REVIEW

Child obesity can be better reduced through vigorous physical activity rather than through energy intake restriction

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ABSTRACT

Until gene therapy allows to detect and manipulate those genes involved in excessive accumulation of fat in children and adolescents, prevention seems to be the only realistic solution for the increasing prevalence of childhood obesity. Traditional approaches include energy intake restrictions and some extra energy expenditure. However, this restricting energy intake might not be the best option for growing youths who need to be in a positive energy balance in order to ingest sufficient amounts of the nutrients needed for optimal growth. Physical inactivity is worldwide one of the biggest problems of public health. In Spain, approximately 66% of boys and girls under 15 years do not perform or rarely perform any kind of physical activity during their leisure free time. Vigorous physical activity (VPA), without restriction of energy intake, can produce favourable effects on body composition (reduction of total and visceral fat mass, and increased bone mass…), fitness levels and other cardio-metabolic risk factors. Moreover, VPA is often accompanied by increases, not decreases, in dietary energy intake. It appears that exercise doses of 155-180 minutes per week at moderate to high-intensity are effective in improving the body composition and fitness of overweight youths. For youths who are not overweight prior to the intervention, larger doses of approximately 300 minutes per week may be needed to prevent excess accretion of fat. Data presented in this review suggests that adding 2-3 hours per week of sport activities to the compulsory physical education courses seems to be effective in preventing excessive fat mass accumulation at the same time that it facilitates lean mass accretion and improves physical fitness in growing youths. The battle against childhood obesity should focus on changing the lifestyles of children and youths. Lifestyle interventions are more likely to be successful if they emphasize reduction of time devoted to sedentary activities and increased participation in daily VPA, rather than restriction of dietary energy intake.

KEY WORDS: Exercise. Sedentary. Energy balance. Health.

RESUMEN

Hasta que los avances en genética permitan detectar y manipular los genes implicados en el alarmante aumento de la prevalencia de obesidad en niños y jóvenes, la única solución realista al problema de la obesidad infantil es la prevención. Hasta el momento, los intentos por reducir el alarmante incremento de obesidad infantil y juvenil siguen el modelo tradicional de reducción de la ingesta energética y aumento de los niveles de actividad física. No obstante, dicho modelo puede no ser el método más adecuado para poner en práctica con niños y niñas en período de crecimiento y desarrollo, dado que éstos requieren un balance energético positivo con el fin de obtener el aporte necesario de nutrientes para el adecuado crecimiento. La inactividad física es actualmente uno de los principales problemas de salud pública a escala mundial. En España, el 66% de los niños y niñas de hasta 15 años afirman no realizar o realizar de forma esporádica alguna actividad física a lo largo de la semana durante su tiempo libre. En niños y niñas con sobrepeso la actividad física vigorosa (AFV) sin restricción calórica produce efectos positivos sobre la composición corporal, y se observa que a través de su práctica se consiguen cambios favorables en el porcentaje de grasa corporal y de grasa visceral, en la densidad ósea, en el fitness cardiovascular y en otros factores de riesgo cardiometabólicos, que a menudo se acompañan de aumentos, no de reducciones, en la ingesta energética. Por tanto, parece que las actuales recomendaciones de actividad física en niños y jóvenes (150-180 min/semana a moderada-alta intensidad) pueden ser efectivos para la mejora de la composición corporal y el fitness en niños y en jóvenes con sobrepeso. Para los que todavía no presentan sobrepeso pueden ser necesarias cantidades incluso mayores (alrededor de 300 min/semana) para prevenir el exceso de acumulación de grasa. Los resultados de los trabajos incluidos en esta revisión muestran que añadir 2-3 h a la semana de práctica deportiva extraescolar durante el crecimiento permite atenuar la acumulación de masa grasa, incrementa las ganancias de masa muscular y de masa ósea, al mismo tiempo que mejora la condición física de los niños y de los jóvenes. La batalla contra la obesidad infantil debería centrarse en modificar los estilos de vida de los niños y jóvenes, no sólo desde el punto de vista nutricional, sino preferiblemente mediante el aumento en los niveles de AFV y la reducción del número de horas dedicadas a la realización de actividades sedentarias.

PALABRAS CLAVE: Ejercicio. Sedentarismo. Balance energético. Salud.

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The epidemiology of childhood obesity

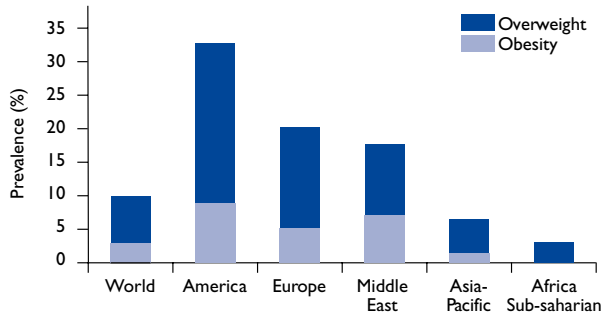
Obesity in children and adolescents is nowadays one of the main worldwide health problems. It is estimated that approximately 10% of schoolchildren in the world have an excess of body fat and therefore a higher risk of developing chronic diseases[1]. Of these overweight children, one quarter are obese and many of them have multiple risk factors associated with the development of type 2 diabetes, cardio-vascular diseases and a large variety of comorbidities before or during early adult age (fig. 1).

The prevalence of weight problems and obesity is higher in countries that are more developed, but is growing significantly in most of the world. In industrialised countries, children from the lowest social-economic groups have the highest risk. In contrast, in developing countries obesity is greater among groups with higher incomes[2]. Recent studies show that the prevalence of schoolchildren who are overweight is already reaching 35% in some parts of Europe, while the incidence of new cases is growing year after year in several countries[3]. In the medium to long-term, obesity in children and adolescents is on the way to causing a real crisis in public health[1]. For example, data from the health services of some countries show that in the 1990s in the USA and Brazil the number of overweight children rose by 0.5% per year. In Canada, Australia and some parts of Europe, this increase was even higher, exceeding 1% annually[4-6].

In Europe, over the last two or three decades, despite the fact that complex patterns have been observed in prevalences and trends, such as age, sex and geographic regions which vary over time, children from the north of Europe (with the exception of the United Kingdom) show prevalence rates of between 10-20%, while those from the south of Europe show a prevalence of between 20-35%[7]. The reasons for this difference between the north and the south are not fully clear[1].

In Spain, the last two National Public Health Surveys (2003 and 2006)[8,9] carried out by the Ministry of Health and Consumer Affairs have included figures for children and adolescents (2-17 years) that stand at between 18.2-18.7% and 8.5-8.9% for overweight and obesity levels respectively. However, the data that appear published in various research studies show a reality that is much more worrying. The enKid study (1998-2000)[10] that included a representative sample of the Spanish child and adolescent population, shows the prevalence of overweight and obese male children and adolescents from 2-17 years as reaching 31.2% and 16.6% respectively, using reference values from national tables for their calculation[11]. According to this work, and by analysing

Figure 1 Prevalence of obesity and overweight levels in schoolchildren from different areas of the world. Overweight and obesity are defined according to the criteria of the IOTF. Children between 5-17 years. Based on studies carried out after 1990. Adapted from Lobstein et al[1].



geographic regions, it can be seen that the areas located farther south in Spain showed higher figures (The Canary Islands, and Andalusia 32.8% and 29.4%, respectively) compared to areas located farther north (the northeast and north 9.8% and 12.3% respectively).

The Spanish Society for the Study of Obesity (SEEDO) published data in 2005[12] regarding overweight and obesity levels in Spain using data from the enKid study, and at the same time adding calculations related to international reference values[13]. The results showed how, by using the reference values proposed by the International Obesity Task Force (IOTF), the overweight and obesity figures were, for Spanish children and adolescents between 2 and 17 years reached 35.1% and 10.4% respectively. However, more recent data show that during recent years even those autonomous communities that seemed to be the least affected (the north) have seen their figures rise alarmingly until almost reaching the same levels as the others[14]. In Spain, the GENUD Group (Growth, Exercise, Nutrition and Development) has been one of the most prolific groups for over a decade in the publication of research studies regarding child and adolescent obesity, which attempt to analyse and study not only its progress but also its causes and the determining factors in its development[14-26].

In 1999 a committee of experts from the IOTF decided that despite the fact that the body mass index (BMI) was not the ideal measurement for measuring adiposity, it had been validated against other more direct measurements of adiposity

and therefore could be used to define overweight and obesity levels in adolescent boys[27]. As it was not clear at what BMI level health risks rose for children, cut-off points were used that were statistically equivalent to the cut-off points used in overweight (25 kg/m^2) and obese (30 kg/m^2) adults. To do this, data regarding 6 different reference populations were used (Great Britain, Brazil, Holland, Hong Kong, Singapore and the USA). Using these data, Cole et al[13] derived the curves with their corresponding percentiles that pass through the 25 and 30 kg/m^2 points at 18 years. This resulted in specific cut-off points for the age and sex that define overweight and obesity levels in children and adolescents.

The tables recommended by Cole et al are useful for epidemiological research in which children are classified as not overweight, overweight or obese by using a simple standard tool that as a last resort enables children from populations of any part of the world to be compared. However, one of the problems of using the BMI based on sex and age tables is that the degree of sexual maturity of the subjects is not taken into account. The BMI of children can rise when their muscle mass increases under the influence of testosterone, without that being confused with a gain in weight.

Programmes to prevent obesity in children begin by identifying those children at high risk. The principal objective of defining overweight and obesity is to forecast risks to health and to be able to compare different types of populations. For practical reasons, until now definitions have been made based on anthropometry, waist circumference and BMI. These are the most used methods both in clinical studies and in population studies. These methods, despite having some advantages (easy to apply, practical and economical), do not offer the possibilities and precision of more direct methods as could be the case with dual x-ray absorciometry (DXA).

Genetic factors in child obesity

Despite the fact that the genetic component is an important factor when explaining and understanding obesity, the very fast changes in the number of obese people within a relatively stable population indicate that genetic factors are not the principal cause of this rapid increase[1]. The influence of surroundings is clearly illustrated when studying subjects that are moved or emigrate to industrialised countries and that develop higher obesity rates in their new locations than in their respective countries of origin[28,29].

With the aim of being able to analyse the way in which subjects with the same genetic component respond to a standardised change in diet, several studies have been carried out using homozygotic twins. In these, a clear genetic predisposition to gain weight was observed in response to over-eating, demonstrated when one of the twins was subjected to an energy intake greater than his or her needs (1000 Kcal/daily extra)[30]. Furthermore, the response to an energy deficit was also observed as potentially determined by genetic factors[30].

Therefore, this demonstrates that for the majority of children the genes to develop overweight conditions express themselves where the environment so permits and favours said expression. A genetic predisposition to gain weight is a significant element in the equation, but its importance should be seen from another perspective: genes that are predisposed to obesity are normal and there is only a small proportion of children capable of resisting weight gain in a permissive or "obesogenic" environment.

Nowadays, several studies are trying to identify the genes and their mutations that are responsible for these effects in children. Recently, studies by Ukkola and Bouchard[31] have managed to identify various genes that play an important role in the response to over-eating. However, the study of interaction between genes and the environment and its effect on adiposity requires the taking into account of factors that could potentially modify the energy balance. For example, variations in levels of physical activity and in the fat content of diets are associated with fluctuations in body fat mass. However, other factors like the variation of carbohydrates in diets, the intake of certain micronutrients like calcium, the content of spices in diets that may contain agents like capsaicin or organochlorates, eating behaviour patterns, alcohol intake and probably many others must also be taken into account.

The catalogue of potential candidate genes for varying fat reserves is increasingly large[32] and will probably continue to grow in the future. This means that it will be increasingly difficult to define relationships between genotypes and the environment. Recently, one of the genes that has been observed that could be a major candidate and whose possible implications for fat mass gain with age are being studied is the glucocorticoid receptor gene[30]. If later studies confirm it, the study of the polymorphism of said gene could be useful in the estimation of the risk of fat mass gain with age or under various energy balance conditions that characterise certain individuals. The leptin gene is also one of the potential target genes in the study of obesity, since it has recently been confirmed that leptin receptors and their signal could be smaller in obese people[33].

Physical inactivity: one of the principal health problems of the XXI Century

In the majority of industrialised societies, changes that take place in the immediate surroundings of children have been described in a report by the World Health Organisation (WHO) for chronic diseases both in this age group and in adults[34]. These changes include transformations in eating behaviour (an increase in the consumption of "high density" energy food that is rich in fat, particularly saturated fats that are low in unrefined carbohydrates) combined with a sedentary lifestyle (habitual use of motor transport, the availability of electrical appliances/equipment that reduce housework, a decrease in manual and physical tasks at work and free time activities that do not require energy expenditure). As a consequence of the latter, physical inactivity is nowadays considered by some of the most prestigious researchers of the health and sport sciences field as one of the principal, if not the principal public health problem of the XXI Century[35].

In a longitudinal study carried out on more than 50,000 adults, the "attributable fraction" to the low cardiovascular physical condition (16-17%) was the highest of all the risk factors included in the study (obesity, smoking, high blood pressure, cholesterol and diabetes). These data indicate that of each 100 dead people, 16 or 17 could have avoided death if this specific risk factor, physical inactivity, had not been present[35]. In Spain, according to the latest published National Health Survey[9], 64% of boys and 68% of girls of between 0-15 years do not do any kind of physical activity in their free time, or do so sporadically. Furthermore, data from the enKid study show similar figures when confirming that in children and adolescents of between 2 and 24 years, more than 60% of the males do not do any exercise or do exercise less than twice a week, while this percentage exceeds 75% in females[36].

Despite their natural tendency towards movement, little by little, children are becoming less active. In fact, some studies indicate that if we compare today's children with those from recent decades (50 years ago), on average they currently expend almost 600 Kcal less daily[37]. In children and adolescents, as well as the added risk of acquiring inadvisable lifestyle habits that could be maintained for the rest of their lives, physical inactivity could have other additional implications insofar as it takes place at the time when children and adolescents are growing and developing into adults.

Until now, the paradigm most normally used in the paediatric field with obese children has come from the adaptation of the model used with adults. On one hand this consists in the reduction of energy intake and also in the inclusion of a certain level of physical exercise in daily routines, which in theory should cause a negative energy balance and finally cause weight reduction. The corollary of this model is that adolescents that become obese eat more than their peers. However, recent data suggest that perhaps this paradigm is not the most suitable in the prevention of child obesity[38].

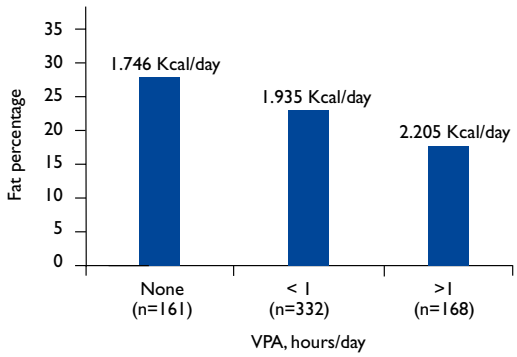
Using this same model, which assumes that children that intake more energy (especially that from fats) should accumulate a higher percentage of body fat (BF%), as would happen with those that do less vigorous and/or moderate exercise, the Dr Gutin group[39] has recently published an illustrative work where in a large group of adolescents (n = 661), and using precise evaluation methods of body composition, more specifically of fat mass and visceral mass (through DXA and magnetic resonance), it is observed that strangely the BF% that had increased when finishing the study was related on one hand to low intake levels and also to low levels of physical exercise, that is, those adolescents that during the term of the study did more vigorous physical activity (VPA) and had a higher intake of energy were the ones that accumulated less fat in their bodies. Furthermore, when the adolescents are grouped into different categories depending on the VPA that they had done, those that had done no VPA showed a BF% of 28.6% and had an intake of 1746 Kcal/day, and those that did at least 1 hr/day of VPA had a BF% of 19.4% and had an intake of 2205 Kcal/day (fig. 2).

Also, other studies show that the most active adolescents usually accumulate less fat and intake more energy than non-active ones[40,41]. It is necessary to indicate that in the aforementioned study, the low levels of BF% were associated with a greater amount of VPA but not with moderate physical activity (MPA). Moderate physical activity was understood to include walking, while VPA was understood to include practising sport, games, dancing, and other activities that probably require a higher mechanical load on musculoskeletal tissues.

Therefore, the main conclusion that we can draw from these studies is that children that are in a growing phase need a positive energy balance in order to obtain the nutrients needed for optimal development and growth. Some of these nutrients will be used in the development of lean mass and/or bone mass and others will be used in adipose tissue, the proportion used in each of these areas being defined by the adiposity level of each child.

Recent studies on bone development clearly show that mechanical stimulation of tissues causes stem cells to divide

Figure 2 Fat percentage of 661 adolescents compared to the hours per day of vigorous physical activity (VPA), adjusted by age, race ans sex ($p < 0.01$ for differences between groups). After making adjustments for the differences in energy intake (Kcal/day), the influence of VPA was still significant ($p = 0.024$). The average energy intake (Kcal/day) of each group is shown above the bars. Adapted from Stallmann-Jorgensen et al[39].



themselves into bone and muscular cells before fat cells[42,43]. Given that VPA supplies said stimulation to tissues, it would be more appropriate to consider the prevention of child and adolescent obesity in accordance with the correct amount of VPA instead of doing so through a reduction in energy intake. These results also indicate that, more than ever, that it is necessary to use body composition indices that are not limited to size and weight (BMI), given that VPA can reduce fat mass at the same time as increasing muscular/bone mass and therefore leading children to have a healthier body composition without this necessarily implying a reduction in weight and/or changing their BMI[44].

Until now, a large amount of research studies have been carried out where they have attempted to analyse the effect of VPA without calorific restrictions has on the body composition of obese children. In all of these studies, it has been observed that it is possible to achieve favourable changes in the BF%, in the amount of visceral fat, in bone density, in cardiovascular fitness and in other cardio-metabolic risk factors that have often been accompanied by increases in energy intake[45-48].

It is evident that VPA is not the only potentially effective solution that exists, it is one more solution among the various efforts that must be made in order to reduce child and adolescent obesity. Other potential objectives that are related to child and/or adolescent behaviour are the hours per day spent watching television and sat in front of computers, the amount of sugary sweets and snacks consumed, dietary composition and eating habits[49,50].

Therefore, the main message is that a change in the model for treating child and adolescent obesity can work successfully and effectively with intervention programmes that attempt to give our children and adolescents a healthier body composition. Eating complete diets that are Rich in nutrients is the best way for adolescents to obtain the nutrients needed for the development of their muscular or bone mass. In contrast, limiting energy intake could be counterproductive for the biological demands that growth requires. Therefore, if we want results to be more satisfactory we must place more emphasis on the amount of VPA performed and not on the reduction of energy intake in growing children.

The importance of physical activity in out-of-school timetables

Studies carried out by our research group[14,51-56] have concluded that the practice of at least 2-3 hours of out-of-school physical activity a week has positive effects on body composition and appears to be sufficient for the correct development of adipose tissue and to prevent the excessive accumulation of fat mass in the extremities and torsos of prepubescent children. Also, with the objective of discovering which children are at risk of obesity, it has been observed that through the simple combination of anthropometric measurements and the 30 m sprint test, it is possible to accurately estimate the fat mass and fat percentage in prepubescent children[52].

The continual practice of 3 years of out-of-school physical activity appears to be sufficient to stop the accumulation of total and regional fat mass accumulation (especially in the torso) and to increase muscular mass. Furthermore, it has been observed how total fat mass increases due to the accumulation of fat mass in all regions, but especially in the torso of less active subjects. Moreover, the practice of physical activity is also associated with increased bone mass and better physical condition.

The American Heart Association (AHA) has recently published[57,58] an official position statement based on scientific evidence that proposes schools as the place of origin and centre for potential initiatives aimed at the promotion and encouragement of healthy behaviours, among which appears the increase in physical activity in children and adolescents.

Said study includes the mention of aspects that include participation in school classes themselves (number of physical education hours, participation time, contents, qualifications of the teaching staff etc.), breaks, the transport of children and adolescents to school, out-of-school activities available, connections between schools and other entities and said document ends with a series of conclusions and practical recommendations. These recommendations highlight the need to perform at least 30 minutes of moderate/vigorous physical activity every day (including physical education classes) and place special emphasis on the need to increase participation in out-of-school activities and school programmes.

References

1. Lobstein T, Baur L, Uauy R. Obesity in children and young people: a crisis in public health. Obes Rev. 2004;5 Suppl 1:4-104.
2. Strauss RS, Pollack HA. Epidemic increase in childhood overweight, 1986-1998. JAMA. 2001;286:2845-8.
3. Lobstein T, Jackson-Leach R. Child overweight and obesity in the USA: prevalence rates according to IOTF definitions. Int J Pediatr Obes. 2007;2:62-4.
4. Moreno LA, Fleta J, Sarria A, Rodriguez G, Gil C, Bueno M. Secular changes in body fat patterning in children and adolescents of Zaragoza (Spain), 1980-1995. Int J Obes Relat Metab Disord. 2001;25:1656-60.
5. Lobstein T, Frelut ML. Prevalence of overweight among children in Europe. Obes Rev. 2003;4:195-200.
6. Magarey AM, Daniels LA, Boulton TJ. Prevalence of overweight and obesity in Australian children and adolescents: reassessment of 1985 and 1995 data against new standard international definitions. Med J Aust. 2001;174: 561-4.
7. Lobstein TJ, James WP, Cole TJ. Increasing levels of excess weight among children in England. Int J Obes Relat Metab Disord. 2003;27:1136-8.
8. Ministerio de Sanidad y Consumo, Encuesta Nacional de Salud Pública 2003. http://www.msc.es/estadEstudios/estadisticas/encuestaNacional/encuestaNac2003/home.htm
9. Ministerio de Sanidad y Consumo, Encuesta Nacional de Salud Pública 2006. http://www.msc.es/estadEstudios/estadisticas/encuestaNacional/encuesta2006.htm
10. Serra Majem L, Ribas Barba L, Aranceta Bartrina J, Perez Rodrigo C, Saavedra Santana P, Peña Quintana L. Obesidad infantil y juvenil en España. Resultados del Estudio enKid (1998-2000). Med Clin (Barc). 2003;121:725-32.
11. Hernández M, Castellet J, Narvaiza J, Rincón J, Ruiz I, Sánchez E, et al. Curvas y tablas de crecimiento. Instituto sobre Crecimiento y Desarrollo, ed. F.F.O. Bilbao. Madrid: Editorial Garsi; 1988.
12. Aranceta-Bartrina J, Serra-MajemL, Foz-Sala M, Moreno-Esteban B. Prevalencia de obesidad en España. Med Clin (Barc). 2005;125:460-6.
13. Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. BMJ. 2000;320(7244):1240-3.
14. Ara I, Moreno LA, Leiva MT, Gutin B, Casajus JA. Adiposity, physical activity, and physical fitness among children from Aragon, Spain. Obesity (Silver Spring). 2007;15:1918-24.
15. Moreno LA, Fleta J, Mur L, Feja C, Sarria A, Bueno M. Indices of body fat distribution in Spanish children aged 4.0 to 14.9 years. J Pediatr Gastroenterol Nutr. 1997;25:175-81.
16. Moreno LA, Fleta J, Mur L, Sarria A, Bueno M. Fat distribution in obese and nonobese children and adolescents. J Pediatr Gastroenterol Nutr. 1998;27:176-80.
17. Moreno LA, Fleta J, Mur L. Television watching and fatness in children. JAMA. 1998;280:1230-1; author reply: 1231-2.
18. Moreno LA, Sarria A, Fleta J, Rodriguez G, Bueno M. Trends in body mass index and overweight prevalence among children and adolescents in the region of Aragon (Spain) from 1985 to 1995. Int J Obes Relat Metab Disord. 2000;24:925-31.
19. Moreno LA, Sarria A, Fleta J, Rodriguez G, Gonzalez JM, Bueno M. Sociodemographic factors and trends on overweight prevalence in children and adolescents in Aragon (Spain) from 1985 to 1995. J Clin Epidemiol. 2001;54:921-7.
20. Moreno LA, Sarria A, Popkin BM. The nutrition transition in Spain: a European Mediterranean country. Eur J Clin Nutr. 2002;56:992-1003.
21. Moreno LA, Pineda I, Rodriguez G, Fleta J, Sarria A, Bueno M. Waist circumference for the screening of the metabolic syndrome in children. Acta Paediatr. 2002;91:1307-12.
22. Rodriguez G, Moreno LA, Sarria A, Bueno M. Physical activity and fatness in prepubertal children. Am J Clin Nutr. 2003;77: 1526-7; author reply: 1527.
23. Moreno LA, Mesana MI, Fleta J, Ruiz JR, Gonzalez-Gross M, Sarria A, et al. Overweight, obesity and body fat composition in Spanish adolescents. The AVENA Study. Ann Nutr Metab. 2005;49:71-6.
24. Moreno LA, Mesana MI, Gonzalez-Gross M, Gil CM, Fleta J, Warnberg J, et al. Anthropometric body fat composition referen-

ce values in Spanish adolescents. The AVENA Study. Eur J Clin Nutr. 2006;60:191-6.
25. Moreno LA, Blay MG, Rodriguez G, Blay VA, Mesana MI, Olivares JL, et al. Screening performances of the International Obesity Task Force body mass index cut-off values in adolescents. J Am Coll Nutr. 2006;25:403-8.
26. Moreno LA, Mesana MI, Gonzalez-Gross M, Gil CM, Ortega FB, Fleta J, et al. Body fat distribution reference standards in Spanish adolescents: the AVENA Study. Int J Obes (Lond). 2007; 31:1798-805.
27. Bellizzi MC, Dietz WH. Workshop on childhood obesity: summary of the discussion. Am J Clin Nutr. 1999;70:173S-5S.
28. Popkin BM, Udry JR. Adolescent obesity increases significantly in second and third generation U.S. immigrants: the National Longitudinal Study of Adolescent Health. J Nutr. 1998;128: 701-6.
29. Ravussin E, Valencia ME, Esparza J, Bennett PH, Schulz LO. Effects of a traditional lifestyle on obesity in Pima Indians. Diabetes Care. 1994;17:1067-74.
30. Tremblay A, Perusse L, Bouchard C. Energy balance and bodyweight stability: impact of gene–environment interactions. Br J Nutr. 2004;92 Suppl 1:S63-S66.
31. Ukkola O, Bouchard C. Role of candidate genes in the responses to long-term overfeeding: review of findings. Obes Rev. 2004;5: 3-12.
32. Chagnon Y, Rankinen T, Snyder E, Weisnagel S, Perusse L, Bouchard C. The human obesity gene map: the 2002 update. Obes Res. 2003;11:313-67.
33. Fuentes T, Ara A, Guadalupe-Grau A, Larsen S, Stallknecht B, Olmedillas H, et al. Leptin receptor 170 KDa (OB-R170) protein expression is reduced in obese human skeletal muscle: a potential mechanism of leptin resistance. Exp Physiol. 2009. En prensa.
34. World Health Organization. Obesity: Preventing and managing the global epidemic. WHO Technical Reports Series No. 894. Geneva: WHO; 2000.
35. Blair SN. Physical inactivity: the biggest public health problem of the 21st century. Br J Sports Med. 2009;43:1-2.
36. Serra-Majem L, Aranceta-Bartrina J, Rodriguez-Santos F. Crecimiento y desarrollo. Estudio enKid. Krece Plus. Barcelona: Masson; 2003.
37. Boreham C, Riddoch C. The physical activity, fitness and health of children. J Sports Sci. 2001;19:915-29.
38. Gutin B. Child obesity can be reduced with vigorous activity rather than restriction of energy intake. Obesity (Silver Spring). 2008;16:2193-6.
39. Stallmann-Jorgensen IS, Gutin B, Hatfield-Laube JL, Humphries MC, Johnson MH, Barbeau P. General and visceral adiposity in black and white adolescents and their relation with reported physical activity and diet. Int J Obes (Lond). 2007;31:622-9.
40. Deheeger M, Rolland-Cachera MF, Fontvieille AM. Physical activity and body composition in 10 year old French children: linkages with nutritional intake? Int J Obes Relat Metab Disord. 1997;21:372-9.
41. Moore LL, Gao D, Bradlee ML, Cupples A, Sundarajan-Ramamurti A, Proctor MH, et al. Does early physical activity predict body fat change throughout childhood? Prev Med. 2003;37:10-7.
42. Rosen CJ, Bouxsein ML. Mechanisms of disease: is osteoporosis the obesity of bone? Nat Clin Pract Rheumatol. 2006;2:35-43.
43. Rubin CT, Capilla E, Luu YK, Busa B, Crawford H, Nolan DJ, et al. Adipogenesis is inhibited by brief, daily exposure to high-frequency, extremely low-magnitude mechanical signals. Proc Natl Acad Sci U S A. 2007;104:17879-84.
44. DeStefano RA, Caprio S, Fahey JT, Tamborlane WV, Goldberg B. Changes in body composition after a 12-week aerobic exercise program in obese boys. Pediatr Diabetes. 2000;1:61-5.
45. Gutin B, Owens S, Okuyama T, Riggs S, Ferguson M, Litaker M. Effect of physical training and its cessation on percent fat and bone density of children with obesity. Obes Res. 1999;7:208-14.
46. Ferguson MA, Gutin B, Owens S, Barbeau P, Tracy RP, Litaker M. Effects of physical training and its cessation on the hemostatic system of obese children. Am J Clin Nutr. 1999;69:1130-4.
47. Gutin B, Barbeau P, Owens S, Lemmon CR, Bauman M, Allison J, et al. Effects of exercise intensity on cardiovascular fitness, total body composition, and visceral adiposity of obese adolescents. Am J Clin Nutr. 2002;75:818-26.
48. Kang HS, Gutin B, Barbeau P, Owens S, Lemmon CR, Allison J, et al. Physical training improves insulin resistance syndrome markers in obese adolescents. Med Sci Sports Exerc. 2002;34: 1920-7.
49. Vicente-Rodriguez G, Rey-Lopez JP, Martin-Matillas M, Moreno LA, Warnberg J, Redondo C, et al. Television watching, videogames, and excess of body fat in Spanish adolescents: the AVENA study. Nutrition. 2008;24:654-62.
50. Rey-Lopez JP, Vicente-Rodriguez G, Biosca M, Moreno LA, Sedentary behaviour and obesity development in children and adolescents. Nutr Metab Cardiovasc Dis. 2008;18:242-51.
51. Casajus JA, Leiva MT, Ferrando JA, Moreno LA, Aragonés MT, Ara I. Relación entre la condición física cardiovascular y la distribución de grasa en niños y adolescentes. Apunts. Medicina de l'Esport. 2006:41(149):7-14.
52. Ara I, Vicente-Rodriguez G, Jimenez-Ramirez J, Dorado C, Serrano-Sanchez JA, Calbet JA. Regular participation in sports is associated with enhanced physical fitness and lower fat mass in prepubertal boys. Int J Obes Relat Metab Disord. 2004;28: 1585-93.
53. Ara IG, Vicente-Rodriguez G, Perez-Gomez J, Jimenez-Ramirez J, Serrano-Sanchez JA, Dorado C, et al. Influence of extracurricular sport activities on body composition and physical fitness in boys: a 3-year longitudinal study. Int J Obes (Lond). 2006;30:1062-71.

54. Vicente-Rodriguez G, Jimenez-Ramirez J, Ara I, Serrano-Sanchez JA, Dorado C, Calbet JA. Enhanced bone mass and physical fitness in prepubescent footballers. Bone. 2003;33:853-9.
55. Vicente-Rodriguez G, Ara I, Perez-Gomez J, Serrano-Sanchez JA, Dorado C, Calbet JA. High femoral bone mineral density accretion in prepubertal soccer players. Med Sci Sports Exerc. 2004;36: 1789-95.
56. Vicente-Rodriguez G, Ara I, Perez-Gomez J, Dorado C, Calbet JA. Muscular development and physical activity as major determinants of femoral bone mass acquisition during growth. Br J Sports Med. 2005;39:611-6.
57. Pate RR, Davis MG, Robinson TN, Stone EJ, McKenzie TL, Young JC. Promoting physical activity in children and youth: a leadership role for schools: a scientific statement from the American Heart Association Council on Nutrition, Physical Activity, and Metabolism (Physical Activity Committee) in collaboration with the Councils on Cardiovascular Disease in the Young and Cardiovascular Nursing. Circulation. 2006;114:1214-24.
58. Pate RR, O'Neill JR. Summary of the American Heart Association scientific statement: promoting physical activity in children and youth: a leadership role for schools. J Cardiovasc Nurs. 2008; 23:44-9.