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Analysis of Obesity Epidemic Modelling: Is There a Solution?

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Abstract

Overweight and obesity have reached pandemic extensions. The World Health Organization has recognized obesity being a disease which means it has to be treated and if/when possible also prevented. At first glance the solution of the problem seems to be very simple, however, the rising prevalence of this disease proves that the problem is much more demanding and is connected with all pores of our lives. Through this work we tried to analyze some epidemiological mathematical and/or simulation models related to the problem of obesity and accompanying processes regarding different goals of models' usage. Of a special importance was the informativeness of modelling results indicating social and/or economic burdens and the efficacy in estimation of the observed problems' solution(s). It was detected that a great potential have multi-model descriptions which enable for each of the sub-processes and/or sub-steps the presentation of only the most important causal interactions. Efficient and correspondingly evaluated mathematical description incorporating also control activities is still a challenge waiting for a successive practical realization.

Keywords: Modelling; Obesity Epidemic; Related Diseases; Social-Economic Burden; Control

1. Introduction and Motivation

Life expectancy has been limited in the past centuries by epidemics of infectious diseases. It is therefore not surprising that epidemiological mathematical models became an important tool for a simplified description of the spread of such diseases and also for the research how to effectively curb these epidemics. After discovering the possibility of using different vaccines, antibiotics, and when the importance of hygiene became clear, the life expectancy in the developed world began to increase significantly. The situation was improving until the time when intensive food production and processing (Dreifus, 2012), as well as a changed lifestyle (predominantly in a sitting position during work-time) have triggered new epidemics that are now considered being non-susceptible diseases. Among them are obesity, type 2 diabetes, high blood pressure, and high cholesterol (Atanasijević-Kunc and Drinovec, 2011). The mentioned chronic diseases cause great social and economic burdens not only for an individual patient, but also for health-care systems, insurance companies, and social organizations, all the way to the state level. The problem has been escalating through few decades into a global one. However, it is not limited to the mentioned diseases. It was discovered that these chronic diseases, especially if they are untreated, or occur in various combinations, are the cause of additionally increased risk for the development of many serious health complications, among which are stroke, myocardial infarction, end-stage renal disease and certain types of cancers (WHO, 2017).

It is also very interesting to note that the solution of the problem is at the individual level well known, at least theoretically (at the cognitive level of each individual patient) (Hall, 2010). Nevertheless, in practice, this approach (energy balance, which must not be positive) is rarely efficient, especially in the longer time range. Medical doctors and many other researchers are intensely investigating this (it is possible to say, at first glance at least) very strange phenomenon (Frank, 2014; Sentočnik et al., 2014).

In this paper, we tried to analyze some of the epidemic modelling results in the field (regarding the abundance of publications in this area a monography would probably not be sufficient) and evaluate the developed models, or at least some of them, regarding used modelling approaches and resulting model structures. In addition attention was devoted also to the related phenomena, to flexibility of developed models, to the possibilities of the evaluation of social and/or economic burdens and to indicated control activities which could contribute in solving the observed problem(s)?

The addressed questions are analyzed through the next sections. In the section 2 first the most important/frequent modelling approaches in the field are identified and resulting structures are analyzed. Estimated social and economic burdens are described in the section 3, while reported control activities and suggestions are presented in the section 4. The paper ends with the concluding remarks and also some ideas for future investigations are indicated.

2. Modelling Approaches and Resulting Structures

2.1. Data ordering and statistical models

Many investigations were motivated by statistical observations, describing the prevalence and/or incidence of inspected diseases where an important example is the paper presented by Mokdad and co-authors (Mokdad et al., 2001) where epidemical investigation results of obesity and diabetes in the USA are presented. Their research revealed that in 2000 19.8% of the adult population was obese (body mass index - BMI=mass[kg]/(height[m])$^2\geq$30, while the prevalence of diabetes was 7.3%, and the prevalence of both combined was 2.9%.

Very important are also the results of statistical analysis presented in (Christakis and Fowler, 2007). The authors have discovered that obesity is spreading also through social ties. They have estimated that a person's chances of becoming obese increase by 57% if she/he has a friend who became obese in a longer time interval; among pairs of adult siblings, if one sibling became obese, the chance that the other would become obese is increased by 40%; if one spouse became obese, the likelihood that the other spouse would become obese is increased by 37%. These results can be evaluated as very important as more than 12000 people were observed inside a densely interconnected social network through more than 30 years long time range.

In Wang and Beydoun (2007) the authors searched studies published between 1990 and 2006 regarding obesity epidemic in the USA. Their research results revealed that among adults, obesity prevalence increased from 13% to 32% between the 1960s and 2004, while in 2006 66% of adults were overweight or obese. The investigation results also confirmed that low-socioeconomic-status groups are disproportionately affected at all ages. Annual increases in prevalence ranged from 0.3 to 0.9 percentage points across observed groups. Future projections regarding obesity prevalence were estimated by using *linear regression modelling*. Their projection predicted that by 2015, 75% of adults will be overweight or obese, and 41% will be obese, which is a very good prediction regarding the actual result was 39.8%, as described in Hales et al. (2017).

When different chronic diseases are observed also transitions between disease phases are important. This problem was addressed in Shih et al. (2007). The authors presented correspondingly adapted *Markov model* for the development of diabetes type 2 for the population in Taiwan. As this statistical model describes also transitions (regarding chosen time interval) it can be interpreted also as a *semi-static (or semi-dynamic) description*.

Prevalence of obesity in European countries was investigated in Berghöfer et al. (2008). They have estimated, that it ranged in men from 4.0% to 28.3% and in women from 6.2% to 36.5%. Considerable geographic variation were observed, with prevalence rates in Central, Eastern, and Southern Europe being higher than those in Western and Northern Europe.

In Andersen et al. (2012) the authors were investigating the development of obesity in Danish children. The method used was *logistic regression*. The presented results proved that both incidence and persistence of obesity contribute to the development of the obesity epidemic.

Statistically analysed associations between changes in national food energy supply and average population body mass in 69 countries (24 high-, 27 middle- and 18 low-income) are presented in Vandevijvere et al. (2015). The findings of Vandevijvere and co-authors suggested that increased food energy supply influence the average population body mass, especially in high-income countries. Their conclusion is that the policy efforts are needed to improve the healthiness of food systems and environments to reduce global obesity.

2.2. Dynamic and combined presentations

Development of dynamic mathematical models was motivated by threatening epidemics data, statistical observations, and by already existing modelling structures known from descriptions of contagious diseases As a consequence several modelling results have been presented, where the statistical analysis in the first step is followed by dynamic model development.

Morales (Morales et al., 2008) and Santonja (Santonja et al., 2010) with co-authors have estimated the situation of obesity epidemic in the region of Valencia, Spain using the *combination of logistic regression analysis and compartmental modelling approach*. Their main observation is that education and prevention are the most effective strategies of epidemic reduction.

Two step modelling approach was proposed also in Keaver et al. (2013) to predict obesity epidemic and related diseases burdens in the Republic of Ireland. In the first step a *non-linear multivariate regression model* was used to project BMI trends, while in the step 2 a *microsimulation approach* was employed to produce longitudinal projections and test the impact of interventions upon future incidence of obesity-related disease (type 2 diabetes (D2), hypertension, coronary heart disease (CHD), stroke, cancer, and knee osteoarthritis). These modelling results projected that it can be expected that overweight and obesity are going to reach levels of 89% in males and 85% in females by 2030, which is very similar to the result, presented in (Wang et al., 2008) for the USA. The expected consequences are: an increase in the obesity related prevalence of CHD and stroke by 97%, cancers by 61% and D2 by 21%.

In Atanasijević-Kunc et al. (2008a) dynamic mathematical models describing the prevalence development of obesity, smoking, D2, hypercholesterolemia, and hypertension through life time of observed population are presented. The authors have combined simulation results with the number of people in Slovenia and so also the numbers of patients in observed groups were estimated. In Atanasijević-Kunc et al. (2008b) and Atanasijević-Kunc et al. (2011) the mentioned models were extended with additional compartments representing the patients with stroke, peripheral arterial-vascular disease, coronary heart disease, congestive heart failure, and end-stage renal disease which are serious health complications and are far more frequent in patients with observed chronic diseases. Such health complications usually seriously decrease life quality of the patients' and affect also the whole families.

In Ejima et al. (2013) the authors are presenting two forms of rather simple dynamic epidemiological obesity models: the time- and age-dependent models. They have taken into account that obesity epidemic transient is expected to reach steady state in the next 200 years and was evaluated to be 60.8% in Southeast Asian countries. They claimed that optimality of intervention programs depends on the contagiousness of obesity which is still under investigation.

In Ejima et al. (2018) also the compartment model form was developed but with the goal to predict the prevalence development of obesity taking into account genetic and non-genetic transmission of this disease. Presented estimations show that obesity is going to reach 41% in the USA at 2030, while in UK this value is expected to be lower, only 27%. In spite of the fact that these results are still under investigation the authors believe that social contagious risk factor has a greater overall impact on the distribution of the population with obesity than spontaneous weight gain risk or mother-to-child obesity transmission risk.

2.3. Special modelling forms

Through the last few decades new modelling approaches were tested also in the field of obesity and related problems. Here we have to mention *agent based modelling* which was tested by several designers (Bruzzone et al., 2012; Ramirez-Nafarrate and Gutierrez-Garcia, 2013; Huang et al., 2016). The advantage of such an approach is the so-called *bottom-up modelling orientation* which has a potential when properties of agents and their environment are understood into more details as the structure and parameters of the whole system. Such an approach was used in Bruzzone et al. (2012) for describing obesity epidemic among adult population in Italy and USA. The authors analyzed the influences of different cultural and social conditions (education, ethnicity, religion, age, social and employment status, marital status, gender, and numerous other parameters) on modelling results.

Agent based modelling approach was used also in Ramirez-Nafarrate and Gutierrez-Garcia (2013) to study the prevalence of child obesity with the goal that it could be used by decision makers to analyze the effectiveness of intervention strategies in schools.

In spite of the fact that modelling results were in mentioned cases evaluated regarding data available, modelling presumptions, which have been taken into account, are still under verification due to very complicated influences to obesity development and they need to be reevaluated also by further investigations. Nevertheless, this modelling approach has great potential and it can be expected it will receive extensive research efforts, not only regarding obesity, but also related chronic diseases and health complications.

In Landi et al. (2010) authors have presented the software development helping in obesity treatment where the first version was using well accepted statistical modelling approach while later on the analysis was extended using artificial neural networks for modelling and predicting the outcome of gastric banding in term of excess weight loss after 2 years.

Very interesting seems also the study proposed by Nawarycz and co-authors (Nawarycz et al., 2013), where the fuzzy model was developed based on simple anthropometric indices such as BMI, waist circumference and waist-to-height ratio which are important for a better assessment of cardio-metabolic risks. They have concluded that such artificial intelligence methods including particular fuzzy inference systems should be more widely used to support health-care systems and policies.

3. Social and Economic Burdens

Dramatic rise in the prevalence of obesity and accompanying diseases stimulated also an interest in the social, health, and economic consequences of these phenomena. These problems are approached in different ways. Mokdad and co-authors (Mokdad et al., 2001) have estimated that the direct costs of obesity are approximately 9.4% of US health care expenditures, while the direct and indirect costs of health care associated with diabetes were in 1997 evaluated to be $98 billion. Results, presented in Wang et al. (2008), predict that total health-care costs because of overweight and obesity will double every decade to 860.7-956.9 billion US dollars by 2030, accounting for 16-18% of total US health-care costs.

Thompson and Wolf (Thompson and Wolf, 2001) have provided a systematic review of the literature on the medical-care cost burden of obesity and some related diseases (D2, dyslipidemias, hypercholesterolemia, hypertension, gallbladder disease, cardiovascular disease, coronary heart disease, myocardial infarction, stroke, osteoarthritis, knee osteoarthritis, musculoskeletal disease, gout, breast cancer, colon cancer, endometrial cancer, genitourinary cancer) in different countries. They have realized that obesity accounts for 5.5–7.0% of national health expenditures in the United States and 2.0–3.5% in other countries (Australia and France-2%, Canada-2.4%, New Zealand-2.5%, Portugal-3.5%, USA in 1986-5.5%, USA in 1995-5.7%-7%). It is obvious that the differences between countries are considerable but the origin of these differences is dual: the prevalence of obesity is in different countries different, but also economic and social situation can contribute to the presented costs in different ways as health care systems are not operating identically due to different health-insurance schemes.

Modelling results presented in Atanasijević-Kunc et al. (2008a), Atanasijević-Kunc et al. (2008b), Atanasijević-Kunc et al. (2011) and Atanasijević-Kunc et al. (2013) enabled the evaluation of the number of patients with increased BMI, D2, hypercholesterolemia and hypertension and several serious health complications. For each of these diseases year treatment costs were evaluated for patients in Slovenia. As simulation results are presented regarding people age, also the influence of population aging is possible.

The modelling results presented in Keaver et al. (2013) project a huge increase of D2, cancers, CHD and stroke by 2030 in Ireland. The direct healthcare costs associated with these increases will amount to 5.4 billion euro. A 5% reduction in population BMI levels by 2030 is projected to result in 495 million euro less being spent in obesity-related direct healthcare costs over twenty years.

4. Control Activities

Starting point regarding the reduction of obesity problem is usually directed into an individual patient, as mentioned in many papers (Mokdad et al., 2001; Hall, 2010; Sentočnik et al., 2014) but results are in a wider time-range rather poor.

In Swinburn et al. (2005) an implicit model is proposed, regarding epidemic level, which consists of five main steps, representing the framework for the obesity-problem solution: 1.) building a case for action on obesity; 2.) identifying contributing factors and points of intervention; 3.) defining the opportunities for action; 4.) evaluating potential interventions; and 5.) selecting a portfolio of specific policies, programs, and actions. It is important to point out that more than two decades later all the problems are still here and have become even more demanding. In addition, evaluation and effectiveness studies are still not available.

In Homer and Hirsch (2006) System dynamics is presented as a modelling approach where also complex public health processes can be described in efficient way. The authors have pointed out that complexity is often characterized by long delays between causes and effects, and also by multiple goals and interests that may in some ways conflict with one another. In such situations, it is difficult to find an optimal intervention taking into account also limited resources or capacities, as can be observed in many countries all over the world.

In Swinburn (2008) it is clearly stated that no country has managed to reduce the burden of obesity using public health approaches. The only possible exception seems to be Singapore with its program for children. Some aspects of the program have recently been revised because of the risk of stigmatizing obese children by singling them out for extra exercise sessions. The author has mentioned that environments that affect our behaviours can be broadly categorized into physical, economic, policy, and socio-cultural. All these elements need to be addressed when trying to decrease the problems of obesity. The proposal in this paper is that the dominant environmental drivers of obesity are economic and that the dominant solutions will need to be policy-based.

An interesting review regarding long-term cost-effectiveness of obesity prevention interventions is presented in Lehnert et al. (2012). The focus is on decision-analytic simulation models, which combine evidence from diverse sources. The authors have grouped these models into three broad categories: Markov cohort simulations, multi-state life table-based Markov models, and microsimulations. They have estimated as the most promising strategy multiple interventions implemented simultaneously, but modelling predictions are still under investigations.

5. Conclusions

Through this paper some of modelling results regarding obesity pandemic and accompanying phenomena are analyzed. As this disease is at the population level relatively slow-developing process very different modelling forms coexist in parallel and complement each other. Statistical models are usually the source of information for dynamic modelling approach which has in most cases resulted into compartmental structures where one or several diseases development is presented. In some cases also economic burden is estimated regarding the presented modelling results. Through the last few decades also more recent modelling approaches were tested, where a great potential seems to have agent-based modelling.

In spite of the fact that obesity pandemic is lasting for several decades, many problems are still representing a huge challenge. In this context it is important to mention the following:

- Evaluation of modelling results where data from different environments and/or different population groups should be taken into account;
- Lack of data linking the development of two or more diseases as a consequence of obesity and related phenomena;
- We are still waiting for mathematical modelling result(s) addressing the control design activity with which the solution trends would be clearly shown; it seems that economic interests are high above population health improvement possibilities, at this moment at least.

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