitamin is too low [10,73,74]. Vitamin B_{12} is only required in small amounts, 1.5 μg per day [75]. In the past some was provided from the soil on poorly cleaned foods. This may in part explain the apparent absence of deficiency in some vegan groups. Today with the emphasis on good food hygiene practices, this source can no longer protect against deficiency in vulnerable individuals.

Liver and kidney are rich sources of pantothenic acid. Although most of the vitamin is leached into the drip loss associated with frozen meat, this is unlikely to be of any nutritional consequence as pantothenic acid is universal in all living matter.

Organ meats are particularly rich sources of folate, although the fact that liver is also a concentrated source of vitamin A means that it is not recommended during pregnancy. Malformation of the developing foetus is a potential hazard if retinol supplements are also taken during pregnancy [76]. This is unfortunate since liver is an excellent provider of two key nutrients for pregnancy, iron and folate. Levels of vitamin A are unnecessarily high in liver due to its addition to animal feeds. Given the continuing low popularity of offal in British diets, it is unlikely that the meat industry will address this issue as a matter of any urgency.

Vitamin A in its active form, retinol, is only found in foods of animal origin, so meat provides this vitamin directly to the body. The NDNS survey of young people in Britain found dietary intakes of Vitamin A below the RNI in all age groups [18].

Vitamin D and Meat

Liver aside, meat was thought to be a poor source of vitamin D. Recent analyses for meat and liver includes significant amounts of 25-hydroxycholecalciferol, assumed to have a biological activity five times that of cholecalciferol. Re-analyses of the British National Diet and Nutrition surveys of adults and young children confirmed meat as a major contributor to natural dietary vitamin D intakes. Meat and meat products appear to provide around 20% of British intakes, compared to previous estimates of just 4% [77]. Vitamin D is present in both the lean and fat of meat although its exact function in the animal is not yet known.

Both osteomalacia in adults and rickets in children result from a deficiency of vitamin D or a disturbance of its metabolism. Clinical features of both conditions are similar with low plasma calcium levels and poor bone mineralisation. Osteomalacia is more common in lacto-vegetarian Asian women, than those who consume meat. Infantile rickets is associated only with late weaning and a lactovegetarian diet in the UK today, having all but disappeared in the 1960s following the introduction of mixed feeding (including meat) to infants at 3–4 months old.

Evidence from the British Asian community suggests that meat protects against privational rickets and osteomalacia. The reasons for this are not fully understood and possible mechanisms are currently under investigation. Dunnigan and Henderson [78] have suggested that meat contains a 'magic meat factor' since the influence meat has on bone metabolism is greater than could be expected from the amount of Vitamin D present alone.

The UK Government's COMA report on bone health [79] raises concerns over vitamin D status in vulnerable groups including older people who are housebound or who eat no meat or oily fish. Cautious concern over the vitamin D status of young people has been highlighted [18] which provokes one to link the recorded lower physical activity levels in young people with more time spent indoors watching TV and using PCs. Further investigation is required to confirm the significance of meat to vitamin D status in the population today.

Meat and cancer

Meat has been associated with various cancers, particularly colorectal cancer. This became a high profile issue during 1997–1998 with the global launch of the World Cancer Research Fund report, timed to coincide with publication of the British COMA report, both on diet and cancer [80,81]. The former was unjustifiably negative towards red meat, as demonstrated by several critical appraisals stimulated as a consequence of the publicity created surrounding its launch [82]. The scientific evidence is not sufficiently robust to recommend a maximum of 80g/day red meat as pronounced by the WCRF and the initial announcement by COMA for a similar recommendation was subsequently revised.

On final publication, COMA reassured UK consumers that average consumption levels (90 g/day of cooked red meat) were acceptable. COMA suggests that high consumers, less than 15% of the UK population [83], eating above 140 g/day might benefit from a reduction. Equally important this report acknowledged that meat and meat products remain a valuable source of a number of nutrients including iron and that for many a moderate intake makes an important contribution to micronutrient status. The potential effect on iron status of further reductions to red meat intakes was subsequently investigated. Given that a 50% reduction in intake would result in a third of women having low iron intakes (below 8 mg/d), the appropriateness of public health messages concerning meat consumption should be carefully considered prior to reaching the media [84].

Confusion over the role of meat on the development of cancer was aptly illustrated at the 1998 Nutrition Society debate on 'Meat or Wheat for the Next Millenium? Key, speaking for vegetarianism in fact supported the pro-meat view with results of his pooled analysis of five prospective vegetarian studies, concluding that meat eaters had no greater mortality from colon cancer than vegetarians [85,86].

Four components of red meat provide the basis for potential mechanisms by which it is proposed meat may play a part in the development of cancer: fat, heterocyclic amines; *N*-nitrosation products; and iron. A thorough discussion of these can be found elsewhere [87,88]. Epidemiologically it is difficult to distinguish the influence of animal fat, protein and meat and no direct link between any dietary factors and human cancers has been found to date. [89]. Heterocyclic amines produced on overcooking meat have been shown to be carcinogenic in rats, although at normal cooking temperatures and average cooking times the level of these compounds produced is not excessive. Nitrates are added to meat products to prevent microbial proliferation. *N*-nitrosamines, produced from these additives, are present at very low levels in meat products, and their carcinogenic potential is likely to be minor at such levels. The significance of *N*-nitrosocompounds within the gut, produced from dietary protein requires further research [81,89].

Of particular importance is a need to assess the role of meat when consumed in normal quantities, by normal cooking methods, and within the context of a mixed, balanced, diet. Future research should take a more specific look at meat eating in context. It is well known that daily consumption of vegetables and meat reduces the risk of cancer at many sites, whereas daily meat consumption with less frequent vegetable consumption increases risk [90–92]. Nevertheless, it is sensible to consider that there must be an optimal range for meat intakes in order to ensure a balanced diet is achieved, whilst optimal weight is maintained. From this practical perspective COMAs suggested intake range of 90–140 g cooked meat per day, is sensible as a public health message. The overemphasis on reducing meat however, rather than encouraging greater accompanying plant food intake has served only to confuse the public [82].

Future eating trends, meat and nutrition

It is predicted that in 20 years, cooking will become the latest DIY pastime, with the majority of the population unable to cook in the true sense of the word. It seems that people are prepared to pay for convenience. Even when budgets are tight, it has proved difficult to persuade people to cook from cheaper raw ingredients to produce nutritious meals. For producers the need will be for appropriate raw ingredients to allow manufacturers to be able to develop a wide range of easy cook dishes, which meet specific nutritional criteria. For meat the trend towards increased convenience in foods lends itself towards improving the nutritional profile, as fat tends to be removed in the development of new cuts and dishes which meet the criteria of minimal preparation, quick cooking, and portion control. Currently the same process with fruit and vegetables (e.g. pre-packed salads, pre-peeled fruit) has the opposite effect causing loss of valuable vitamin C!

The past two decades have demonstrated that a reduction in red meat consumption will not have an effective impact on either total fat or saturated fat intakes. Appropriate public health strategies are required to favourably influence future population eating habits and result, among other things, in a reduction in saturated fat. Since there is more saturated fat provided in a tablespoon (15 ml) portion of olive oil than a 100 g portion of lean beef, the inappropriateness of emphasising red meat reduction as a means to achieving lower dietary saturated fat intakes seems obvious. However, the average consumer would be sure the converse was true! (Compare this with the years it has taken (at least 15) to persuade dieters that bread and potatoes are not 'fattening'!). Achieving a reduction in saturated fat intakes will take considerable public health (re-) education.

The Mediterranean diet is characterized by not only its olive oil content but also a more significant proportion of fruit and vegetables than the typical British diet. Greeks typically consume nearly four times the quantity of fruit and vegetables than the British. Generally in countries where meat consumption is high, intake of protective fruit and vegetables tends to be low and *vice versa*. [89]. There are many paradoxes concerning the apparent associations between meat consumption and both CHD and cancer. Some of these are listed in Box 1. They serve to demonstrate that the diet and health story, at least as far as meat is concerned, is both complex and unfinished. Two reasons for this are firstly, that meat is but one influential aspect of the diet, and its effects are modified by other foods (e.g. fruit and vegetables), such that the net effect may be quite different. Secondly, the changing lipid composition of meat, in response to increased knowledge of lipids in relation to health, will continue to alter the role played by meat in this context. Fortunately, since most of the valuable nutrients in meat are within the lean component, reducing the visible fat has little bearing on its contribution to micronutrient status.

Emerging interest in evolutionary nutrition has produced perhaps the most significant explanation for the current paradoxes in nutrition, and specifically for meat, turns on its head the recent health drive to reduce its consumption [80]. Dietary dependence on cereals (contributing 56% of food energy) is a relatively recent feature of human diet in evolutionary terms. Prior to the last 10, 000 years homo-erectus had thrived on a hunter-gatherer diet for 1.7 million years! Cordain [93] suggests that our genetic make-up remains adapted to this meat, fruit and vegetable diet and that there is growing evidence that the human immune, digestive and endocrine systems have not fully adapted to a cereal based diet. The 'carnivore connection' hypothesis [94] proposes that the high meat/low carbohydrate diet typical during the Ice Ages encourages selection for insulin resistance since insulin sensitivity would have compromized survival and reproductive performance. Early man also expended significantly more energy than modern man. Chen [95] estimates the mean ratio of total energy expenditure to resting metabolic rate (TEE/RMR) of 1.80 for homo-erectus compared to 1.18 for a sedentary office worker today. Humans are not genetically adapted to chronic physical inactivity and diseases of modern civilization are associated with insulin resistance and 'syndrome X'. It would be naive to conclude from these hypotheses that we should abandon current dietary recommendations, although it is interesting to note the similarities between the lipid profiles of wild meats and those potentially expected for red meat over the next few years (even if only as niche products).

Conclusions

Red meat has a positive part to play within today's national diet and lifestyles. Past concerns on the fat contributed by meat are outdated since, when trimmed of visible fat, red meat can now be considered a relatively low fat food, with a preferred fatty acid profile than 20 years ago.

Unless population physical activity patterns dramatically change, perhaps through increased leisure pursuits, energy intake, specifically from fat, must be controlled to balance our sedentary lifestyle today. Fat provides over 40% of our energy with the main contributors being vegetable oils and fats, not meat. It is important therefore that red meat is not blamed for the increasing obesity problem in Western societies. A look at our ancestors' predominantly meat based diet provides useful clues to modern diseases of affluence, and is redirecting interest away from single food groups such as meat to our more complex genetic make-up, and how

Box 1. Paradoxical associations between meat and health

- There is a lower risk of colon cancer among South Asian immigrants to the UK, than in the general population, and this is equally true of vegetarian and meat eating Asians [97].
- Mormons who abstain from alcohol, tea, coffee, and smoking but consume meat have death rates from cancer and CHD similar to vegetarian groups, indicating that meat is not the major determinant [96].
- Blood pressure is reduced by switching from a meat-based diet to a vegetarian one, but adding meat to a vegetarian diet is not associated with an increase, suggesting that the potassium to sodium ratio is more influential than the presence of meat *per se* [96].
- Consumption of meat has almost doubled in Japan since the 1970s, yet CHD morbidity has reduced from an already low level. Meat consumption in the USA remains higher than in the UK, yet, unlike the UK, morbidity from CHD has been falling steadily over the last 20 years.
- Red meat consumption is *higher* in most Southern Mediterranean countries (52–72 kg/p/yr) than in Britain (46 kg/p/yr) and the incidence of colorectal cancer is higher in Britain [89].

environmental influences may be modified to protect the genetically susceptible.

The choice to follow a vegetarian diet remains personal and cannot be considered as a fool proof, or simple route to improved diet for long term health gains. What is needed now is a prospective comparative study of current vegetarian dietary practices and the currently recommended omnivorous diet. It is possible to construct omnivorous and vegetarian diets that meet nutrient requirements, in theory, although allowing for differences in bioavailability of some micronutrients, and practical issues (preparation time and cooking), this task is easier for an omnivorous diet. It is unknown whether or not there would be any significant differences between the two diets that would impact on long-term health.

The last decade of COMA reports on dietary recommendations and chronic diseases provide adequate scope for reassuring the public that red meat can and should be consumed as part of a balanced diet to protect our long-term health. The trend downwards in daily energy intake may have a consequence on micronutrient intake, enabling once again the nutrient dense nature of meat to become an important characteristic.

Government dietary recommendations require appropriate practical interpretation for the general public. A whole diet, whole lifestyle approach is necessary to optimize long-term health. Clearly, eating too much of any single food, including meat, will not help us to achieve a good, balanced diet. No single food can take the responsibility for health risk. Nutritionally the future potential for meat in the diet looks more positive than we have been led to believe in the past, and the importance of fruit and vegetables continues to accrue. The challenge for nutritionists is to communicate appropriate dietary information and inspire those population groups most likely to benefit from dietary intervention.

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