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Research article

Diabetes and Obesity—An Evolutionary Perspective

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Abstract: Obesity and type II diabetes belong to the most serious public health challenges of the 21st century. Initially both diseases were typical of affluent societies. Currently both conditions however are increasingly found in low and middle income countries. In future obesity and diabetes are expected to reach epidemic proportions and affect developing countries to a greater extent than developed ones. A globalization of obesity and diabetes is observable. Recently prevalence rates increased, especially in Asia, the Near and Middle East, the Western Pacific region and even in Sub-Saharan Africa. Evolutionary Anthropology tries to understand the evolutionary mechanisms promoting rising obesity and diabetes type II rates. *Homo sapiens* evolved in an environment quite different from our recent one. Profound changes in physical activity patterns and nutritional habits during the last 10,000 years and increasingly during the last 200 years increased the risk of obesity and diabetes type II. Consequently our recent environment is called “obesogenic”. This mismatch has been recently observable among societies experiencing rapid cultural changes characterized by Westernization and modernization. This review focuses on obesity and type II diabetes from the viewpoint of evolutionary anthropology.

Keywords: Diabetes Type II; obesity; evolutionary anthropology; human evolution; modernization; westernization

1. Introduction

The prevalence of obesity and type II diabetes has increased dramatically since the beginning of the 21st century and consequently both are seen as global epidemics [1–4]. In 2008 for the first time in the long history of *Homo sapiens*, the number of obese people on earth exceeded the number of people suffering from starvation and malnutrition [5]. Currently more than 1.9 billion adults, 18 years and older, are overweight. Of these over 600 million correspond to the definition of obesity [6]. Obesity however is not only an adult problem, currently overweight or obesity affects one in ten children or adolescents worldwide [6]. In Europe one in five children can be classified as overweight or obese [7]. From the viewpoint of public health the high rates of obesity among children as well as adults are a major concern. It is well known that obesity may damage health demonstrated by an increased risk of several chronic diseases such as heart disease, stroke, hypertension, but also pancreatitis, osteoarthritis and cancer [8,9]. An especially strong association has been documented between obesity and type II diabetes, one of the most serious metabolic diseases with disastrous long term consequences such as blindness, nephropathy or the amputation of the lower extremities. The exceptionally strong interaction between obesity and type II diabetes was pointed out by the past president of the American Diabetes association, Francine Kaufman, who introduced the term "diabesity" [10]. Currently obesity as well as diabetes type II represent a global health crisis that threatens the economies of all nations [11]. Numerous strategies have been developed to prevent obesity as well as type II diabetes, nevertheless the prevalence of obesity as well as type II diabetes is still rising. From a medical point of view the development of preventive measures as well as treatment strategies is the major goal of obesity and diabetes research. Evolutionary anthropology in contrast tries to understand how such conditions evolved. Can the worldwide epidemic of obesity and type II diabetes be interpreted as a result of a mismatch between the environmental conditions in which *Homo sapiens* has evolved and the recent environment? The aim of the present review is to discuss the rising rates of obesity and type II diabetes from the viewpoint of evolutionary anthropology.

2. Definition of Obesity

The first question is: how can we define obesity? There are different approaches to define and to determine obesity. From a medical viewpoint obesity is defined as a state of increased body weight, in particular increased adipose tissue, of sufficient magnitude to produce numerous adverse health consequences [12]. Consequently obesity can be defined as a level of adiposity that is sufficiently excessive to damage health, demonstrated by an increased risk of metabolic and cardiovascular diseases, such as diabetes, hypertension, stroke and some forms of cancer [13]. For an appropriate determination of obesity commonly the body mass index (BMI) based on body weight and height (kilograms per square meter) and waist circumference, which is an indicator of central obesity, are used [14,15]. The World Health Organization defines overweight as a BMI above 25.00 kg/m^2, while a BMI above 30.00 kg/m^2 is an indicator of obesity. A BMI above 40.00 kg/m^2 is interpreted as

morbid obesity [16]. These cut offs are defined for adults with the exception of South Asian populations. This is mainly due to the fact that South Asian populations such as Indians show a characteristic obesity phenotype with a relatively lower BMI but increased central obesity [17]. This phenotype, characterized by excess body fat, abdominal and truncal adiposity is also called the "Asian Indian Paradox" [18]. Therefore the threshold for obesity and overweight for South Asian populations has been modified using various metabolic abnormalities as gold standard [15]. The World Health Organization Expert Consultation has taken these data into account in reducing the cut offs of overweight and obesity in South Asians to 23.00 kg/m^2 and 25.00 kg/m^2 respectively [19]. The definition of obesity among subadult individuals [20–23] represents another important problem. Subadult individuals are still growing additionally the growth differs according to sex. Consequently to define overweight and obesity, age and gender have to be taken into account. Commonly BMI percentiles for each separate sex and age class are used for the determination of overweight and obesity among children and adolescents [24].

3. Definition of Diabetes Type II

Diabetes type II belongs to a group of metabolic disorders, called diabetes mellitus, characterized by chronic hyperglycemia [6]. Diabetes is a chronic progressive disease that occurs either when the pancreas is unable to produce the hormone insulin sufficiently or when the target cells are unable to use the insulin effectively even if the pancreases produces it [6]. Consequently blood glucose levels increase dramatically and may lead to severe damage of the heart, eyes, kidneys, nerves and blood vessels. Type II diabetes is caused by the body´s ineffective use of insulin, e.g. insulin resistance. According to the American Diabetes Association Expert Committee on Diagnosis and Classification of Diabetes Mellitus the criteria for the diagnosis of type II diabetes are: a random plasma glucose $\geq$ of 200 mg/dl (11.1 mmol/l), a fasting plasma glucose (FPG) of $\geq$ 126 mg/dl (7.0 mmol/l); or a two-hour oral glucose tolerance test with plasma glucose $\geq$ 200 mg/dl. A FPG $\leq$ 110 mg/dl (6.1 mmol/l) and a FPG 110–126 mg/dl is defined as impaired glucose tolerance, impaired fasting glucose or prediabetes [25]. The World Health Organization defines diabetes a FGP $\geq$ P 140 mg/dl (7.8 mmol/l) [6].

4. Adverse Consequences of Obesity and Diabetes Type II

Obesity and type II diabetes are clearly associated. Obesity is without any doubt a major risk factor of developing type II diabetes. Furthermore obesity increases the risk of some other metabolic diseases such as hypertension, dyslipidemia, coronary heart disease, pancreatitis, osteoarthritis, but also some forms of cancer such as breast cancer or colon cancer [26–29]. Additionally obesity affects reproduction in an adverse manner, in particular obesity is associated with increased infertility rates in women as well as in men [30,31]. Childhood obesity represents a special problem because of the long term health consequences [32–35]. Furthermore obesity may increase psychological and

emotional morbidity [36]. In detail social stigmatization, psychosocial stress and psychic problems are commonly associated with obesity and may result in a markedly reduced health related quality of life [36,37].

Symptoms of type II diabetes are frequent urination, hunger, thirst and weight loss [25]. Long term effects of type II diabetes are the damage and dysfunction of the beta cells of the pancreas, nephropathy, retinopathy, diabetic cataracts and the damage of blood vessels [25]. As long term consequences blindness, amputations and dialysis are common among people suffering from type II diabetes.

The magnitude of obesity associated diseases and the long term consequences of type II diabetes also represent an economic burden [38]. Obesity is costly to individuals and societies and the increase in the prevalence of obesity and type II diabetes carries potentially serious implications for health care expenditures of many countries [2,29]. As a consequence prevention and effective treatment of obesity and diabetes type II are crucially important public health issues today. In order to prevent or to treat obesity effectively reasons for the global epidemic have to be identified and analyzed.

5. Prevalence of Obesity and Type II Diabetes

The dynamics of obesity and diabetes type II are changing rapidly [11]. During the twentieth century obesity and type II diabetes were mainly found in western affluent societies. Consequently "diabesity" was seen as a "Disease of affluence". At the beginning of the 21st century however, obesity but especially diabetes type II, have become increasingly common in low- and middle income countries [6,11]. For a detail description see tables 1 to 5. According to the World Health Organization 422 million adults were suffering from diabetes worldwide in 2014 [6]. More than 90% were affected by type II diabetes. Since 1980 the prevalence of diabetes has doubled from 4.7% to 8.5% worldwide. The increase in absolute numbers is even higher. While in 1980 worldwide 108 million people suffered from diabetes, this was true of 422 people in 2014 [6]. This dramatic increase is mainly due to general population growth and the fact that life expectancy increased markedly during the last four decades. Considering regional prevalence patterns it turned out that prevalence rates increased dramatically mainly in low income regions and so-called threshold countries such as India and China. Furthermore an especially high increase could be observed for the Eastern Mediterranean region from 5.9% to 13.7%. Even in poor regions such as Africa the prevalence rates doubled from 3.1% to 7.1%. In Europe in contrast the rates increased from 5.3% to 7.3% only. As pointed out above diabetes mellitus is no longer a disease of affluence, it is now increasingly common in poor societies. The largest absolute numbers of affected people are found in South Asia, East Asia and the Pacific Region. These three regions account for more than 50% of people affected by diabetes worldwide [6]. The association between poverty and diabetes type II is also found within First world countries. Even in western industrialized countries diabetes type II is mainly found among people belonging to the low social strata. Consequently diabetes type II has increasingly

become a disease of the poor worldwide. Another transition in diabetes prevalence is observable with regard to the affected age groups. For a long time diabetes type II was found nearly exclusively among elderly and middle aged people, during the past few decades however, increasingly children, adolescents and young adults have been affected [6]. Consequently we are confronted with a dramatic social dynamic in diabetes type II prevalence. In the present review this dynamic should be analyzed from the viewpoint of evolutionary Anthropology.

Table 1. Obesity and diabetes prevalence (%) in Africa. Source: WHO 2016 [6].

Africa	**diabetes**			**obesity**		
	men	**women**	**total**	**men**	**women**	**total**
Angola	5.8	5.5	5.6	5.1	11.9	8.5
Algeria	10.2	10.7	10.5	18.0	29.3	23.6
Benin	5.1	5.1	5.1	3.7	12.4	8.1
Botswana	4.9	7.1	6.0	10.9	28.2	19.5
Burkina Faso	4.6	3.8	4.2	2.8	7.7	5.2
Burundi	2.7	2.6	2.6	0.6	3.6	2.1
Cameroon	4.5	4.9	4.7	4.9	14.3	9.6
Chad	5.1	4.1	4.6	3.3	9.9	6.6
Congo	5.7	5.8	5.7	5.7	13.7	9.7
Egypt	14.2	18.2	16.2	19.4	36.0	27.7
Ethiopia	4.0	3.6	3.8	1.3	5.4	3.3
Gambia	6.5	5.2	5.8	5.0	13.1	9.1
Kenya	3.8	4.2	4.0	2.5	9.2	5.9
Morocco	12.6	12.3	12.4	15.6	27.6	21.7
Mozambique	4.5	4.7	4.6	1.6	7.4	4.5
Namibia	5.0	5.8	5.4	8.0	25.2	16.8
Niger	4.5	3.7	4.1	1.7	5.7	3.7
Nigeria	4.4	4.3	4.3	5.3	14.3	9.7
Rwanda	2.7	3.0	2.8	1.0	5.4	3.3
Senegal	4.9	5.3	5.1	4.0	12.5	8.3
Sierra Leone	4.9	4.6	4.8	2.8	10.4	6.6
Somalia	5.2	4.5	4.8	1.8	6.0	3.9
South Africa	7.7	11.8	9.8	14.6	36.0	25.6
Sudan	6.0	7.2	6.6	3.6	9.6	6.6
Tanzania	4.1	4.5	4.3	2.4	9.5	5.9
Togo	4.8	5.0	4.9	2.6	10.1	6.4
Tunisia	11.7	12.7	12.2	20.2	33.9	27.1
Uganda	2.7	3.0	2.8	1.3	6.5	3.9
Zambia	4.1	4.4	4.2	2.9	11.5	7.2
Zimbabwe	4.0	5.2	4.6	1.9	14.8	8.4

Table 2. Obesity and diabetes prevalence (%) in Asia. Source: WHO 2016 [6].

Asia	diabetes			obesity		
	men	women	total	men	women	total
Afghanistan	8.9	8.8	8.4	1.5	3.3	2.4
Armenia	11.1	13.5	12.3	17.1	22.9	19.9
Azerbaijan	10.5	12.6	11.6	18.5	29.9	22.2
Bahrain	8.7	8.2	8.5	29.7	41.3	34.1
Bangladesh	8.6	7.4	8.0	2.0	4.6	3.3
Cambodia	5.7	6.1	5.9	1.5	4.2	2.9
China	10.5	8.3	9.4	6.2	8.5	7.3
North Korea	5.6	6.7	6.2	1.7	3.3	2.5
India	7.9	7.8	7.8	3.1	6.5	4.7
Indonesia	6.6	7.3	7.0	3.6	7.8	5.7
Iran	9.6	11.1	10.3	19.3	30.6	24.9
Israel	7.6	6.8	7.2	23.7	27.8	25.8
Japan	11.8	8.5	10.1	3.4	3.6	3.5
Jordan	12.9	13.5	13.1	21.0	35.6	28.1
Kuwait	14.8	14.6	14.7	34.8	43.5	38.3
Laos	5.5	5.7	5.6	1.8	4.1	3.0
Malaysia	10.2	9.5	9.8	10.3	15.3	12.9
Mali	5.5	4.5	5.0	3.2	8.2	5.7
Mongolia	9.7	9.5	9.6	13.7	17.7	15.7
Myanmar	5.9	7.2	6.6	1.4	4.2	2.9
Nepal	10.5	7.9	9.1	1.7	4.1	2.9
Oman	7.2	8.3	7.5	22.7	33.5	26.5
Pakistan	10.0	9.7	9.8	3.3	6.4	4.8
Philippines	5.5	6.1	5.8	3.4	6.1	4.7
Qatar	12.6	13.2	12.8	38.9	47.8	41.0
Korea	10.6	8.4	9.5	5.1	7.5	6.3
Saudi Arabia	14.7	13.8	14.4	29.5	39.5	33.7
Thailand	9.1	10.1	9.6	6.1	12.1	9.2
Turkey	12.2	14.2	13.2	22.6	35.9	29.4
United Arab Emirates	7.8	8.5	8.0	31.6	41.2	34.5
Yemen	8.4	7.1	7.7	9.1	19.4	14.2

Table 3. Obesity and diabetes prevalence (%) in Australia and Pacific region. Source: WHO 2016 [6].

Australia + Pacific Region	diabetes			obesity		
	men	women	total	men	women	total
Australia	8.1	6.5	7.3	29.4	30.5	29.9
Cook-Islands	27.4	26.2	26.8	45.8	54.4	50.0
Fiji	14.9	18.3	16.6	30.2	41.9	35.9
Kiribati	21.7	22.2	22.0	32.5	48.0	40.1
Marshall Islands	20.4	21.1	20.7	36.4	48.3	42.3

Micronesia	16.1	19.9	18.0	27.2	39.5	33.2
Nauru	29.8	28.0	28.9	39.3	51.1	45.1
New Zealand	9.5	7.6	8.5	28.7	32.5	30.6
Palau	24.5	21.2	22.8	42.6	51.7	47.1
PapuaNewGuinea	11.9	11.6	11.8	20.6	30.7	25.9
Samoa	20.6	25.1	22.8	34.3	49.5	41.6
Solomon Islands	9.8	11.8	10.8	19.6	30.5	25.0
Tonga	19.1	24.5	21.9	34.0	48.2	41.1
Tuvalu	22.4	23.8	23.1	33.8	45.7	39.6
Vanuatu	12.9	13.3	13.1	27.2	38.7	32.9

Table 4. Obesity and diabetes prevalence (%) in Europe Source: WHO 2016 [6].

Europe	**diabetes**			**obesity**		
	men	**women**	**total**	**men**	**women**	**total**
Albania	8.4	8.1	8.3	16.7	19.4	18.1
Austria	7.1	5.0	6.0	22.1	18.1	20.1
Belarus	8.8	10.0	9.5	22.1	27.8	25.2
Belgium	7.5	5.4	6.4	24.0	20.2	22.1
Bosnia and Herzegovina	9.6	9.1	9.3	17.1	21.2	19.2
Bulgaria	10.7	10.0	10.3	23.6	27.5	25.6
Croatia	10.7	9.2	9.9	24.3	26.8	25.6
Cyprus	8.9	6.7	7.8	22.3	26.8	24.5
Czech Republic	10.2	9.1	9.6	28.1	30.1	29.1
Denmark	7.2	5.0	6.1	23.3	18.8	21.0
Estonia	9.1	9.5	9.3	23.5	25.4	24.5
Finland	8.7	6.8	7.7	23.4	22.2	22.8
France	9.5	6.6	8.0	25.3	26.1	25.7
Georgia	15.0	15.0	15.0	17.9	25.9	22.1
Germany	8.4	6.4	7.4	24.1	21.4	22.7
Ghana	4.6	5.0	4.8	4.9	16.8	10.9
Greece	9.5	8.8	9.1	23.6	26.7	25.1
Hungary	10.6	9.4	10.0	25.5	26.5	26.0
Iceland	8.9	5.3	7.1	25.0	22.8	23.9
Ireland	8.4	6.2	7.3	27.3	26.8	27.0
Italy	9.6	7.4	8.5	22.5	24.8	23.7
Lativa	9.2	9.6	9.4	23.2	27.7	25.6
Lithuania	9.8	9.5	9.7	24.0	30.5	27.5
Luxembourg	8.3	5.3	6.8	28.3	21.3	24.8
Malta	11.4	8.8	10.1	26.2	31.1	28.7
Montenegro	8.9	8.5	8.7	20.3	22.5	21.4
Netherlands	7.0	5.3	6.1	23.2	20.6	21.9
Norway	7.8	5.5	6.6	26.1	23.5	24.8
Poland	9.8	9.3	9.5	24.8	29.1	27.0
Portugal	10.7	7.8	9.2	21.4	22.8	22.1
Romania	8.5	8.4	8.4	21.8	24.9	23.4

Russian Federation	8.0	10.3	9.3	21.3	30.4	26.2
Serbia	8.7	8.5	8.6	19.7	22.5	21.1
Slovakia	9.2	8.1	8.6	25.9	28.9	27.4
Slovenia	9.2	9.8	9.5	26.7	28.2	27.4
Spain	10.6	8.2	9.4	24.9	28.0	26.5
Sweden	7.8	6.0	6.9	23.6	20.4	22.0
Switzerland	6.9	4.4	5.6	23.8	18.9	21.0
Ukraine	8.3	9.7	9.1	17.9	24.9	21.7
United Kingdom	8.4	6.9	7.7	28.5	31.1	29.8

Table 5. Obesity and diabetes prevalence (%) in America. Source: WHO 2016 [6].

	diabetes			obesity		
	men	**women**	**total**	**men**	**women**	**total**
North-America						
Belize	7.6	12.2	9.9	14.8	26.4	20.6
Canada	7.8	6.5	7.2	28.6	31.5	30.1
Cuba	8.7	11.8	10.2	20.4	34.0	27.2
Guatemala	6.8	8.2	7.5	11.3	21.2	16.4
Mexico	9.7	11.0	10.4	22.1	32.7	27.6
United States of America	9.8	8.3	9.1	33.7	36.3	35.0
South-America						
Argentina	10.0	10.5	10.2	23.6	29.4	26.6
Bolivia	5.5	7.7	6.6	11.1	20.6	15.8
Brazil	7.4	8.8	8.1	17.2	22.9	20.1
Chile	10.7	12.0	11.4	23.7	33.1	28.5
Colombia	7.6	8.5	8.0	15.7	25.5	20.7
Costa-Rica	8.4	8.7	8.5	19.0	29.2	24.0
Ecuador	6.7	7.9	7.3	13.9	22.2	18.0
Paraguay	6.8	7.1	6.9	12.2	18.0	15.1
Peru	6.4	7.5	6.9	15.2	25.5	20.4
Uruguay	10.1	11.9	11.1	22.9	31.9	27.6
Venezuela	9.1	8.5	8.8	19.8	28.8	24.3

6. Obesity and Type II Diabetes from the Viewpoint of Evolutionary Anthropology

The aim of Evolutionary Anthropology is not to develop new treatment strategies, but to analyze the evolutionary basis of the phenomenon obesity and diabetes type II. Evolutionary biology provides two different approaches to analyze a phenomenon such as obesity and/or diabetes type II. One the one hand a proximate approach should determine the physiological causes of a specific condition. On the other hand the focus of a specific condition is on the ultimate or evolutionary basis. In other words the question is why has this specific condition evolved? [39]. Evolution is the central paradigm in biological science and consequently Theodosius Dobzhansky stated "*Nothing in biology*

makes sense except in the light of evolution" [40]. From this point of view obesity and diabetes type II have to be considered within the framework of human evolution [41–46].

7. Obesity and Type II Diabetes in History

In a first step we have to find out if obesity and diabetes type II are completely new conditions in the evolution of *Homo sapiens*. The recent extraordinarily high rates of obesity and type II diabetes might indicate that both conditions are exceptionally recent phenomena. This idea may be supported by the assumption that our history was characterized by starvation and famine while obesity and associated metabolic diseases never existed. This is clearly not true. There is sufficient evidence for the emergence of obesity on an individual basis since the Upper Paleolithic [45,47]. Although it is not possible to reconstruct obesity or diabetes type II from skeletal remains, the existence of obese individuals can be reconstructed by iconodiagnostic analyses of the so-called Venus figurines. Throughout the twentieth century numerous Upper Paleolithic statues portraying extremely corpulent females, characterized by a large abdomen and breasts and an excessive amount of adipose tissue have been excavated by archaeologists. One famous example is the nearly 30,000 year old Venus of Willendorf which was discovered in the Danube Valley in Austria in 1908 [48]. It is a logical assumption that the unknown artists of these wonderful figurines had seen obese and severely obese women in reality. Hundreds of obese Venus figurines have been excavated in Europe and western Asia. The majority dates back to Upper Paleolithic and Neolithic times [49]. Nevertheless obesity was a very uncommon condition during prehistory. In general for a long time increased body weight and obesity were only a minority problem or a condition of single individuals. At a population level obesity was largely unknown up to the 1950s [50]. Across history only few individuals and privileged groups have been able to demonstrate wealth by above average body size including overweight and fatness [50,51]. The adverse effects of obesity however were recognized during ancient times. The famous Greek physician Hippokrates (460–377 BC) recognized the general adverse health consequences of obesity. He wrote "*It is very injurious to health to take more food than the constitution will bear, when, at the same time one uses no exercise to carry off this excess… For as aliment fills, and exercise empties the body, the result of an exact equipoise between them must be to leave the body in the same state they found it, that is in perfect health"* [47]. Obesity was also known in ancient Rome as the description of efficient treatment of obesity by the second century AD physician Galenos of Pergamon (129–200 AD) indicates: *"...I reduced a huge fat fellow to a moderate size in a short time, by making him run every morning until he fell into a profuse sweat; I then had him rubbed hard and put into a warm bath, after which I ordered him a small breakfast and sent him to the warm bath a second time. Some hours after I permitted him to eat freely of food which afforded but little nourishment, and lastly set him to some work which he was accustomed to for the remaining part of the day"*. [47]

Not only obesity has been described quite early in history. Diabetic symptoms have been described too. Diabetes is probably one of the oldest diseases known to man. The symptoms of

diabetes, called polyuric syndrome, have been described in the papyrus Ebers dating from 1550 BC. Furthermore detailed descriptions of diabetic symptoms can be found in Vedric medical books from ancient India [52]. The first time an association of polyuria with a sweet-tasting substance was reported, was by Sushrant, an Indian physician from the 5th–6th century AD. Araetus of Cappodocia (81–138 AD) described diabetes as a polyuric wasting disease. "*Diabetes is a wonderful affection being a melting down of the flesh and limbs into urine. The patient never stops drinking water but the flow is incessant as if from the opening of aqueducts. The patient is short lived".*

The ideas of ancient physicians were adopted by medieval physicians such as Avicenna or Maimonides but also by early modern European doctors and writers [47]. The Arab physician, Avicenna (960–1037), described accurately the symptoms and some complications of diabetes such as peripheral neuropathy, gangrene and erectile dysfunction [47].

In early modern Europe obesity and diabetes type II were nearly exclusively a problem of affluent sections of society and not an epidemic phenomenon. Increasingly the etiology of obesity was focused on in order to prevent the adverse health consequences of excessive body fat. Dr. Andrew Boorde, the physician of the English King Henry VIII, identified alcohol as the major risk factor for developing obesity. “All sweet wines and grass wine doth make a man fat” [53]. King Henry VIII suffered from obesity and diabetes type II.

During the late eighteenth century obesity became a common condition among the English upper classes [50]. George Cheyne (1671–1743), the foremost physician of his day, himself suffered from severe obesity. He described himself as “excessively fat, short breathed, lethargic and listless” and demonstrated the strong relationship between excessive obesity and a low quality of life [47]. At this time the modern era of diabetes research began. In 1675 Thomas Willis rediscovered the symptom of sweetness of urine in diabetic patients. He added the Latin word mellitus, meaning honey sweet, to the Greek diabetes to describe the disease. Approximately a century later, Mathew Dobson (1735–1784) confirmed the presence of sugar in both urine and blood of diabetic patients in 1776. John Rollo erroneously concluded that diabetes was a disease of the stomach as a result of abnormal transformation of vegetable nutrients into sugar in 1798. He suggested carbohydrate restriction as a treatment [52,54].

At the end of the 18th century major technological developments foreshadowed economic, social and cultural changes accompanying the Industrial revolution. Living circumstances changed dramatically. Rapid urbanization, but also dramatic changes in agricultural techniques such as the introduction of farming machines and fertilizers led to an unprecedented increase in food production. During the second half of the 19th century sufficient food was available for the majority of people in those parts of the world profiting from these developments such as Europe and Northern America. Consequently starvation and famine decreased and the prevalence of overweight, obesity and associated metabolic diseases such as diabetes type II increased. At a population level however, an obesity or diabetes epidemic did not occur. Two world wars and the great economic depression during the late 1920s and the early 1930s postponed the increase of obesity and associated metabolic

diseases to the second half of the 20th century. During this time of the so called "Wirtschaftswunder" (economic miracle) living conditions changed, the daily workload declined and in the majority of industrialized countries sufficient food rich in energy was available for nearly everybody. These changes had positive effects on growth and maturation, but on the other hand obesity and metabolic diseases such as diabetes type II developed into an epidemic. Consequently obesity rates and the prevalence of diabetes type II increased rapidly worldwide during the last 30 years [21,55], posing a significant health problem in nearly all industrialized countries but also in threshold and developing countries [56–59].

This short historical overview of obesity and diabetes show that both have been human conditions since prehistoric times. Yet economic, social and cultural changes during the 20th century have increased prevalence rates dramatically. Obesity and diabetes have increasingly been interpreted as diseases or conditions of affluence [60].

But why does *Homo sapiens* accumulate excessive amounts of body fat and develop insulin resistance? From a biological viewpoint there is no doubt that storing energy as adipose tissue is typical of several organisms, in particular of mammals [61]. Excessive obesity and diabetes type II resulting from a highly positive energy balance and a diet rich in sugar is exclusively found among domesticated pets. Even among the closest relatives of *Homo sapiens*, the non-human primates, obesity and diabetes are quite unknown among wild animals [62]. This leads to the question: Is there an evolutionary basis for human fatness and the tendency to suffer from diabetes? Evolutionary explanations of obesity and diabetes are based on the complex interaction between genetic and environmental factors. Before we can begin the discussion of biological and evolutionary approaches to explain obesity and diabetes prevalence rates we have to consider two important terms: genotype and phenotype. The genotype is the part (DNA sequence) of the genetic makeup of an organism or individual which determines a specific characteristic (phenotype) of an individual. The phenotype is the composite of an individual's observable characteristics, such as its morphology, development, biochemical or physiological properties and behavior. A phenotype results from the expression of an organism's genetic code, its genotype, as well as the influence of environmental factors and the interactions between the two.

8. The Thrifty Genotype Hypothesis

The first evolutionary explanation of diabetes type II and human obesity was provided by James Neel in the early 1960s [63]. Neel focused on the important role of genes in the pathogenesis of obesity and diabetes. He proposed a so-called thrifty genotype for glucose utilization among Native American populations as an evolutionary explanation for their high prevalence of type II diabetes [25]. The so-called Thrifty genotype hypothesis suggested that populations varied genetically in their predisposition to store energy in fat deposits on account of differential ancestral exposure to cycles of feast and famine. According to Neel populations or individuals experiencing frequent famines were assumed to have undergone selection for thriftier genes [46]. According to Neel, genes which

are part of the human gene pool must have had survival benefits during our evolution. A high frequency of periods of famine and starvation resulted in increased survival and reproductive success among individuals which were able to store energy efficiently. Obesity and diabetes type II are consequently interpreted as symptoms of affluence, caused by genes predisposing the human body to store energy efficiently. The transition to a modern lifestyle characterized by a lack of food shortages, famines, a reduction in physical activity but an abundance of energy dense food rendered a once adaptive genotype detrimental, resulting in obesity and type II diabetes [25]. Although Neel did not point out when in our evolution or history the proposed cycles of feast and famine might have occurred, his hypothesis still dominates thinking about the evolutionary basis of obesity and type II diabetes. Neel's hypothesis has been expanded to include so-called model populations such as Pacific Islanders or Pima Indians. Beside famine other stress factors were proposed that make efficient energy storage in fat tissue adaptive. Extreme cold stress was seen as the reason for high obesity rates among Inuit populations [64] and high seasonal energy demands during slavery for African Americans [65]. The thrifty genotype hypothesis has been reconsidered in recent genetic analyses [66,67].

9. Thrifty Phenotype Hypothesis

During the 1980s and the early 1990s an alternative hypothesis to explain the high rates of obesity and diabetes type II was introduced [68]. The British epidemiologists Barker and Hales proposed the concept that environmental stress factors such as malnutrition in early life, in particular in utero, might influence the development of diabetes type II later on in life [69,70]. They developed a theory of fetal origin or prenatal programming of later life diseases based on in utero nutritional deficiencies [25]. According to Barker and Hales life course plasticity was the key to explain the obesity and diabetes epidemic. In utero malnutrition leads to low birth weight newborns who respond to their low level of nutritional intake in early life through alterations in growth and metabolism which increase the risk of obesity and diabetes type II in later life [69]. Barker postulates that low birth weight newborns have metabolically thrifty mechanisms for fat storage and glucose sparing with reduced rates of glucose oxidation in insulin-sensitive target tissues [70]. The so-called thrifty phenotype hypothesis has been extremely influential, a recent meta-analysis however failed to support the predictions of the thrifty phenotype hypothesis [71].

10. Evolutionary Medicine

The recent obesity and diabetes epidemic can also be focused on from the point of view of evolutionary medicine. The concept of evolutionary or Darwinian medicine was formalized in the early 1990s, most notably by the evolutionary biologists George C. Williams and psychiatrist Randolph Nesse [72–75]. More than 150 years after the publication of Charles Darwin´s fundamental work "On the Origin of Species by Means of Natural Selection" in 1859 [76] and 140 years after the

publication of his second important publication “The Descent of Man and Selection in Relation to Sex” in 1871 [77], recent medical conditions have been increasingly interpreted in an evolutionary sense. Initially Williams and Nesse tried to understand why natural selection has left the human body so vulnerable to diseases [72,73,78,79]. According to the principles of evolutionary medicine recent obesity and diabetes epidemics represent a mismatch between the environment in which our ability to store energy efficiently in adipose tissue evolved and our recent environment. Therefore we have to look at the evolution of the genus *Homo* and the environment in which the genus *Homo* evolved.

11. The Evolution of the Genus Homo and the Environment of Evolutionary Adaptedness

The first members of the genus *Homo* appeared about 1.8 to 2 million years ago in eastern Africa. Starting with *Homo erectus* marked changes in social behavior and dieting habits occurred. The trend of encephalization and general larger body size typical of *Homo erectus* made an increased energy supply essential [80,81]. The increased demands of energy to meet the metabolic costs of the energy expensive brain resulted in numerous anatomical as well as behavioral adaptations [82]. On the one hand the size of the energy-expensive gut was reduced and on the other hand nutritional habits changed towards an increased meat and fat consumption [83]. Encephalization dispersal to habitats much colder than that of eastern Africa had a profound impact on the energy demands of *Homo erectus*. Increased energy stores represented a clear advantage in cold environments because adipose tissue ensures a supply of energy for thermogenesis and provides a buffering against negative energy balance which is an important stress factor in cold environments [86]. About 100,000 years ago modern *Homo sapiens* originated in Africa and colonized, with the exception of Antarctica, the whole world [84]. Modern *Homo sapiens* has adapted to widely different habitats and showed a huge developmental plasticity to survive and reproduce successfully under widely different environmental circumstances.

The environment experienced by members of the genus *Homo* and by *Homo sapiens* has been called the environment of evolutionary adaptedness (EEA) [85]. This environment was characterized by a foraging subsistence based on hunting and gathering, the use of stone and wooden tools, a mobile (nomadic) life style, small multi-aged egalitarian groups consisting of 20 to 30 group members. For a comparison between the environment of evolutionary adaptedness and recent environment see table 6. There was a lack of domesticated animals with the exception of the dog. This typical hunter gatherer or forager lifestyle was typical of 98% of our evolution and history [25,86]. During the 1980s the idea of a so called Paleolithic diet to which we are adapted was introduced [87–89]. Ethnographic analyses of the few remaining contemporary forager populations such as the Hadza in Tanzania, the !Kung of Namibia and Botswana, Ache of Paraguay or Efe of central Africa provided insights into a kind of lifestyle typical of paleolithic foragers [90–92]. This lifestyle was characterized by diets mainly consisting of vegetabile food, protein (50 to 80%) but of a low fat content [93–97] and a high degree of physical activity. Daily activities included walking and running in order to gather food, hunt, following wounded prey, flight or migrate to a new base camp

or water hole. Additionally carrying game, meat, children or gathering goods, but also tool making, meat butchering, digging roots were typical subsistence activities. Physical activity was a major part of their lives because it was essential for survival. Only physically active individuals were able to survive long enough to reproduce successfully and ensure the survival of their offspring to reproductive age. Consequently physical activity was an adaptive behavior. It can be assumed that non-communicable diseases such as hypertension, heart disease, cancer, diabetes or obesity were rather unknown [25,95,98]. *Homo sapiens* is clearly adapted to an environment and lifestyle like that of the hunter gatherers. Efficient energy stores however were essential for reproduction and growth under these living conditions [46]. Especially a sufficient amount of adipose tissue, but not obesity, enables females to reproduce successfully [99]. Famines as proposed by Neel [63] however were a rare condition among forager populations [100].

Table 6. Environment of evolutionary adaptedness (EEA) and recent environment—a comparison.

Characteristics		EEA	Recent environment
Society		Egalitarian band society	Complex Industrialized society
Group size		20 to 30 members	Up to megacities > 10 million inhabitants
Life style		Highly mobile	sedentary
Physical activity level		high	low
Characteristics of diet	Energy density	low	high
	Energy intake	adequate	excessive
Composition of diet	Protein (animal)	high	moderate
	Protein /(vegetable)	moderate	low
Carbohydrate	Complex carbohydrate	moderate	moderate
	Simple carbohydrate	low	high
Fiber		high	low
Fat	Fat (Vegetable)	low	Low
	Fat (animal)	low	High

12. The Neolithic Transition

The typical hunter gatherer lifestyle of the Upper Paleolithic changed dramatically with the process of the so-called Neolithic transition. About 20,000 years ago the Neolithic transition started resulting in the emergence of agriculture and a complete change in subsistence economy and life circumstances about 10,000 years ago in the area of the fertile crescent [101,102]. Domestication of animals and plants was adopted and allowed the production of a surplus of food. Consequently humans developed semi-permanent settlements and gave up their mobile lifestyle. The adoption of agriculture and animal husbandry allowed a considerable population growth because more people could be supported by food production. The Neolithic transition also resulted in dramatic dietary

changes. Dietary breadth was reduced dramatically and diet consisted of high carbohydrate crops such as rice, barley or wheat and tuber such as potatoes [103]. Analyses of Neolithic skeletal remains indicate caries caused by increased carbohydrate consumption but also protein deficiencies and signs of periodic food shortages, skeletal conditions which can clearly be interpreted as results of famine and starvation. Maybe the Neolithic transition characterized by famines and malnutrition is the basis for the thrifty genes proposed by Neel [63]. On the other hand the domestication of animals exposed humans to a variety of new pathogens resulting in an increased frequency of infectious diseases [103,104]. Beside the increased incidence of infectious diseases, changes in lifestyle patterns during the Neolithic transition resulted in the appearance of non-communicable diseases. The Horus study using CT scans of artificial and natural mummies of four ancient populations yielded high prevalence rates of atherosclerosis among post-Neolithic ancient Egyptians, ancient Peruvians and ancestral Puebloans of the South West US. The prevalence of atherosclerosis among post-Neolithic populations indicates the major lifestyle changes associated with the Neolithic transition. Consequently the Neolithic transition has led to the so-called first epidemiologic transition [105–107]. Apart from diet, physical activity patterns changed. Nevertheless there was still an obligatory and natural linkage between caloric acquisition as food energy and caloric expenditure as physical activity. This kind of physical activity patterns established during the Neolithic transition remained more or less stable until the Industrial Revolution started at the end of the 18th century when the second epidemiologic transition occurred.

13. Recent Obesogenic Environment

During the 20th century and the 21stcentury the third epidemiologic transition took place, mainly characterized by a decline in infectious diseases and a rise of non-communicable and degenerative diseases often as a consequence of increased life expectancy [104,105]. During a period of only about 200 years *Homo sapiens* actively changed his environmental conditions dramatically. Rapid urbanization resulted in an increasing number of people living in urban environments, many of them in so-called mega cities of more than 10 million inhabitants. Technical advances and modernization resulted in a marked transition in human lifestyle. Exemplary medical interventions and practices changed human morbidity and mortality rates remarkably and resulted in an increase in life expectancy and consequently in an enormous population growth. Daily energy effort to gather and prepare enough food has been reduced nearly to zero since only few individuals are working in food production. Mechanized transportation, sedentary jobs and labor-saving household technologies reduce physical activity too. In addition an abundance of energy dense food, mainly consisting of sugar and fat, is easily available [86,89,108,109]. From a physiological point of view overweight and obesity but also diabetes type II are caused by diet changes and a lack of physical activity, i.e. an imbalance between energy intake and expenditure [110]. This imbalance between energy intake and expenditure is mainly attributed to environments that are obesogenic [111,112]. Physical inactivity is typical of many postmodern societies. For example 26% of 8 to 16 year old US children watch TV

for at least 4 hours per day and 67% watch TV for at least 2 hours per day, only 19% of high school students are physically active for 20 minutes or more in daily physical education classes. 60% of US adults are not regularly physically active and 25% not at all. Consequently an obesogenic environment characterized by low levels of physical activity and high energy intake clearly promotes obesity and diabetes type II.

14. The Globalization of Obesity and Type II Diabetes

At the beginning of the 21st century obesity and diabetes type II are no longer conditions restricted to affluent societies. The dynamics of both are changing rapidly [11]. Once a disease of western affluent societies, obesity and type II diabetes have spread to nearly every country in the world. Obesity and type II diabetes are now increasingly conditions of the poor [3,113]. In developed countries an obesogenic environment and consequently high rates of obesity and type II diabetes are mainly found among lower socioeconomic groups. In poor developing countries however this relationship is reversed. People of high socioeconomic status who have undergone a rapid transition in nutritional habits and general lifestyle are more likely to be obese and suffering from type II diabetes [114]. In societies of economic and nutritional transition the paradox situation can be observed that malnutrition and obesity as well as diabetes type II rates increase parallel [115]. As developing countries have become wealthier and modernization as well as urbanization took place, eating habits and physical workload changed dramatically. The mechanization of jobs, improvement of transportation services, the availability of processed and fast food of high energy density and reduced physical activity are typical features of this trend [109,114]. In other words with modernization and westernization energy intake increased and energy expenditure decreased. Consequently obesity and diabetes type II rates accelerate in the wake of these developments. This is especially true of rising economies in Asia. In 1980 less than 1% of Chinese adults suffered from obesity and diabetes type II, in 2008 the prevalence had reached nearly 10% [6,11]. Another epicenter of obesity and diabetes type II epidemic is India. In urban centers of India the prevalence of diabetes type II has already reached about 20% [6].

Especially high rates of obesity and type II diabetes associated with westernization and modernization are found among Pacific Islanders [116–118]. The prevalence rates of diabetes Type II and obesity on Nauru Islands are more than 60% [118]. The typical traditional subsistence at the small Micronesian atoll Nauru depended on fishing and farming. Colonization but mainly economic change characterized by phosphate mining transformed Nauruans into the world´s wealthiest and most sedentary population [118]. Beside physical activity patterns nutritional habits changed dramatically. Nearly exclusively imported and energy dense food was consumed, consequently obesity and diabetes type II rates increased dramatically [18].

Extraordinarily high rates of obesity and diabetes type II are generally found among Pacific Islanders. Typical examples are native Hawaiians [116], Cook Islanders, but also Maori of New Zealand [117]. On the one hand the extraordinarily high rates of obesity and type II diabetes among

Pacific islanders were explained by rapid modernization [118], on the other hand the thrifty gene hypothesis was applied. In detail cold stress from water and long oceangoing voyages were discussed as selection factors [119–121].

Another example of the profound impact of Westernization and modernization on obesity and diabetes type II are Australian aborigines. Most Australian Aborigines today live a westernized lifestyle characterized by the consumption of western foods and a high level of physical inactivity [122]. A few groups of Australian aborigines still following a traditional way of life show a traditional diet and a high level of physical activity characterized by walking long distances digging in rocky grounds for tuber, reptiles, eggs and water deep below the surface, copping with a stone axe, gathering and carrying firewood. Among Australian Aborigines following a traditional hunter gatherer lifestyle non-communicable diseases are nearly unknown. Among their westernized counterparts obesity and type II diabetes are prevalent and much more common than among Australians of European origin [122].

Beside modernization and westernization, migration has an important impact on the development of obesity and diabetes type II [123,124]. Numerous studies show clearly that migrant status increases the risk of obesity and type II diabetes [125]. This is true of Hispanic immigrants in the United States [126] as well as of immigrants originating from Mediterranean countries or the Middle East in Central and Northern Europe [127–130]. Immigrant obesity is partly the result of rapid modernization and transition into an obesogenic environment. Another factor is that immigrants belong mainly to the poor of the guest society and poverty represents a special risk factor of obesity and type II diabetes [127].

15. Conclusion

From the point of view of evolutionary anthropology obesity and diabetes type II epidemics are the result of a dramatic mismatch between our current environment and the environment of our evolutionary adaptedness. For 99% of his evolutionary history *Homo sapiens* followed a hunter-gatherer lifestyle characterized by high physical activity and a Stone Age diet. The gene pool of *Homo sapiens* was shaped by natural and sexual selection towards an optimal adaptation to these environments and life circumstances. Starting with the Neolithic transition human lifestyle changed dramatically. Although there is no doubt that also some genetic changes had occurred since the Neolithic transition, we are still not fully adapted to our recent habitat. Modern lifestyles in affluent and rapidly westernized societies promote the development of obesity and diabetes type II. The current worldwide observable high rates of obesity and diabetes type II are the consequences of a profound mismatch between the environment of evolutionary adaptedness and our recent westernized lifestyle patterns.

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Conflict of Interest

The authors declare no conflict of interest in this work.

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