Burdens of Obesity: Multi-Model Description

Maja Atanasijević-Kunc[1*], Jože Drinovec[2], Tina Sentočnik[3]

[1]University of Ljubljana, Faculty of Electrical Engineering, Tržaška 25, 1000 Ljubljana, Slovenia;
*maja.atanasijevic@fe.uni-lj.si

[2]University of Maribor, Faculty for Medicine, Slomškov trg 15, 2000 Maribor, Slovenia

[3]Medico dr. Sentočnik, d.o.o., Levčeva 11, 1000 Ljubljana, Slovenia

Simulation Notes Europe SNE 23(2), 2013, 85 - 92
DOI: 10.11128/sne.23.tn.10187
Received: Jan. 25, 2013 (Selected MATHMOD 2012 Postconf. Publ.); Revised Accepted: June 15, 2013;

Abstract. Obesity was in 1997 by World Health Organization recognized as a disease. It has reached epidemic extensions and as such it has become an important social and economic burden, not only because of itself but also because it is an important risk factor for developing diabtes type 2, hyperdislipidemia and hypertension. These four chronic diseases are known as deadly quartet because they are essentially increasing the development of cardiovascular diseases which have already become the main reason for mortality. In the paper the modeling structure is proposed with which it is possible to evaluate the diseases' burdens important for certain country or population. In this case a number of active and inactive people, overweight and obese, and a number of people with healthy nutrition habits were estimated for Austria and Slovenia. Their influence to development of pre-diabetes and diabetes type 2 is also presented. In addition the costs for health care and also some expectations regarding population ageing are illustrated.

Introduction

Unhealthy life style very frequent consists of inactivity, stress, improper and/or too rich or abundant food resuling in a number of problems among which the first one is usually overweight. A simple index of weight-for-height (known as body mass index - BMI) is commonly used in classifying overweight and obesity in adult populations. It is defined as the weight in kilograms divided by the square of the height in meters (kg/m2).

It provides rough but very useful population-level measure of overweight and obesity as it is the same for both sexes and for all ages of adults [22]. It is important to mention that nowdays physicians pay attetion also to waist circumference but this parameter was not taken into account during this study because of the lack of statistical data.

Regarding WHO [22] overweight is defined as a BMI equal to or more than 25, and obesity as a BMI equal to or more than 30. Children were defined as overweight or obese using the 85^{th} and 95^{th} percentiles of the reference curves. WHO's latest estimations indicate that globally in 2008 approximately 1.5 billion adults (age 20+) were overweight [22].

It is important to point out that overweight and obesity are not the problem only by itself (more difficult movement, not very high self-opinion, social elimination), but they lead also to serious health consequences. Risk increases progressively as BMI increases. Raised body mass index is a major risk factor for chronic diseases such as diabetes type 2, hyperdislipidemia and hypertension, but can evolve also to serious cardiovascular disease (mainly heart disease and stroke), musculoskeletal disorders, and also some cancers [22].

These conditions have also a significant social consequences and economic impact on the health care systems. Medical treatment can be separated into non-pharmacological measures, pharmacological treatment and surgical treatment.

On the other hand costs are frequently regarded as direct and indirect [11], [1]. Direct medical costs include diagnostics and treatment services, while indirect costs are very often caused by health problems because of decreased immune system due to obesity. These patients have to visit their physician more frequently as the people with healthy body mass.

Their rehabilitation time after surgical operations or other health problems is longer, and therefore also the absence from work. Sometimes they need to be requalified, retired and also mortality is among these people earlier. It was estimated that indirect costs are in the same range (sometimes even higher) as direct expenses [2], [3], [4].

In this paper a four – level modeling structure is suggested. The goal is to enable the estimation of social and economic burdens. At the same time also the advantage of the coexistence of different dynamical processes can be taken into account.

The paper is organized in the following manner. In the next section the proposed modeling structure is presented. Some of simulation results are illustrated in the third section where also burden estimations are given. Further also some predictions regarding the problems of population aging are presented. The paper ends with conclusion remarks where also some of the topics for future study are indicated.

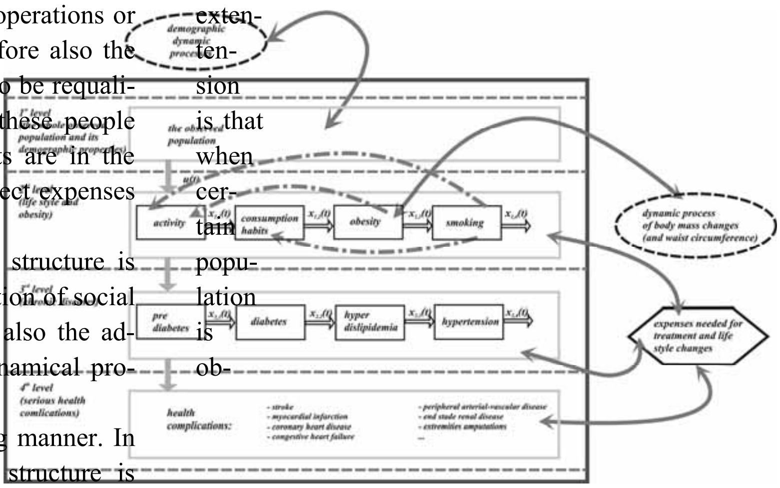

Figure 1: Propsed modelling structure.

1 Modeling Process

Proposed modeling structure is illustrated in Figure 1. It consists of four main levels which indicate problem observation from the population perspective. In addition also some other important dynamical processes or modeling results of complementary models can be combined with the results of the main structure.

At the first level therefore the whole observed population is taken into account. The input signal to the second level is a unity step indicating the observation start time that is at birth. At the second level the processes which are defining life style are taken into account. Among them is, as an exception, also obesity as one of the earliest chronic diseases. In the third level the most frequent chronic diseases are indicated, starting with the prediabetes which can sometimes be regarded as a curable disease. At the fourth level serious health complication are taken into account.

This representation can be understood as an extension of decision tree formalism [5], [6] which is frequently used in pharmacoeconomical studies [1], [20]. In contrast to classical decision tree it comprises also a time component, namely the age of observed people (or patients). This time component is of crucial importance because the prevalence of great number of diseases is in correlation with patients' age. Another advantage of this exten-tension is that when certain population is observed proposed structure responses (prevalence) can be combined with demographic data to evaluate the number of observed people or patients as will be presented in the next section. In addition it is important to point out that this information can further be combined with treatment expenses and so also economic burden can be estimated.

Such representation is very useful when the whole population is taken into account, and when mainly sequential influences are observed. But in some cases such interpretation can be extended to include also dynamical processes at individual level of certain patient or at a group of patients. This can be important also from treatment and prevention activity which can have feedback consequences as indicated in Figure 1.

In this paper one part of the whole structure in Figure 1 is used to present some important aspects of obesity:

- the connections to the main reasons which lead to development of obesity; here activity and nutrition habits are taken into account;
- the influence of obesity to development of other health problems; here different approaches are indicated: the simplest way is to present the average statistical expectations; more demanding approach uses further structural model development;
- estimation of social and economic burdens on the basis of diseases' development; regarding this step it is important to evaluate patients' number and direct and indirect costs in observed population.

Modeling has started taking into account the following important facts. Inactivity is an important risk factor regarding health threatening [13], [10] and it can't be neglected when body weight is observed. It is not very important during slimming programs, but is very helpful for body mass maintenance. Those people who are active 30 minutes or more at least five days a week are classified as active [8]. Usually activity in men and women slightly differ (men and boys are slightly more active), but average data, which were used for modeling purposes, are summarized in Table 1 [8]. Here also statistical information regarding physical activity of children is included. It is recommended that children are active 60 minutes or more on all seven days per week.

age [years]	0	1	2	3	4	5
average [%]	70	69	68.5	69	70	62
age [years]	6	7	8	9	10	11
average [%]	62.5	69	68.5	64.5	64.5	64
age [years]	12	13	14	15	16-	25-
average [%]	64.5	64.5	58.5	56.5	43	44
age [years]	35-	45-	55-	65-	75+	
average [%]	40.5	36	31	18.5	6.5	

Table 1: Prevalence of activity.

The prevalence of obesity differs from country to country and is also different regarding men and women. An average situation is presented in Table 2 [9]. The ratio between overweight and obese population is slightly changing through the life time, but as these changes are not very distinctive the assumption that it is equal to 1.33 (average value from Table 2) can be taken into account.

age [years]	2-15	16-34	35-54	55-74	75+
average prevalence: 25=<BMI<30 [%]	13.5	27	39	41.5	37.5
Average prevalence: BMI=>30 [%]	16	19	33.5	31.5	22.5
Average prevalence: BMI>=25 [%]	29.5	46	72.5	73	60

Table 2: Prevalence of overweight and obesity.

It is also very well known that people who are overweight or obese are inclined to inactivity, but there is practically no quantitative data available regarding the statistical correlation on the population level among these two variables. The interesting exception represents the paper of Brock [10], where the association between physical inactivity and the prevalence of obesity is described for the USA in the form of linear regression model. Testing this description in comparison to information from Table 2 and developed model response showed that it is expected that the prevalence of obesity is slightly lower in EU countries. Further also nonlinearity can be presumed because of complex involved processes.

Both, inactivity and obesity are very important regarding the development of diabetes type 2 (D2) [21]. It was discovered that most adults (85.4 - 86% in average) with diagnosed diabetes were overweight or obese [15], 52% were obese, and 8.1% had morbid obesity [12].

Before this chronic disease is fully developed patients have a pre-diabetes which in general significantly differ from D2 regarding the fact that when strict life change is adopted taking into account corresponding diet and activity, sometimes complemented by corresponding drug treatment, patients can return to normal condition. Sometimes this transition is (for example due to a long lasting pre-diabetes) not possible, but in such situations D2 development is in most cases significantly postponed. Prediabetes is not a true disease but can be interpreted as a serious risk factor for developing D2 and cardiovascular diseases. Over 30% of people with pre-diabetes develop D2 within five years [21]. The average conversion rate was estimated at 5.8% per year with wide variations which depend on differences in age, BMI, ethnicity, etc..

It is very important to accent that several well-designed randomized controlled trials [21] have been reported that categorically confirm the benefits of interventions in the prediabetes. Standardized diet with reduced food intake, increased physical activity and sometimes also additional drug treatment can reduce the incidence of D2 for almost 60% (in mentioned studies from 25% to 58%). But, it is important to point out that the intensive lifestyle modification was nearly twice as effective in preventing D2. It is therefore evident that an active management of pre-diabetes can be very effective in preventing the progression of diabetes.

For modeling purposes the information given in Tables 3 [16], [14], [17], [21] and 4 [7] was taken into acount. Again the average data between men and women are presented.

age [years]	5-11	12-19	20+	40-75	65+
average prevalence [%]	3.7	16.1	35	40	50

Table 3: Prevalence of pre-diabetes.

age [years]	25-34	35-44	45-54	55-64	65+
average prevalence [%]	3.5	4.2	8.9	15.5	19

Table 1: Prevalence of diabetes type 2.

2 Simulation Results

From data given in Tables 1 to 4 it is clear that activity or inactivity, as well as overweight and obesity can together with other diseases be interpreted as dynamical processes where age of people is chosen as an independent variable. In Figure 2 the first modeling result is presented – the prevalence of activity through practically the whole life time.

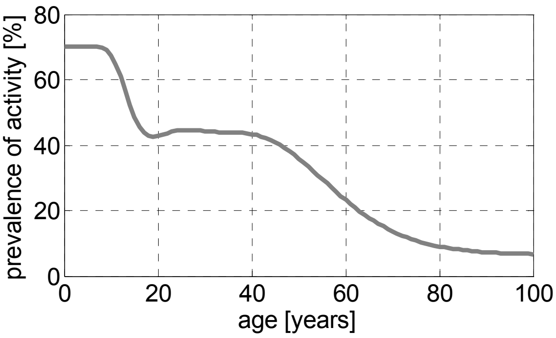

Figure 2: Prevalence of activity.

This model response shows that activity is decreasing through the whole life time and is becoming especially intensive after the age of 40. When activity is defined also the prevalence of inactive population is known. The dynamical structure which gives this result was identified so that good matching was achieved with data in Table 1 (dynamical nonlinear model of 11th order).

Taking into account all previously mentioned data in the next modeling step also the model (11th order with time delays) of overweight and obese population was identified. Responses are presented in Figure 3. It is also possible to differ among overweight and obese taking into account mentioned ratio.

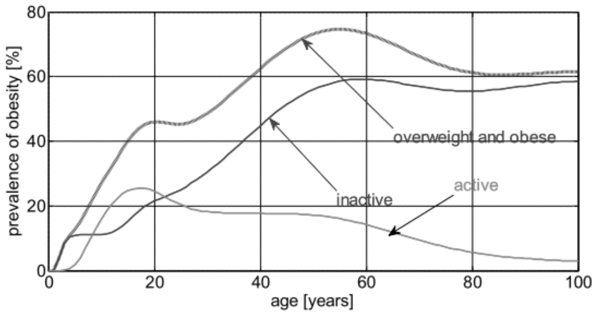

Figure 3: Prevalence of overweight and obesity.

Only 15% of all people in observed population have healthy nutrition habits, but they are not from the group of overweight or obese. We have made an assumption that among active population there is two times more such people than from inactive. The results are illustrated in Figure 4.

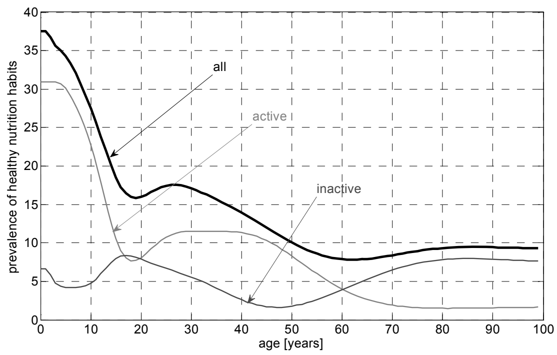

Figure 4: Prevalence of healthy nutrition habits.

In Figure 5 model responses are given regarding prediabetes (16th order model with time delays) and D2 (5th order with time delays).

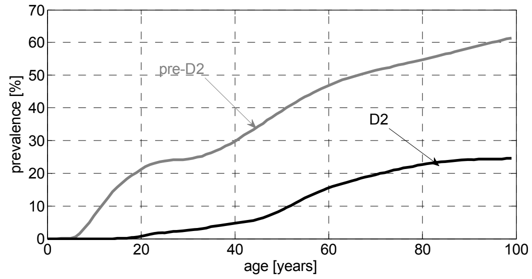

Figure 5: Prevalence of overweight and obesity.

When prevalence of observed processes is calculated, these results can be combined with demographic data for chosen population. We have decided to study and to compare the situation in Slovenia and Austria. In both countries populations are growing older. To estimate contemporary and also possible future burdens, for both countries, popultion models were developed, taking into account average values of mortality and migrations in the past five years and average fertility among the population from 18 to 45 years [19], [18]. These results are for both countries illustrated in Figs. 6 and 7. For Austria the results are presented only in intervals of ten years.

Now it is possible to combine the presented results and calculate the number of observed groups of people or patients in both countries. In Figure 8 number of active people is illustrated regarding their age. From this it becomes clear that in Austria live 3.2 million people who are active, while in Slovenia this number is over 780 000. For both countries this represents approximately 38% of the whole population.

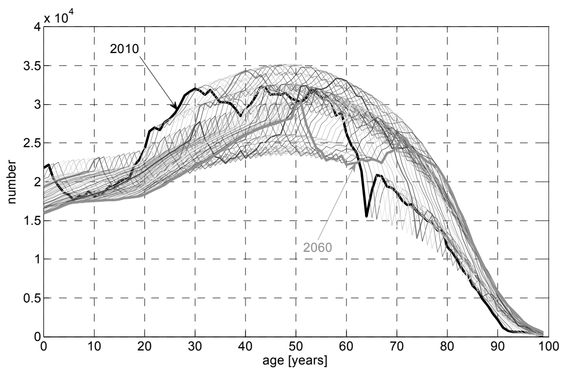

Figure 6: Number of people in Slovenia from 2010 (real number) to 2060 (model prediction).

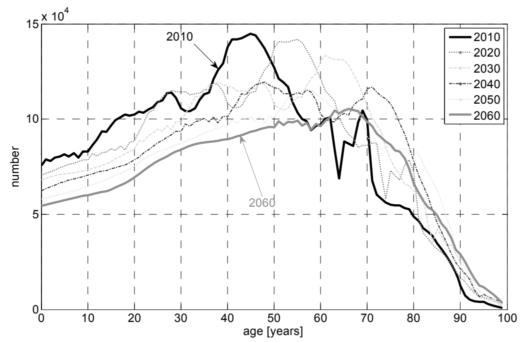

Figure 7: Number of people in Austria from 2010 (real number) to 2060 (model prediction).

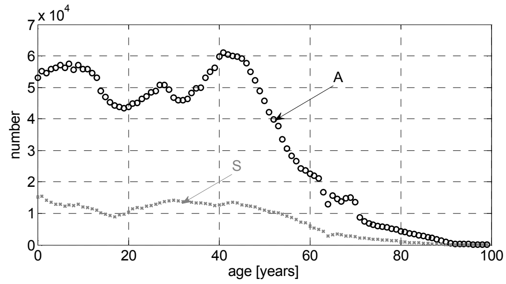

Figure 8: Number of active people in Austria and in Slovenia in 2010.

Regarding the number and distribution of overweight and obese population the situation is illustrated in Figure 9 for Austria, while in Figure 10 normalized distributions regarding patients' number in both countries are compared. In both countries around 55% of population is overweight or obese and the model enables to distinguish among those who are active and those, who are not.

As patients' number and distribution is known also the expenses can be evaluated. Practically all who have unhealthy body mass would like to lose their weight. 40% from the age window of 18 to 60 are experimenting with the drugs which are available without the medical prescription. 30% of people from the same age window are using drugs, prescribed by physician (20%- sibutramin; 80%- orlistat). 80% of patients with BMI>40 need also anti-depressive treatment (fluoxetin). In addition the expenses are needed for these patients due to examination and laboratory. Slovenia and Austria have practically the same costs for drugs, while the prices of medical services are two to three times higher in Austria.

The exceptions are only bariatric operations which are in Austria ten times more expensive than in Slovenia. In Table 5 the expenses are presented needed only for the treatment of overweight and obesity. Cosmetic surgical treatments were not taken into account because these data are not available.

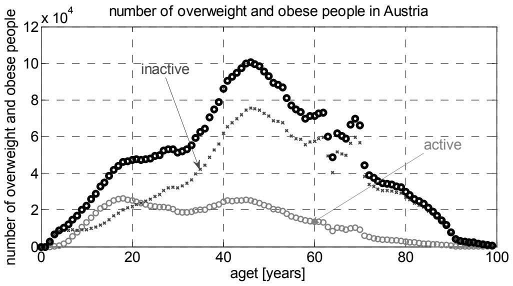

Figure 9: Number of overweight and obese people in Austria (4.4 million people or 55% have BMI >= 25).

	Slovenia	Austria
Alli	73 311 606€	288 161 848€
orlistat	167 220 900€	657 284 400€
sibutramin	14 631 750€	57 512 385€
fluoxetine	14 368 050€	56 475 630€
prescriptions+lab.	48 772 710€	383 415 900€
bariatric operations	1 000 000€	8 000 000€
specialists' treatment + medical service	5 838 750€	63 585 000€
	325 143 766€ per year	**1 514 435 163€ per year**
	159 (318)€/each per year	181 (362)€/each per year
	288 (576)€/each with BMI>=25 per year	329 (658)€/each with BMI>=25 per year

Table 5: Expenses for patients with BMI>=25.

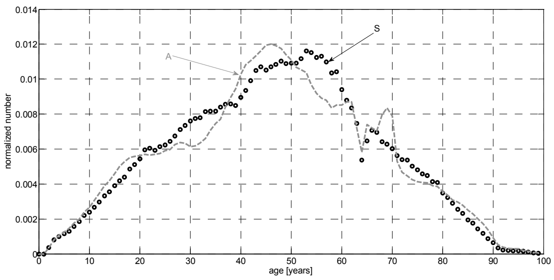

Figure 10: Normalized number (regarding the population number) of overweight and obese people in Slovenia and in Austria (55% have BMI>= 25).

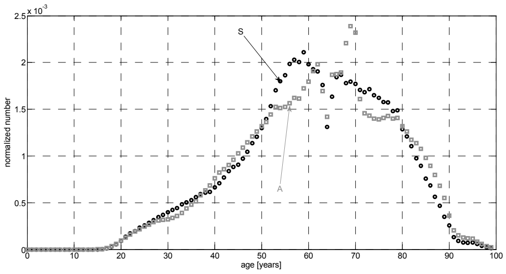

Figure 11: Normalized number (regarding the population number) of D2-patients in Slovenia and Austria.

The huge expenses are needed for the treatment of consequences of obesity, among which is also diabetes type 2 (D2), to mention only one. In Slovenia there are over 645 000 patients with pre-diabetes (31%) and 159000 (7.8%) with D2. Percentage of these patients is the same in Austria. Normalized distribution of D2-patients is presented in Figure 11 for both countries. For these patients additional 56 million € is needed in Slovenia and 231 million € in Austria.

We have to include also indirect expenses, which are of the same range. Each inhabitant of Slovenia has to pay more than 370€ and in Austria more than 410€ per year because of increased body mass in their population. That what is even more concerning is the population distribution in 2010 and expectations for 2060. If D2 prevalence remains unchanged this will influence the distribution of patients, as is for Slovenia illustrated in Figure 12. Number of D2 patients will increase, but only for 16% in Slovenia and 11% in Austria. But as the number of young people is decreasing the ratio between D2 patients and active population will increase for almost 50% in both countries.

A great number of mathematical models is available to compute energy - balance strategies for healthy body mass reduction [6]. But, two main obstacles can be identified regarding this important social and economic aspect: relative low budget for prevention purposes and insufficient integrative treatment activities which would increase efficacy of slimming process.

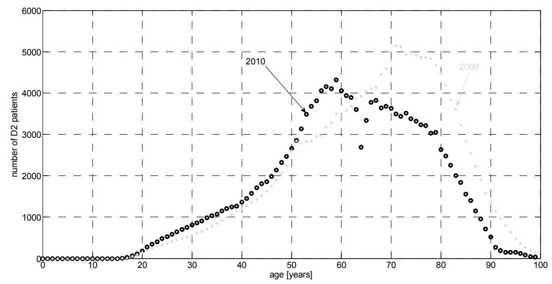

Figure 12: Number of D2-patients in Slovenia in 2010 and 2060.

3 Conclusions

In the paper modeling structure is introduced, which can be used for estimation of economic and social burdens of different diseases. It also enables the combination of modeling results, what was used for estimation of overweight and obesity burdens in Slovenia and Austria. In the future the strategy with which this burden could be decreased, will be investigated.

References

[1] Arnold RJG, Editor. *Pharmacoeconomics, From Theory to Practice.* Boca Raton: CRC Press, Taylor & Franics Group, Drug Discovery Series/13; 2010.

[2] Atanasijević-Kunc M, Drinovec J, Ručigaj S, Mrhar A. Modelling of risk factors and chronic diseases that influence the development of serious health complications. *Slovenian Medical Journal*. 2008a; 487-98.

[3] Atanasijević-Kunc M, Drinovec J, Ručigaj S, Mrhar A. Modeling the influence of risk factors and chronic diseases on the development of strokes and peripheral arterial-vascular disease. *Simulation Modelling Practice and Theory*. 2008b; vol. 16 (8), 998-1013.

[4] Atanasijević-Kunc M, Drinovec J, Ručigaj S, Mrhar A. Simulation analysis of coronary heart disease, congestive heart failure and end-stage renal disease economic burden. *Mathematics and Computers in Simulation*. 2011. http://dx.doi.org/10.1016/j.matcom.2010.10.024

[5] Atanasijević-Kunc M, Drinovec J. Burden of diabetes type 2 through modelling and simulation. *Topics in the prevention, treatment and complications of type 2 diabetes*. Zimering, M. B. (Ed.). Rijeka: InTech, cop.; 2011a; 3-28.

[6] Atanasijević-Kunc M, Drinovec J. Social and economical burden of obesity - multi-model analysis. *Proceedings of the ITI 33 rd International Conference on Information Technology Interfaces*. 2011b; ITI, 509-514.

[7] Behl GFE, Copeland JA, Wiggins J. The District of Columbia Diabetes Surveillance Report. Washington, DC: DC Department of Health; 2004. http://dchealth.dc.gov/doh/lib/doh/services/special_programs/diabetes/pdf/final data_and_stat_diabetes.pdf. #search=%22columbia%20diabetes%20prevalence%22

[8] British Heart Foundation Statistics Website – BHFSW. *Age differences and physical activity*. 2008. http://www.heartstats.org/atozpage.asp?id=4955.

[9] British Heart Foundation Statistics Website – BHFSW. *Trends in the prevalence of overweight and obesity*. 2010. http://www.heartstats.org/datapage.asp?id=1011.

[10] Brock DW, Thomas O, Cowan CD, Allison DB, Gaesser GA, Hunter GR. (2009). Association Between Insufficiently Physically Active and the Prevalence of Obesity in the United States. *Journal of physical activity & health*. 2009; 6(1): 1-5.

[11] CDC - Centers for Disease Control and Prevention. *Overweight and Obesity*. 2011. http://www.cdc.gov/obesity/defining.html.

[12] Daousi C, Casson IF, Gill GV, MacFarlane IA, Wilding JPH, Pinkney JH. Prevalence of obesity in type 2 diabetes in secondary care: association with cardiovascular risk factors. *Postgraduate Medical Jounal*, 2006; 82: 280-284. doi:10.1136/pmj.2005.039032.

[13] Defay R, Delcourt C, Ranvier M, Lacroux A, Papoz L. Relationships between physical activity, obesity and diabetes mellitus in a French elderly population: the POLA study. *International Journal of Obesity*. 2001; 25(4): 512-518.

[14] Li C, Ford ES, Zhao G, Mokdad AH. Prevalence of Pre-Diabetes and Its Association With Clustering of Cardiometabolic Risk Factors and Hyperinsulinemia Among U.S. Adolescents. *Diabetes Care.* 2009; 32(2): 342-347.

[15] MMWR. Centers for Disease Control and Prevention (CDC). Prevalence of Overweight and Obesity Among Adults with Diagnosed Diabetes - United States, 1988-1994 and 1999-2002. *Morbidity and Mortality Weekly Report (MMWR)*. 2004; 53(45): 1066-1068. http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5345a2.htm.

[16] Narayanappa D, Rajani HS, Mahendrappa KB, Prabhakar AK. Prevalence of Prediabetes in School-Going Children. *Indian Pediatrics*. 2011; 48:295-299.

[17] NDS. U.S. Department of Health and Human Services, National Institutes of Health. National Diabetes Statistics. *NIH Publication*. 2011; 11:3892. http://diabetes.niddk.nih.gov/DM/PUBS/statistics/DM_Statistics.pdf.

[18] Statistik Austria, http://www.statistik.at. 2011.

[19] Statistical Office of the Republic of Slovenia, http://www.stat.si/eng/index.asp. 2011.

[20] Stahl JE. Modelling Methods for Pharmacoeconomics and Health Technology Assessment, An Overview and Guide. *Pharmacoeconomics.* 2008; 26(2), 131-148, ISSN 1170-7690.

[21] Valensi P, Schwarz P, Hall M, Felton AM, Maldonato A, Mathieu C. (2005). Pre-diabetes essential action: a European perspective. *Diabetes & Metabolism.*2005; 31(6), 606-620.

[22] WHO - World health organization. Obesity and overweight. *Fact sheet No. 311*. 2011. http://www.who.int/mediacentre/factsheets/fs311/en/.