Modeling dynamics of infant obesity in the region of Valencia, Spain

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Abstract

In this paper we present a finite-time 3–5 years old childhood obesity model to study the evolution of obesity in the next years in the Spanish region of Valencia. After a statistical study, it can be seen that sociocultural characteristics determine the nutritional habits and the unhealthy ones such as high frequency of consumption of bakery, fried meals and soft drinks (BFS), which are prevalent factors in childhood obesity. This analysis allows us to consider obesity as a disease of social transmission caused by high frequency consumption of BFS and to build a mathematical model of epidemiological type to study the childhood obesity evolution. The parameters of the model using data from surveys related to obesity in the Spanish region of Valencia are computed adjusting the model to real data of the years 1999 and 2002. Furthermore the simulation shows an increasing trend of childhood obesity in the following years.

Keywords: Mathematical modeling; Childhood obesity; Finite-time dynamics; Epidemiological model; System of ODEs

1. Introduction

Obesity is growing at an important rate in developed and developing countries and it is becoming a serious disease not only from the individual health point of view but also from the public socioeconomic one, motivated by the high cost of the Health Public Care System due to the assistance expenditure of people suffering from related fatal diseases such as diabetes, heart attacks, blindness, renal failures and nonfatal related diseases such as respiratory difficulties, arthritis, infertility and psychological disorders, see [1,2]. One disease of particular concern is Type 2 diabetes, which is linked to overweight and obesity and has increased dramatically in children and adolescents [3].

Several studies correlate infant and adult obesity to the point that infant obesity is a powerful predictor of adult age obesity [4–6]. For instance, according to [5], an obese 4 year old child has a 20% increased probability to become
an obese adult. Looking at the long-term consequences, overweight adolescents have a 70% chance of becoming overweight or obese adults, which increases to 80% if one or both parents are overweight or obese [7].

Although there are still some differences in criteria around the optimal measure for children obesity, for obesity measurement, we use here the Body Mass Index (BMI), which is a number calculated using individual’s height and weight. Nevertheless, the change of the criterion will only produce minor changes in the conclusions.

There are many factors that play a role in body weight, and therefore, in becoming obese. But the main fact is the excess intake of calories, higher than the daily expenditure of energy, that leads to weight gain and can eventually lead to obesity. Other factors include individual’s environment, socioeconomic status, culture, metabolism, genes, etc.

In this work we study obesity as a disease of social transmission, from an epidemiological point of view, which means the study of the spread of the disease, in space and time, with the objective to trace factors that are responsible for, or contribute to, this occurrence [8]. We consider obesity as a disease that spread by social contact, this contact depends on the social environment around the people [9]. Of course this environment considers media, time, accessibility of foods, economical status and others which have influence over the probability of transmission of the obesity.

To the best of our knowledge the only antecedent of obesity mathematical models for populations appears in [10] where a fast-food obesity mathematical model for the USA population is proposed. The infinite-time behavior of the obesity study developed in [10] is based on the equilibrium points of the underlying system of differential equations. However, the model proposed in [10] presents several drawbacks, as the invariance of parameters of the system in the infinite-time domain is an unrealistic hypothesis or the rough parameter estimation used could be improved by means of the use of reliable data coming from local health institutions.

Here it is worth pointing out the difficulties to obtain reliable data. For instance, in the Spanish region of Valencia, a health survey is done every 5 years and data should be prepared, processed and stored in the database before their availability. Moreover the economic cost of this survey is very high. Therefore we had to search in several sources to complete the needed data, but data corresponding to children are not easy to find. Estimation of parameters is all-important for the validation of the model, since even if we have a well-designed model but incorrect parameters, our model will not fit the real world.

In this paper, we develop a statistical analysis of factors influencing obesity focused on the target population of children between 3 and 5 years old. This analysis helps us in the construction of a finite-time childhood obesity mathematical model, somewhat different from the one considered in [10], based on a more carefully adapted modeling to the real situation and solving numerically systems of quadratic type ordinary differential equations in finite-time intervals. The results and simulations will lead us to present conclusions about the nearby future evolution of the obesity for a 3–5 years old infant population.

Note that our goal is to model and to obtain future behavior of the childhood obesity, but the model also helps us to understand the mechanisms of the obesity spread. Mathematical models, simpler than the reality, allow us to understand the global dynamical behavior of obesity in the population and to establish sustainable public health programs for the prevention of the childhood obesity.

The paper is organized as follows. In Section 2 a statistical analysis of the data from Encuesta de Salud de la Comunidad Valenciana 2000–2001 (Health Survey of the Region of Valencia 2000–2001) [11] to identify the prevalent factors of childhood obesity is presented. Once the prevalent factors are identified, we assume that obesity is mainly transmitted by the quoted factors. Section 3 addresses the model building, estimation of the model parameters, numerical simulation and sensitivity analysis. Section 4 is devoted to a short discussion about how the model analysis may suggest general health public strategies to avoid the increase in childhood obesity. Conclusions are presented in Section 5.

2. Significance analysis of influence factors in childhood obesity

The region of Valencia [12] is located in eastern Mediterranean Spain, with an extent of 23,255 km² and a population of 4543,304 inhabitants (2004), composed of three provinces, Castellón (north) with 527,345 inhabitants, Alicante (south) with 1657,040, and Valencia (middle) with 2358,919.

In this section, we study the predictive influence factors in 3–5 years old childhood obesity in the region of Valencia according to the logistic regression analysis [13, Chapter 5], based on the database of 1187 children belonging to different families from the Health Survey of the Region of Valencia 2000–2001 [11], where the dependent variable is
The results of the logistic regression are shown in Table 1 (see [16]). The level of significance of the $p$-value is 0.05.

The observation of the $p$-value column of Table 1 reveals that the combination of the parents’ education level and the residence have influence on children obesity, for instance, if a child belongs to a family without higher studies and lives in Alicante increases the risk of being overweight or obese because, in this case, the $p$-value is less than 0.05 and $\beta = 0.53$, $\beta = 0.62$, positive values.

On the other hand it can be seen that variables such as gender or age have no influence on obesity since the associated $p$-value is greater than 0.05. Therefore, the logistic regression statistical study suggests that the obesity of 3–5 years old children in the region of Valencia depends mainly on sociocultural characteristics where they live and grow. Other similar studies such as [17,9] support this idea.

But, how does sociocultural characteristics determine the children’s nutritional habits? And what is the type of food underlying unhealthy nutritional habits? To answer these questions we carried out the correspondence analysis [13, Chapter 9] of Health Survey of the Region of Valencia 2000–2001 shown in Fig. 1.

First, in Fig. 1 (left) we consider the consumption frequency of bakery, fried meals and soft drinks (BFS). The cluster statistical analysis [13, Chapter 9] allows us to define two groups of people according to their nutritional habits, one composed of those children consuming a low frequency, less than 2 portions per week of each product, of bakery, fried meals and soft drinks, and a second group where the consumption frequency of each of the mentioned products is more than 3 portions. Furthermore, the correspondence statistical analysis [13, Chapter 10] permits us...
to correlate the consumption frequency of bakery, fried meals and soft drinks, together. The proximity between the categories Primary and High indicates that the BFS consumption habit is greater in children whose parents have only primary education. This results are in well accordance with other Spanish studies, for instance [18].

Second, in Fig. 1(right) we find a statistical relation between the residence and the parents’ level of education. To be precise, the parents with primary education are concentrated mainly in Alicante. The proximity between the categories Primary and Alicante indicates this fact. Also, in Table 1 with a p-value less than 0.05. Hence we can consider residence as an additional sociocultural characteristic.

Summarizing, obesity can be considered as a disease of social transmission where the transmission is done by unhealthy nutritional habits, BFS consumption, that depends on the sociocultural characteristic parents education level. The non-parametric contrast carried out shows the significant statistical relation between the parents’ education level and the inclusion of the child in a certain group of BFS consumption (p-value less than 0.05). Therefore, in the rest of the paper we will refer to high BFS consumption as the prevalent factor in childhood obesity, where the BFS consumption frequency (nutritional habit) is determined by the education level of the parents (sociocultural characteristic).

3. The mathematical model

In this section, let us build a mathematical model of the evolution of infant obesity, regarded as a social disease transmitted by social environment. The statistical study in the previous section allows the hypothesis of childhood obesity as a social transmission epidemic disease produced by a high BFS consumption frequency. These facts lead us to propose an epidemiological-type model.

For model building, childhood population is divided into six subpopulations, individuals with normal weight ($N(t)$), latent individuals, that is, people with the habit of BFS consumption but are still normal weight ($L(t)$), people with overweight ($S(t)$), obese individuals ($O(t)$), people who became overweight on diet ($D_S(t)$) and obese individuals on diet ($D_O(t)$). In addition we consider the following assumptions:

- Let us assume population homogeneous mixing [19, p. 320 and p. 328].
- From Section 2, we can assume that BFS consumption increases the individual weight of the children. Hence, the transitions between the different subpopulations are determined as follows:
  - Once a child starts having BFS he/she becomes BFS addicted, $L(t)$, and starts a progression to overweight $S(t)$ due to continuous BFS consumption. We assume that once a child is in the latent subpopulation he/she will progress, after a period (latency period), to overweight subpopulation. If the child continues having BFS he/she can become an obese individual $O(t)$. Children in both classes can stop having BFS, and then move to diet classes $D_S(t)$ and $D_O(t)$, respectively.
  - An individual of class $D_S(t)$ becomes a member of class $N(t)$ if he/she gives up or reduces the BFS consumption in an appropriate rate, or return to $S(t)$ otherwise. Analogously, a child of class $D_O(t)$ becomes a member...
of class $D_S(t)$ if he/she gives up or reduces the BFS consumption in an appropriate rate, or return to $O(t)$ otherwise.

- The transits between the subpopulations $N, L, S, O, D_S, D_O$, are governed by terms proportional to the sizes of these subpopulations. However since the transit from normal to latent occurs through the transmission of BFS consumption from latent, overweight and obese subpopulations to normal weight subpopulation, which depends on the meetings between their parents and due to our assumption that these social encounters between parents of different subpopulations are proportional to the product of the children’s subpopulations, the transit is modeled using the term,

$$\beta N(t)[L(t) + S(t) + O(t)].$$

- For this model, transition time-constant parameters are more suitable since our goal is to model the evolution of child obesity over a short finite time.

- We also assume that the parents’ nutritional habits and lifestyle determine the children’s habits, for instance, a child is on diet if their parents are on diet [20]. The values that determine the transition between subpopulations on diet are estimated using adult statistic surveys explained later.

- The subpopulations’ sizes and their behaviors with time will determine the dynamic evolution of infant obesity population.

- The increase in excessive weight gain does not occur during infancy [21], then we also assume that the 3 year old newly recruited children are normal weight.

Under the above assumptions, this dynamic obesity model for 3–5 years old in the Spanish region of Valencia is depicted graphically in Fig. 2 and is given by the following nonlinear system of ordinary differential equations

$$\begin{align*}
N'(t) &= \mu + \epsilon D_S(t) - \mu N(t) - \beta N(t)[L(t) + S(t) + O(t)], \\
L'(t) &= \beta N(t)[L(t) + S(t) + O(t)] - [\mu + \gamma_L]L(t), \\
S'(t) &= \gamma_L L(t) + \varphi D_S(t) - [\mu + \gamma_S + \alpha]S(t), \\
O'(t) &= \gamma_S S(t) + \delta D_O(t) - [\mu + \sigma]O(t), \\
D'_S(t) &= \gamma_D D_O(t) + \alpha S(t) - [\mu + \epsilon + \varphi]D_S(t), \\
D'_O(t) &= \sigma O(t) - [\mu + \gamma_D + \delta]D_O(t),
\end{align*}$$

where the constant parameters of the model are:

- $\beta$, transmission rate due to social pressure for BFS consumption (family, friends, marketing, TV, etc.),
- $\mu$, inversely proportional to time spent by 3–5 years old children in the system,
- $\gamma_L$, rate at which a latent individual moves to the overweight subpopulation,
- $\gamma_S$, rate at which an overweight individual becomes an obese individual by continuous consumption of BFS,
- $\epsilon$, rate at which an overweight individual on diet becomes a normal weight individual,
- $\alpha$, rate at which an overweight individual stops or reduces BFS consumption, i.e., the individual is on diet,
- $\varphi$, rate at which an overweight individual on diet fails, i.e., the individual resumes a high BFS consumption,
- $\sigma$, rate at which an obese individual stops or reduces BFS consumption,
- $\delta$, rate at which an obese individual on diet fails,
- $\gamma_D$, rate at which an obese individual on diet becomes an overweight individual on diet.

### 3.1. Parameter estimation

The estimate of some of the parameters of the model is intrinsically difficult due to the strong influence of intangible variables such as advertising, marketing, public education programs, health programs, etc. Moreover, the lack of the specific data for 3–5 years old children leads us to consider data from adult surveys considering that adults are the parents of the children and the family habits are the same. Despite these facts, we obtained all parameters of the model except $\beta$ and $k$ ($k$ is a parameter related to $\gamma_S$ and $\gamma_D$) using the following sources:

- the Health Survey of the Region of Valencia 2000–2001 [11],
- a technical report published by the Valencian Health Department where the present situation of infant obesity is described and data from 1999 to 2005, in regard to obesity and overweight, are available [14].
• a survey about alimentary habits developed by the Nutritional Observatory of the company Nutricia [22],
• a report from Abbot laboratories about the success in obtaining normal weight from overweight and obese people on diet [23],
• and a survey we prepared with 4 questions about population diet habits which were posed to the members of the Valencian Society of Endocrinology and Nutrition [24].

Parameters $\beta$ and $k$ will be estimated by fitting the model with the data. The following parameters are computed for time $t$ in weeks as:

- $\mu = \frac{1}{156}$ weeks$^{-1}$, the average time spent by a child in the system is 3 years, that is, 156 weeks.
- $\gamma_L = 0.0089$ weeks$^{-1}$, is estimated using the weekly growth of the average weight of a child in the region of Valencia [14]. This rate shows how many weeks a latent child (normal weight) takes to become an overweight individual by continuous high consumption of BFS, that is,
  \[ \frac{1}{\gamma_L} = \frac{1}{0.0089} = 112.36 \text{ weeks}. \]
- $\gamma_S$, we consider this parameter proportional to $\gamma_L$ because it is describing a phenomenon with the same characteristics as $\gamma_L$ with an increasing difficulty to become obese based on two main facts; one is that once the individual is overweight he/she realizes more his/her overweight problem and takes more care about his nutrition (from data about overweight and obese people on diet in [11]), and the second fact is that the basal metabolic rate increases with weight, therefore the body of heavier people consume more calories [25,26]. So,
  \[ \gamma_S = k \gamma_L = k \times \gamma_L \text{ weeks}^{-1}, \quad 0 < k < 1, \]
  where $k$ will be determined by fitting the model to the real data.
- $\varepsilon$, an individual with BFS consumption takes $\frac{1}{\gamma_L}$ weeks to transit from normal weight to overweight, then if he/she gives up BFS consumption, he/she will take $\frac{1}{\gamma_L}$ weeks multiplied by the success rate [24] to come back to normal weight, that is,
  \[ \varepsilon = 0.0089 \times 0.312 = 2.7768 \times 10^{-3} \text{ weeks}^{-1}. \]
- $\alpha$, this parameter is estimated taking into account the average time that an individual finishes a diet and starts another, $1.56 \times 52$ weeks [22], and the percentage of overweight individuals who are put on diet [24], that is,
  \[ \alpha = \frac{1}{1.56 \times 52} \times 0.33 = 4.068 \times 10^{-3} \text{ weeks}^{-1}. \]
- $\varphi$, this parameter is estimated using the average time that people stay on diet, 5.4 weeks [23], and the percentage of failure of overweight individuals on diet [24],
  \[ \varphi = (1 - 0.312) \times \frac{1}{5.4} = 0.12735 \text{ weeks}^{-1}. \]
- $\sigma$, this parameter is estimated taking into account the average time that an individual finishes a diet and starts another, $1.56 \times 52$ weeks [22], and the percentage of obese individuals who are put on diet [24], that is,
  \[ \sigma = \frac{1}{1.56 \times 52} \times 0.36 = 4.4379 \times 10^{-3} \text{ weeks}^{-1}. \]
- $\delta$, this parameter is estimated using the average time that people stay on diet, 5.4 weeks [23], and the percentage of failure of obese individuals on diet [24],
  \[ \delta = (1 - 0.137) \times \frac{1}{5.4} = 0.15974 \text{ weeks}^{-1}. \]
- $\gamma_D$, this parameter measures the partial success of an obese individual in his/her goal of reaching a normal weight, specifically measures the flow from obese individuals on diet to overweight individuals on diet. $\gamma_D$ is estimated using the value of $\gamma_S$ and the percentage of obese individuals on diet who have success [24],
  \[ \gamma_D = \gamma_S \times 0.146 = k \times 1.2994 \times 10^{-3} \text{ weeks}^{-1}. \]

We summarize the obtained parameters in Table 2.
Table 2
Obtained parameters of the model given by the system of differential equations (1) for the region of Valencia

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \mu )</td>
<td>156 ( \frac{1}{156} )</td>
<td>( \gamma_L )</td>
<td>0.0089</td>
</tr>
<tr>
<td>( \gamma_S )</td>
<td>( k \times 0.0089 )</td>
<td>( \varepsilon )</td>
<td>( 2.7768 \times 10^{-3} )</td>
</tr>
<tr>
<td>( \alpha )</td>
<td>( 4.068 \times 10^{-3} )</td>
<td>( \varphi )</td>
<td>0.12735</td>
</tr>
<tr>
<td>( \sigma )</td>
<td>( 4.4379 \times 10^{-3} )</td>
<td>( \delta )</td>
<td>0.15974</td>
</tr>
<tr>
<td>( \gamma_D )</td>
<td>( k \times 1.2994 \times 10^{-3} )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Remark 1.** Each one of the parameters \( \mu, \gamma_L, \gamma_S, \varepsilon, \alpha, \varphi, \sigma, \delta, \gamma_D \) can be interpreted as the mean of the length of the transit period between two subpopulations. Length of the transit period for a subpopulation is usually assumed to follow an exponential distribution [27, p. 41 and p. 283]. Therefore the above numerical values computed for each parameter should be considered as average length of transition periods between two subpopulations and not be regarded as a fixed time after which each individual crosses to a new subpopulation.

3.2. Numerical simulations

We obtain the initial conditions (year 1999, i.e., \( t = 0 \)) and final conditions (year 2002, i.e., \( t = 156 \)) for the model from [14]. We use this final condition (2002) because it is the last data available for the subpopulation proportions.

With the obtained parameters from surveys and data and the initial and final conditions, we performed several simulations for different values of \( \beta \) and \( k \) in an appropriate range \( (\beta, k \in (0, 1)) \) in order to find the value of \( \beta \) and \( k \) that minimize the mean square error of the difference between the solutions of the model for the proportions of subpopulations of normal weight (including latents), overweight and obese and the real data in the year 2002 (final condition). The obtained values for \( \beta \) and \( k \) were

\[
\beta = 0.02, \\
k = 0.32584.
\]  
(2)

Then, we use the model with the parameters of Table 2 and the just obtained parameters (2) to extrapolate for the following 8 years (until 2010). The result is presented in Fig. 3.

In Fig. 3, a trend of increase in obese and overweight 3–5 years old children subpopulations until 2010, in well accordance with the tendency observed in several countries [28] can be noted. Also, there exists a decrease in normal weight subpopulation and the percentage of people on diet remains constant and low. In Table 3, we present some of the numerical values represented in Fig. 3.

3.3. Model sensitivity analysis

We performed several simulations varying the parameters of the model in order to find out what is the influence of the changes on the final solution. We observed that the most sensitive parameters were \( \beta, \gamma_L \) and \( k \).

As we did in Fig. 3, in the following Figs. 4–6 latent individuals are included in normal subpopulation.

In Fig. 4 we present a simulation of the proposed model where parameter \( \beta = 0.02 \) has been changed to \( \beta = 0.04 \). This change implies an increase in the transmission rate of BFS consumption and, consequently, more people may become overweight by continued high BFS consumption. Comparing with Fig. 3, an increase in overweight subpopulation and a decrease in normal weight subpopulation can be noted. Therefore, the increase in \( \beta \) implies an increase in overweight subpopulation.

In Fig. 5 the parameter \( \gamma_L = 0.0089 \) has been changed to \( \gamma_L = 0.02 \). This change implies a faster transition to become an overweight individual by continued BFS consumption. In this case, at the beginning, there is an increase in the overweight and obese subpopulations and finally a stabilization.

In Fig. 6 the parameter \( k = 0.32584 \) has been changed by \( k = 1 \). This change affects to parameters \( \gamma_S \) and \( \gamma_D \) and implies a faster transit from overweight to obese individual and a faster transit from obese on diet to overweight on diet. Because \( \gamma_S \) is much greater than \( \gamma_D \), in this case, there is an increase in the obese population, until it goes above the overweight population.
Fig. 2. The diagram for 3–5 years old children obesity model in the Spanish region of Valencia as defined in Eq. (1). The boxes represent the subpopulations and the arrows represent the transitions between the subpopulations, labeled by the parameters of the model.

Fig. 3. Evolution of the different subpopulations of 3–5 years old children in the region of Valencia, 1999–2010. Note a slight but sustained increase in the overweight and obese subpopulations. Latent individuals are included in normal subpopulation.

Table 3
Evolution of proportion of normal weight (including latents), overweight and obese subpopulations for different years in the proposed model

<table>
<thead>
<tr>
<th>Year</th>
<th>Normal + latent</th>
<th>Overweight</th>
<th>Obese</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>0.656</td>
<td>0.2025</td>
<td>0.0515</td>
</tr>
<tr>
<td>2000</td>
<td>0.6639</td>
<td>0.227801</td>
<td>0.0987835</td>
</tr>
<tr>
<td>2001</td>
<td>0.6524</td>
<td>0.238055</td>
<td>0.0998146</td>
</tr>
<tr>
<td>2002</td>
<td>0.6386</td>
<td>0.249237</td>
<td>0.101979</td>
</tr>
<tr>
<td>2003</td>
<td>0.6274</td>
<td>0.256948</td>
<td>0.104708</td>
</tr>
<tr>
<td>2004</td>
<td>0.6207</td>
<td>0.261257</td>
<td>0.10739</td>
</tr>
<tr>
<td>2005</td>
<td>0.6162</td>
<td>0.26327</td>
<td>0.109685</td>
</tr>
<tr>
<td>2006</td>
<td>0.6138</td>
<td>0.263993</td>
<td>0.111485</td>
</tr>
<tr>
<td>2007</td>
<td>0.6122</td>
<td>0.264087</td>
<td>0.112818</td>
</tr>
<tr>
<td>2008</td>
<td>0.6114</td>
<td>0.263929</td>
<td>0.113765</td>
</tr>
<tr>
<td>2009</td>
<td>0.6109</td>
<td>0.263705</td>
<td>0.114417</td>
</tr>
<tr>
<td>2010</td>
<td>0.6107</td>
<td>0.263494</td>
<td>0.114857</td>
</tr>
</tbody>
</table>

This model predicts that 61.07%, 26.34% and 11.48% of the 3–5 years old children in the region of Valencia will be of normal weight, overweight and obese, respectively, in 2010.
Due to the sensitivity of the estimated parameter $\gamma_L$, we repeated the model fitting with the real data in the year 2002 (final condition) to compute the parameters $\beta$, $k$ and moreover the parameter $\gamma_L$, in order to check the consistency of its previous estimation. The obtained values were

$$\beta = 0.021,$$

$$k = 0.30539,$$

$$\gamma_L = 0.00907.$$ 

Note that the new obtained values for these parameters of the model are very similar to the previous ones. In particular, the parameter $\gamma_L$ is almost equal to our estimation carried out in Section 3.1 using data in [14].

4. Discussion. Model application to Health Public System strategies

Medicine covers the prevention and treatment of illnesses. The proposed obesity model considers both possibilities. With parameters $\beta$, $\gamma_L$ and $\gamma_S$ prevention can be controlled whereas treatment parameters are $\gamma_D$, $\varepsilon$, $\alpha$ and $\sigma$. 

Fig. 4. Simulation of the proposed model with $\beta = 0.04$. The increase in $\beta$ implies an increase in overweight subpopulation.

Fig. 5. Simulation of the model with $\gamma_L = 0.02$. The increase in $\gamma_L$ implies an increase in overweight and obese subpopulation at the beginning and a stabilization of both subpopulations at the end.
The simulations carried out suggest that the obesity prevention strategies should lead to the reduction of $\beta$, $\gamma_L$ and $\gamma_S$, that is, reducing the pressure on BFS consumption and the amount and the frequency of consumption. Two main strategies may be suggested to achieve this objective: in long term, using the statistical study carried out in Section 2, in developing educative plans in order to increase the education level of families; in short term, reducing the BFS products advertising spots and designing health programs and advertising campaigns to show the population how to change to healthier nutritional habits.

On the other hand, for overweight and obese individuals, the objective is to increase the treatment parameters $\gamma_D$, $\varepsilon$, $\alpha$ and $\sigma$. This could be done if the Health System carries out a monitoring with primary attention to the people who decide to go to the physician to be put on diet. The monitoring may prevent the majority of the individuals from giving up the diet in the first stages of the process.

5. Conclusions

In this paper we present a finite-time 3–5 years old childhood obesity model to study the evolution of the obesity in the next years in the Spanish region of Valencia. After a statistical study, high frequency of consumption of BFS (bakery, fried meals and soft drinks) is detected as prevalent factor in childhood obesity. This analysis allows us to consider obesity as a disease of social transmission caused by high frequency consumption of BFS and to build a mathematical model of epidemiological type to study the childhood obesity evolution. Once the mathematical model is built and most of the parameters are obtained using several surveys of the Spanish region of Valencia, we find the best estimated values only for the parameters $\beta$ and $k$ fitting the model in order to minimize the mean square error between the model and the real data in the year 2002.

The simulations carried out with this model indicated an increasing trend in the 3–5 years old overweight and obese populations in the next years. Based on the sensitivity analysis, we find that the parameters $\beta$, $\gamma_L$ and $k$ are the most important in the proposed model. Hence, childhood obesity should be faced through public health programs in order to reduce the values of these parameters. To be precise, the transmission rate due to social pressure on BFS consumption measured by $\beta$ (family, friends, marketing, TV), and the frequency of BFS consumption measured by $\gamma_L$ and $\gamma_S$ should be targeted. Some possible general strategies are suggested.

Finally, as we noted in the introduction, these kinds of models works well over a short time span, since as we said it is difficult to believe that parameters remain constant for long time periods and it is more suitable to use varying parameters that can be modeled through time-dependent parameters.

References


