The role of nutrition in human evolution

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Professor Michael A Crawford, Director of the Institute of Brain Chemistry and Human Nutrition, Faculty of Science, Computing and Engineering at London Metropolitan University is a leading authority on brain development and evolution. His main current research interest is understanding the key interaction between nutrition affecting membrane lipids and gene expression. He has been recently appointed as The Danone Chair at the University of Ghent and Honorary Professor of the Albert Schweitzer University.

The Caroline Walker Trust

The Trust was set up in memory of the nutritionist and campaigner Caroline Walker who died in 1988. The aim of the Trust is the improvement of public health through good food. In addition to the Annual Lecture, the Trust is involved in a variety of activities including the production of a range of expert reports.

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Introduction

What can nutrition tell us about how our species has evolved? Has the diet of our ancestors had an impact on human evolution? If so, what are the implications for promoting public health?

The origins of life on earth

600 million years ago, the evolution of the brain and nervous system originated in the marine environment in a rich supply of docosahexaenoic acid (DHA). This essential fatty acid has been conserved since then for the structure and function of neurological and visual membranes. It constitutes some 50% or more of the fatty acid component of the photoreceptor membranes which supports rhodopsin in which vitamin A sits as the photon sensitive system. The origins of both vitamin A and DHA have their parenting in the photosynthesis of plants. For 2.5 billion years or more, algal photosynthetic life dominated the proto oceans of the planet. They converted sunlight into carbohydrates, proteins, lipids and more. Some 600 million years ago, the oxygen tension had risen above the Pasteur point and air breathing systems became thermodynamically possible. An explosion of evolution took place and within a short period of geological time, all 32 phyla known today had appeared on the planet. The trick used by the first primitive air breathing systems was to convert sunlight not into carbohydrate and proteins but into electricity. This was achieved by the combination of rhodopsin, vitamin A and DHA.

The importance of docosahexaenoic acid (DHA)

The brain and indeed the photo receptor, is a fat rich organ in which 60% of its structural material is lipid. DHA is selectively taken up and concentrated in synapses and photoreceptors. In all 42 mammalian species, which have been studied, DHA is the major component of the fatty acids in neural cell membranes and photoreceptors. This high conservation implies DHA has a 600 million year track record in neural and visual function. Interestingly, the difference between species is not the chemistry but the extent to which the brain is developed. This difference, combined with the animal experiments showing deficiency of brain DHA induced cognitive and visual loss, led to the idea that a rich source of DHA would have provided a selective advantage for cerebral expansion. The conservation of DHA is all the more remarkable because its immediate precursor would. by force of the metabolic synthetic sequence, have been more abundant. It has the same 22 carbon chain length but one less double bond (C22:5w3). Yet despite it being easier to synthesise and less susceptible to peroxidation it has not been found to replace DHA in the photoreceptor or synapses of the fish, amphibia, reptiles or mammals so far studied.

The savannah view of human evolution

Originating from Raymond Dart early last century and adhered to this day, the conventional view was that humans evolved on the hot, dry savannahs of Africa where competition with the top carnivores furnished the selective pressure to evolve a large brain. Upright stance evolved out of the need to stand up right to throw spears at animals. The success in killing large animals was a prerequisite for the selection pressure necessary for cerebral expansion. According to Richard Dawkins, hairlessness evolved because males preferred copulating with the less hairy females. Elaine Morgan has commented extensively in her books on the naivety of this approach and its inconsistency. Indeed, the macho concept of human cerebral expansion has a remarkable Lamarkian feel. It has little if any science base to it.

Criticism of the savannah hypothesis

I came to question this savannah view when working in East Africa. I discovered to my cost, we were loosing water at the rate of 1.5 litres per hour on the savannah. That suggested to me the savannah might be an inhospitable habitat for a primate with a high requirement for water to keep cool. Dick Taylor and others at that time were demonstrating that the physiology of savannah species was devoted to extreme water conservation. They allowed their body temperatures to rise in the day and fall at night rather than waste precious water in evaporation to keep cool. They had lung and intestinal adaptations to avoid water loss. Humans are inconsistent as they loose water by the litre on the savannahs! Moreover, a most serious criticism against the savannah hypothesis arose from our discovery that the savannah food chain is a very poor source of DHA. The large mammals accumulated docosapentaenoic acid (w3) in their muscle and liver stores but relatively little DHA. The richest source of DHA is the marine food chain.

Another nutrient which is richest in sea foods and disadvantaged inland is iodine. According to WHO, 1.6 billion people are at risk to iodine deficiency disease today. These are all inland and flood plain people. In Indonesia, where I wrote a report for Indonesian Government and WHO in 1992, there were 60% of the school children with palpable goitre. There were 1.5 severely mentally retarded children and 800,000 cretins. This problem was all inland. There was no goitre, cretinism or mental retardation that I observed, in the fishing villages. A similar situation was described in India at a conference on Nutrition and the Brain in New Dehli organised by Gopalan. In classical Darwinian terms the evolutionary advantage of the chemistry of the marine food chain would have been enormous and not just confined to DHA.

Another piece of evidence which convinced me of the fallacy of the savannah hypothesis was that the brain/body weight ratio of all land species diminishes logarithmically as they increased body size. The rhinoceros reaches a one ton of body weight by four years of age. The animal obtains all the protein, calories and minerals it needs to support this prodigious rate of body growth from the simplest food resource, namely grass. It has only a tiny brain – less than 0.05% of its body weight. Small mammals such as the squirrel or capuchin monkey have 2.1-2.3% of their body as brain. The chimpanzee has about 0,45%. The gorilla, with a larger body size has actually less brain and a smaller proportion of only 0.25%. Although the same principle of diminishing relative brain capacity applies to the marine mammals, they are far in advance of the land mammals. In a 70 Kg human with 1,3 Kg brain, the proportion is 1.8% and the only species which comes close to that is the dolphin at 1.1%.

The problem with the marine food chain is that it is dominated by w3 fatty acids. Both arachidonic (C20:4w6) and docosahexaenoc (C22:6w3) acids are used exclusively in the brain in roughly similar proportions. So whilst land mammals have a problem accessing DHA, the marine mammals have a problem with arachidonic acid (AA). However, this simplistic rule breaks down in the tropics where the marine and indeed fresh water products contain substantial amounts of arachidonic acid. This distinction applies to the East Coast of Africa and the Rift Valley lakes, which we have studied.

Coastal origins of human life

One of the main criticisms of the paleoanthropolgists about the coastal origin of H. sapiens was that there was no fossil evidence. As it happens the large majority of the fossils discovered were in the Rift Valley or Chad where at the time they were living, they were living beside inland seas or lakes. According to the geophysicist Leigh Broadhurst, the Gulf of Aden and Red Sea was in the process of creating an ocean down the African valleys when tectonic plate movements isolated the Rift Valley. None the less, studies on Rift Valley fishing communities by Claudio Galli and ourselves, testify to the arachidonic and docosahexaenoic acid value of the lake fish as well as he superior cardio-vascular risk factors of these lake fishing peoples. In addition, their status for plasma fatty acids with regard to both AA and DHA was substantially greater than that of their inland cousins with little access to fish and to Europeans living in East Africa at the time. Indeed, the blood cholestereol levels of the El Molo children we studied remained steady as they grew up. The blood cholesterols of European children living in East Africa rose and the separation reached a statistically significant level above the El Molo children in the 6-8 year age group.

Consequently, we developed the hypothesis that the cerebral expansion which led to the evolution of H. sapiens occurred in association with the use of sea and lacustrine foods. The paleonthropologists would not consider this evidence until the Dual Congress in South Africa in 1998 where Professor Tobias, a world leader in paleoanthropology invited presentations on the topic. In December 1998, Professor Tobias wrote "Where ever humans were evolving they had to have water to drink" and of the savannah hypothesis he said 'We were all profoundly and unutterably wrong!' He concedes that the paleontological evidence fits far better with an evolutionary history at the water's edge. Apart from explaining cerebral expansion, it is consistent with the water crossings as early as 800,000 years ago and Chris Stringer's view of way the planet was populated around coast-lines. They were certainly not eating Cape buffalo as they made this journey.

Recent fossil discoveries provide incontrovertable evidence of intense exploitation of the marine food chain dating to 120,000 - 80,000 years ago which fits with the period of the recent cerebral expansion. Discoveries in the

coral reefs at the Red Sea coastline of Eritrea similarly provide evidence of early human locations at the coast, again coincident with evidence of habitation by modern humans. Moreover, the origins of civilisations were geographically located beside water. Indeed, the first written languages, which heralded the beginnings of civilisations, were beside water. Some have said this juxtaposition was for trade. But before trade could begin, people were fishing and utilising the best resources of both land and water. They built boats as we have seen as early as 800,000 years ago. All of that, including the brain, had to come first. Even recent history from the Egyptians, Minoans, Greeks, Romans, 1492 and dare one say it, Rule Britannia, were deeply embedded in origins that started with harvesting the products of the lakes, rivers and seas. The Museum of London contains exhibits of amphora, which the Romans used to import fish oils from Spain. At the turn of last century, the Bars in the East end of London served oysters free with the beer as they were so plentiful along the Thames shore line. The productivity of the marine and fresh water systems was so rich and the oceans so vast, that they were taken for granted. Whilst humans developed land based agriculture 10,000 years ago we are still hunting and gathering the sea foods with the same primitive philosophy that dates back to unrecorded history. The continuation of this naïve policy has been to our cost in the death by pollution of the rivers and estuaries and the decimation of marine resources.

There is an interesting comment on the macho view of human evolution – what Robert Ardrey called "The Killer Ape". Loren Cordain has tried to maintain support for this view with the argument that DHA could have been provided on the savannahs from the brains of the animals they killed. Bear in mind the very small size of the brains of the savannah species and one wonders if this was enough? Moreover, it is a formidable task to cut through a rhinoceros's or buffalo's skull to get at the brain and then the balance between meat and brain would be about 1,000 to 1. So there would not be much there. Bear in mind that the journey back to camp where the women and children were would at the high temperatures of the savannahs, have resulted in considerable deterioration with precious little to share around the community.

By contrast, the coast lines would have been extremely rich and particularly so in food rich in DHA. Land mammals migrated from land to the oceans over a 60 million year period. This migration came to an end about 10-5 million years ago by which time, these originally land based species had become fully aquatic. The end of the migration left the coastal and estuarine resources empty. Now Nature exploited all possible extremes in search of food – the desert rat, polar bear, snow leopard, the tree eating giraffe to name but a few extreme examples. It is unthinkable that the vacated coastal resources would have been left vacant. It may be a coincidence but it is noteworthy that the vacation of the coastal resources occurred at the time the geneticists tell us the line that came to us humans separated from the great apes. Bearing in mind that we separated that means we were in a geographically different location so we did not continue to interbreed. The coastlines would have provided for that requirement.

This brings us to another key point. It is not the macho men that matter. It is the women, the embryo, fetus and new born child that need the proper nourishment. The women would be all important biologically to secure the increasing supply of neural nutrients so that brain size evolved in harmony with body size. A coastal or best an estuarine habitat would enable even heavily pregnant women to wander around the coast and gather as much food as she needed. Indeed, the children would have done the same. If the men brought back some meat that would be well and good. But it would not matter one little bit if their macho efforts went unrewarded. A coastal habitat would not have furnished the challenge of a struggle for survival. It would have furnished the rich environment that would have stimulated the evolution and growth of the brain. Indeed, there is now evidence that DHA is not only a ligand for the retinoid X receptor, an obligatory step in communicating to the genome, but it also stimulate neural gene expression in a manner consistent with neural growth and development.

Limits of genetic determinism

The importance of the relationship between DHA and gene expression and its 600 million year conservation, is that it explains a puzzle which only really can now be understood with the solution of the human genome. With only 35,000 genes discovered instead of an expected 150,000 Craig Ventor, head ot he USA project declared that we can forget about genetic determinism. It is the way the genome is influenced and its expression controlled that matters. Like DHA, many of our genes have been conserved over great periods of geological time.

The Puffer Fish genome has recently been published. Professor Ted Tuddenham of Imperial College described in a recent lecture to the McCarrison Society how its blood clotting factors are the same as in humans and share a coding identity which stretches from 50-80% identity. In other words the essence of our coagulation factors was in place 450 million years ago. He said that the explanation for the epidemic of thrombosis cannot be explained by a change in genes. It is a change in diet operating on ancient genes that has done the trick. Our genome is only about 1.5% different from the chimpanzee. It is quite plausible that again the change in diet was a key to the ultimate change from a chimpanzee to a human. In view of the experimental and gene expression evidence, nothing more complex is needed.

The evidence for the requirement of the brain for DHA is now robust and confirmed in two, joint International Expert Consultations by FAO and WHO (1978, 1994). Animal experiments have shown that deficiency of essential fatty acids during early development resulted in reduced cognitive and visual function, which was later irreversible. DHA is the major w3 fatty acids in neural and other cell membranes. Deficiency of w3 fatty acids during brain development has been found to result in loss of cognitive function in rodents and primates and in the extreme case, in brain hemorrhage and death in chickens. Feeding infants on formula without DHA result in a loss of DHA from the infant's circulating triglycerides, plasma and red cell phosphoglycerides. Maternal milk replacement formulae with and without AA and DHA have provided further evidence of the requirement for developing cognitive and visual function in the human infant. Human studies in peroxisomal disease indicate the adverse effects of deficiency on very early neural development. During treatment with DHA, Manuela Martinez witnessed MRI evidence of myelination in response to DHA supplementation.

In the contemporary health scene, there is now evidence of a sharp, recent rise in mental ill health, which is following from country to country the previous rise in death from coronary heart disease. Dr. Joe Hibbeln of the National Institutes of Health in the USA points to the correlations for mental ill health and depression inversely with fish intakes. The rise in mental ill health he also says is amongst young people born after 1950. It is predicted to be in the top three burdens of ill health by the year 2020 (www.globalburdenhealth.org).

A new paradigm of human evolution

The implications of this new paradigm of human evolution are wide reaching to contemporary health issues. If food was only gathered because of its protein and calorific value, the past and future food policies would only be concerned with procurement of such foods.

Last century, protein and body growth dominated nutrition thinking. However, this new body of evidence on lipid and neural requirement says that marine and lacustrine foods from the beginning of time played a critical role in the supply of brain and vascular specific nutrients. For 99.8% of our time we were eating wild foods largely exploiting the extremely rich lacustrine and coastal resources and making the best of both worlds of surf and turf. This means that sea and lake foods are not important for protein. Their importance lies in the DHA.

During the last century there has been a nutrition driven rise in average height of 0.4 inches per decade. This has been associated with cardio-vascular disease rising from a rarity to be no 1 killer. It is noteworthy that a major cause of the rise in blood lipids, atherosclerosis and cardio-vascular disease, was the rise and excessive use of land animal fats this century. Marine fats are protective. WHO now considers diabetes and heart disease will become the major cause of death in developing countries in the next decade. Heart disease is already the no 1 cause of mortality in Manila. The rise in obesity is also spreading from North America to Europe and the developing countries. That is we were changed in shape, size and disease pattern in one century. If nutrition can underpin such a rapid change in such a short time, think what it could do over evolutionary times scales.

Implications for action

The case now to be addressed is the health and abilities of children to be born in this new century. A new approach to nutrition education in primary, secondary and medical schools is urgently needed to empower children and indeed adults to make informed decisions about their nourishment and health.

A new and urgent approach is required to arrest the continued pollution of the lakes, river, estuaries and coastlines. The productivity of the oceans, rivers and lakes needs to be restored. In particular the pivotal importance of the mother and her young needs proper recognition. What is at stake is the health and abilities of the children yet to be born. Without action, the mistakes in food policy of last century which are now so visible, will continue to exert their multi-generational affect to the detriment of health, intelligence and the social cohesion of human society.

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A great deal of recent scientific interest has refocused attention on Darwinian theories of human evolution. A lively debate has arisen over the relevance and significance of human evolutionary theory on contemporary society.

In the Fifteenth Annual Caroline Walker Lecture, Professor Michael A Crawford, Director of the Institute of Brain Chemistry and Human Nutrition at London Metropolitan University outlines the possible role of nutrition in human evolution. Michael Crawford as a distinguished and experienced researcher into brain chemistry and evolution provides an expert vision of this topic.

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