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Childhood Obesity in the Region of Valencia, Spain: Evolution and Prevention Strategies

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In this study there are two main aims. The first one is to model and predict the incidence of obesity in the 3-5 years old population in the coming years in the region of Valencia, Spain. The second aim of this research is to use the constructed model to analyze the possible strategies in order to prevent the spread of obesity. At first a logistic regression statistical analysis of sociocultural variables of children with weight problems is performed. The result of this logistic regression statistical analysis suggests that sociocultural factors in the region of Valencia where the child grows up influence the development of overweight or obesity. Thus, this result permit to consider the hypothesis that the obesity is a health concern that depends on sociocultural factors and it is transmitted by the spread of unhealthy eating habits. In this way the hypothesis permits to construct a mathematical epidemiological type model in order to forecast obesity prevalence and to understand the mechanisms of the obesity spread. Using the constructed epidemiological mathematical model it is predicted that in the coming years, an increasing trend in the overweight and obese 3-5 years old children in the region of Valencia is predicted if the actual parameters of the mathematical model stay invariant. In addition, the different numerical simulations performed with the constructed epidemiological mathematical model indicate that the most likely successful strategy to tackle the obesity is through educational campaigns about the risk of unhealthy eating habits. This study shows how an epidemiological type mathematical model is an interesting tool to study the obesity transmissions dynamics in the population. It is useful to predict the prevalence of the obesity and study strategies to tackle it.

Key words: Modelling, obesity factors, prediction, overweight population, epidemiological mathematical type model

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INTRODUCTION

Obesity is a health concern of complex treatment and difficult monitoring. This difficulty increases when the childhood population is considered, since the control measures often do not specifically target this population. Obesity is growing at a significant rate in both developed and developing countries and it is becoming a serious health concern not only from the individual health point of view but also from the public socioeconomic one.

In the adult population more than 50% are affected by overweight and obesity. In the childhood and adolescence, the numbers are around 25% (Lobstein and Frelut, 2003). The age group with greatest increase in the prevalence of obesity is that between 6 and 12 years old with a disturbing 16.1% (Serra *et al*., 2003). The problem is present also in early years, although here data are less known. However, it is precisely in the early childhood when this fact is more important, since this is when eating habits are established and remain until adulthood (Krebs and Jacobson, 2003).

Several studies correlate children and adult obesity at the point that children obesity is a powerful predictor of adult age obesity (Krebs and Jacobson, 2003; Dietz, 1998; Whitaker *et al*., 1997). For instance, an obese 4 years old child has a 20% increased probability to become an obese adult (Krebs and Jacobson, 2003). 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 (Heindel, 2003).

In this study, it is studied the evolution of the 3-5 years old overweight and obesity population of the region of Valencia, Spain, until the year 2010. The result of alogistic regression statistical analysis suggests that sociocultural factors in the region of Valencia where the child grows up influence the development of overweight or obesity. Thus, this result permit to consider the hypothesis that the obesity is a health concern that depends on sociocultural factors and it is transmitted by the spread of unhealthy eating habits. This fact permits to study the spread of the obesity using an epidemiological type mathematical model based on ordinary differential equations. It is important to notice that, based on statistical analysis of database of 1,187 children belonging to different families of the region of Valencia, the problems of overweight and obesity in Valencian children between 3-5 years are related to the high consumption of bakery snacks, fried food and sugared soft drinks (BFS) (Jódar *et al.,* 2006, 2008). Therefore, through this study this fact is taken into account.

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

MATERIALS AND METHODS

The region of Valencia is located in eastern Mediterranean Spain, composed by three Provinces, Castellón (north), Alicante (south) and Valencia (middle). First, a binary logistic regression statistical analysis to identify possible sociocultural predictive factors of obesity is developed (Hair *et al*., 1989). This analysis is carried out using the data set from the region of Valencia. This database set contains data of 1,187 boys and girls, between 3-5 years old.

The dependent variable of the model is binary, indicating normal weight (0) or obese and overweight (1). The possible predictive variables used in the binary logistic regression model are shown in Table 1. The level of significance used is 5% (*p-value<0.05). That is, a p-value less than 0.05 indicate a significant relation between the dependent variable and each of the possible predictive variables. Otherwise, a p-value greater than or equal to 0.05 indicates an absence of significant relation.

The results of this statistical analysis together with study earlier reported by Christakis and Fowler (2007), Jódar *et al.* (2006) and Wang (2001), permit us to consider childhood obesity as a health concern with a clear sociocultural component, which is propagated by social contact between individuals. That is, a health concern caused by unhealthy eating habits transmitted from family to family. This allows us to develop an epidemiological type mathematical model of ordinary differential equations.

For the model building, the childhood population is divided into six subpopulations: Children with normal weight (N(t)), those with normal weight and unhealthy eating habits, named latent (L(t)), overweight children (S(t)), obese children (O(t)), overweight children on diet (Ds(t)) and obese children on diet (Do(t)).

Table 1: Possible predictive variables used in the logistic regression

Sex	Age	Educational level of parents	Province
Male	3	Illiterate	Alicante
Female*	4	Primary education	Castellón
	5*	Secondary education	Valencia*
		Higher education*	

* Reference category considered for each variable

A child is considered normal weight if his BMI is in the 85th percentile for his age, overweight if the BMI is between 85th and 95th and obese if BMI is the 95th percentile (Bautista-Castaño *et al*., 2004). Moreover we consider the following assumptions, some based on statistical analysis of data:

- The overweight and obesity in Valencian children between 3 to 5 years is due to the consumption of bakery snacks, fried food and sugared soft drinks (BFS) (Jódar *et al*., 2006)
- For children of this age group, it is considered that the eating habits of the parents determine those of the children. That is, if the parents consume BFS food group, the children consume too and if the parents are on diet also the children are on diet (Carter *et al*., 1993)
- We assume a homogeneous mixing population; that is, all family units have an equal probability of interrelation (Murray, 2003). It is assumed that the social contacts are random and that unhealthy eating habits and thereby obesity is acquired through this contact

Assuming that the high consumption of BFS increases the children BMI, the transition between the different subpopulations is determined as follows:

- Once a child begins the high consumption of BFS he is considered addicted to unhealthy eating habits and passes from N(t) to L(t) and begins the progression to overweight, S(t). If the child continues high BFS consumption, he will become obese, O(t). If a child in any of these two latter subpopulations stops high consumption of BFS, then the child moves to diet classes Ds(t) or Do(t) subpopulation, respectively
- A child in the Ds(t) subpopulation will become member of class N(t) if he reduces his BMI to the normal limits. If the child resumes high consumption of BFS, he will become S(t). Likewise, a child in the Do(t) subpopulation will become member of class Ds(t) if stops high consumption of BFS. As well, a child in the Do(t) subpopulation, resumes high consumption of BFS , will return to the O(t) subpopulation
- We assume that the 3 year old newly recruited children are normal weight

With these assumptions, the mathematical model that allows the study of the dynamics of childhood obesity in Valencian children with respect to time t in weeks is given by a system of nonlinear ordinary differential equations. The proposed mathematical model can be represented in Fig. 1, where the boxes are the defined subpopulations and the arrows the respective transitions among them.

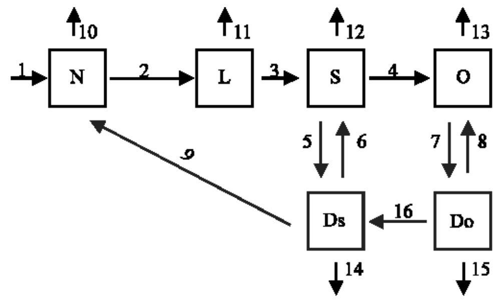

Fig. 1: Flow diagram of the population in the mathematical model. Children transit between the subpopulations N, L, S, O, Ds and Do. Labels: 1 (μ), 2 (β N (L+S+O)), 3 (γ_LL) 4 (γ_SS), 5 (α S), 6(φ Ds), 7 (σ O), 8 (δ Do), 9 (ε Ds), 10 (μ N), 11 (μ L), 12 (μ S), 13 (μ O), 14 (μ Ds), 15 (μ Do) and 16 (γ_DDo)

The parameters of the model are:

- β, transmission rate to BFS consumption due to social pressure (family, friends, marketing, TV, etc.)
- μ, inversely proportional to time spent by a child in the 3-5 year old population
- γ_L, rate at which a latent individual moves to the overweight subpopulation
- γ_S, rate at which an overweight individual becomes an obese individual by continuous high consumption of BFS
- ε, rate at which an overweight individual on diet becomes a normal weight individual
- α, rate at which an overweight individual stops or reduces BFS consumption, i.e., the individual is on diet
- φ, rate at which an overweight individual on diet fails, i.e., the individual resumes a high BFS consumption
- σ, rate at which an obese individual stops or reduces BFS consumption
- δ, rate at which an obese individual on diet fails
- γ_D, rate at which an obese individual on diet becomes an overweight individual on diet

The estimation of the parameters in the epidemiological mathematical model is based on several sources (Fullana *et al*., 2004; Jódar *et al*., 2006;

González-Parra *et al*., 2007). The estimated parameter values and their means are the following:

- $\mu = 1/156$ 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}; it is estimated using the weekly growth of the average weight of a child in the region of Valencia (Fullana *et al*., 2004). This rate shows how many weeks take a latent child (normal weight) to become an overweight individual by continuous high consumption of BFS
- $\gamma_S = k\times0.0089$ weeks^{-1}; this parameter is considered proportional to γ_L because it is describing a phenomenon of the same characteristics as γ_L with an increasing difficulty to become obese based on two main facts; one is that once a individual is overweight he/she realizes more his/her overweight problem and takes more care about his nutrition and the second fact is that the basal metabolic rate increases with the weight, therefore the body of heavier people consume more calories (Ravussin *et al*., 1982; De Luis *et al*., 2006)
- $\varepsilon = 0.0089\times0.312$ weeks^{-1}; a child with BFS consumption takes $1/\gamma_L$ weeks to transit from normal weight to overweight and then if he/she gives up BFS consumption, he/she will take $1/\gamma_L$ weeks multiplied by the success rate to come back to normal weight. It is known that the fraction of persons who recover their normal weight after dieting is 31.2% (Jódar *et al*., 2008; González-Parra *et al*., 2007)
- $\alpha = 1/(1.56\times52)\times0.33$ weeks^{-1}; this parameter is estimated by considering the time that a individual ends one diet and begins another, 1.56×52 weeks and the percentage of overweight people who begin dieting, 33% (Jódar *et al*., 2008; González-Parra *et al*., 2007)
- $\varphi = (1-0.312)\times1/5.4$ weeks^{-1}; this parameter is estimated considering the mean time a individual is dieting, 5.4 weeks and the percentage of dieting, overweight people who abandon the diet (Jódar *et al*., 2008; González-Parra *et al*., 2007)
- $\sigma = 1/(1.56\times52)\times0.36$ weeks^{-1}; this parameter is estimated by considering the time that a individual ends a diet and begins another, 1.56×52 weeks and the percentage of obese people who begin dieting, 36% (Jódar *et al*., 2008; González-Parra *et al*., 2007)
- $\delta = (1-0.137)\times1/5.4$ weeks^{-1}; this parameter is estimated considering the mean time an individual is dieting, 5.4 weeks and the percentage of obese people on diet who abandon the diet (Jódar *et al*., 2008; González-Parra *et al*., 2007)
- $\gamma_D = \gamma_S\times0.146$ weeks^{-1}; this parameter is estimated based on γ_S and the percentage of dieting obese individuals who achieve a normal weight (Jódar *et al*., 2008; González-Parra *et al*., 2007)
- $\beta = 0.02$ weeks^{-1}, $k = 0.32584$ weeks^{-1}; these values are estimated by adjusting the mathematical model based on the values of subpopulations N(t), L(t), S(t), O(t), Ds(t) and Do(t) in 1999 and 2002 (Jódar *et al*., 2008)

RESULTS

Predictive factors analysis: In this research we study the predictive factors of obesity in 3-5 years old population of the region of Valencia using a logistic regression analysis. The analysis is performed using the database of 1,187 children belonging to different families from Valencia. The result of the logistic regression model reveals that the combination of the parents study level and the residence have influence on the problems of overweight and obesity in the children. The binary logistic regression results are shown in Table 2.

Consideration of the p-values indicates that educational level and place of residence influence excess weight of Valencian children between 3-5 years old. It can be observed that the risk of excess weight is increased in children residing in Alicante with parents with no higher education level. In these cases, the p-values associated with the wald contrast are less than 0.05. Likewise, it is observed that age and gender of the children do not significantly influence overweight problems. In both cases the p-value is greater than 0.05. Thus, the logistic regression analysis suggests that sociocultural factors in the region where the child grows up influence the development of overweight or obesity. This finding is also emphasized in other research (Wang, 2001; Welsh *et al*., 2005).

Table 2: Results of the logistic regression

Variables	β	Wald contrast	p-value
Educational level×		13.71	*0.01
Place of residence			
Illiterate×Castellón	21.81	0.00	1
Primary×Alicante	0.53	8.81	*0.00
Primary×Castellón	-0.11	0.11	0.73
Secondary×Alicante	0.62	5.94	*0.01
Secondary	-0.10	0.06	0.80
Age		0.28	0.86
3 year	0.09	0.26	0.60
4 year	0.07	0.15	0.69
Sex (male)	0.03	0.06	0.79
Constant	-0.73	17.71	0.00

The β column measures influence of each independent variable on dependent variable (overweight and obesity). The p-value column shows the variables with influence on excess weight (*$p<0.05$)

Epidemiological mathematical model results: The earlier multivariate statistical result and other studies by Christakis and Fowler (2007), Jódar *et al*. (2006) and Wang (2001) support the idea that obesity in Valencian children of 3-5 years old is a health concern caused by unhealthy eating habits acquired by contact from family to family. On this fact is based the epidemiological type model we have described to predict the future trends in overweight and obesity. In Fig. 2 it is shown the predictions until 2010 regarding overweight and obese subpopulations.

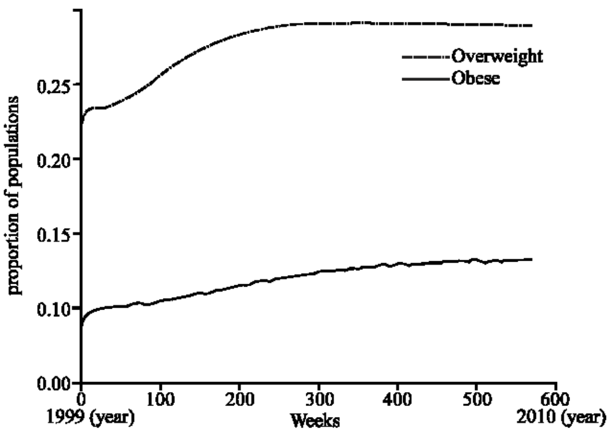

Fig. 2: Evolution of overweight and obese subpopulations of 3-5 years old children in the region of Valencia, 1999-2010 using numerical simulation of the epidemiological mathematical model. The model predicts a slight but sustained increase of overweight and obese populations. This result is obtained using parameter values estimated form real population data

Table 3: Evolution of the proportion of overweight and obese subpopulations using the epidemiological mathematical model. The model predicts that the 26.34% and the 11.48 of the 3-5 years old children in the region of Valencia will be overweight and obese, respectively, in 2010. The prediction is a slight but sustained increase of overweight and obese populations for year 2010

Year	Percentage of childhood population between 3-5 years overweight	Percentage of childhood population between 3-5 years obese
1999	20.25	5.15
2000	22.78	9.87
2001	23.80	9.98
2002	24.92	10.19
2003	25.69	10.47
2004	26.12	10.73
2005	26.32	10.96
2006	26.39	11.14
2007	26.40	11.28
2008	26.39	11.37
2009	26.37	11.44
2010	26.34	11.48

In well accordance with the tendency observed in other countries (Lobstein and Frelut, 2003; Wang and Lobstein, 2006), it is predicted a slight increase in overweight and obesity in the Valencian population between 3 to 5 years old. This fact can also be noted in Table 3. As it can be seen, for the year 2010 it is predicted that 26.34% of the Valencian population of 3-5 years old will be overweight and 11.48% will be obese.

DISCUSSION

This study presents a forecast for 2010 in regard to overweight and obesity in the 3-5 years old population in the region of Valencia. Additionally, we present simulations of the model varying some of the most relevant parameters. The goal is to observe how these changes affect the final prediction.

The obesity treatment effect: Analysis of the incidence of obesity and overweight in 2010 in case that the number of children that transit to diet increase, i.e., the rate a child stops or reduces BFS consumption increases (α and σ increases).

The aforementioned predictions for 2010 have been computed considering that the parameters α y σ are equal to 0.004, i.e., considering that every 250 weeks, one child with overweight or obese decreases the high consumption of BFS. Let us show what happens if we increase the number of children with overweight or obese on diet.

A prediction for 2010 has been computed simulating that, starting in 2007, the transit to the diet stage gradually increases from one child every 250 weeks ($\alpha = \sigma = 0.0044379$) to one child every 100 weeks. In order to achieve this goal, a simulation is carried out replacing parameters α and σ with the following function:

$$\alpha(t) = \sigma(t) = 0.0044379 + \frac{0.006}{1 + \mathrm{Exp}(-0.25 \times (t - 364) + 0.25 \times 25)}$$

In this particular case the prediction for 2010 is that 25% of the 3-5 years old Valencia children population will present overweight and 10.7% obesity. As it can be seen in Fig. 3, the prevalence of obesity and overweight is reduced due to the treatment effect.

The obesity prevention effect: Analysis of the incidence of obesity and overweight in 2010 in case that the number of children who acquired high BFS consumption habit decreases, i.e., the transmission rate to BFS consumption due to social pressure decreases (β decreases).

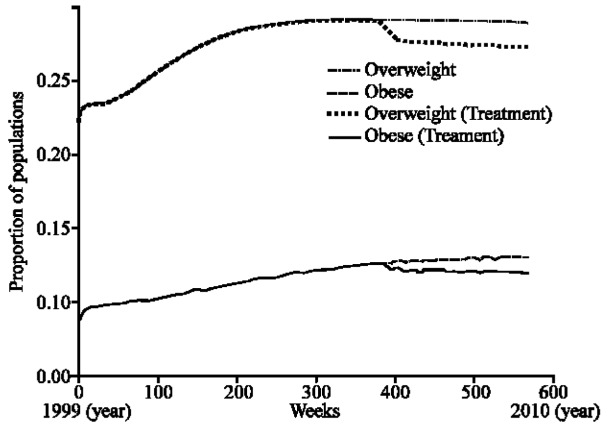

Fig. 3: Evolution of overweight and obese subpopulations of 3-5 years old children in the region of Valencia, if starting in 2007, the transit to the diet stage is gradually increased from one child every 250 weeks to one child every 100 weeks. In this particular case the prediction for 2010 is that 25% of the 3-5 years old Valencia children population will present overweight and 10.7% obesity. Thus, the prevalence of obesity and overweight is reduced due to the treatment effect

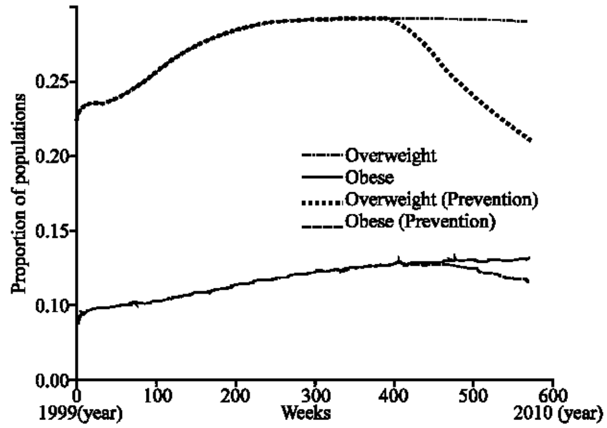

Fig. 4: Evolution of overweight and obese subpopulations of 3-5 years old children in the region of Valencia, if starting in 2007, the transit to BFS consumption is gradually decreased from one child every 50 weeks to one child every 100 weeks. In this case the prediction for 2010 is that 19% of the 3-5 years old Valencian population will present overweight and 10% obesity. The mathematical model shows that the prevalence of obesity and overweight is reduced due to the prevention effect

Predictions for 2010 have been computed simulating that starting in 2007, the transit to high consumption of BFS gradually decreases from one child every 50 weeks (β =0.02) to one child every 100 weeks. In order to achieve this goal, a simulation is carried out replacing parameter β with the following function:

$$ß(t) = 0.02 - \frac{0.01}{1 + \text{Exp}(-0.25 \times (t-364) + 0.25 \times 25)}$$

In this case the prediction for 2010 is that 19% of the 3-5 years old Valencian population will present overweight and 10% obesity. As it can be observed in Fig. 4, the prevalence of obesity and overweight is reduced due to the prevention effect.

Taking into account that the parameters variation in treatment case is greater than prevention case, if we compare both simulations, we can say that the prevention strategy is better than the treatment one because the reduction of the overweight and obesity prevalence is much greater. Therefore, to reduce the incidence of childhood obesity in the Valencian population of 3 to 5 years old in 2010, it would be more beneficial to implement campaigns that would warn about the dangers of high consumption of BFS than putting children on diet once they have excess weight.

CONCLUSION

In conclusion, in this study we present a mathematical model that analysis the dynamic evolution of obesity in the Valencian population of 3 to 5 years old in the coming years. The statistical analysis of sociocultural variables of children with weight problems reveals that obesity is a health concern that depends on sociocultural factors and may be considered transmitted by the spread of unhealthy eating habits, as have been suggested by Christakis and Fowler (2007), Jódar *et al.* (2006) and Wang (2001). This result permitted us to construct a mathematical epidemiological type model in order to predict obesity prevalence and to understand the mechanisms of the obesity spread. In the coming years, an increasing trend in the overweight and obese 3-5 years old children in the region of Valencia is predicted if the actual parameters stay invariable. Furthermore, the simulations suggest that the most likely successful strategy to tackle the obesity is through educational campaigns about the risk of unhealthy eating habits as was suggested by Jódar *et al.* (2006, 2008).

Finally, it is important to notice that the mathematical model permits a better understanding of the mechanisms within the obesity spread in the children population. In addition, this type of models work well over a short time span, since it is difficult that social environment and therefore parameters of the model remain constant over more than two or three decades. In order to consider longer scale predictions it would be necessary to present a model with time-varying parameters as we have done in this section with the parameters β, α y σ, as have been mentioned by Jódar *et al.* (2008). Also, it is important to remark that the output depends on the reliability and validity of the data and assumptions. However, the general process developed here gives a guide to future studies in other diseases affecting populations. Future studies can include the investigation of other age groups in order to observe the obesity predictive factors and using mathematical models provide future predictions for overweight and obese populations.

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