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Review Article

Glycemic index, glycemic load and childhood obesity: A systematic review

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Abstract

Background: Several evidences have been reported so far in terms of the relationship between obesity and glycemic index and glycemic load in children. However, the number of review studies that have dealt with recent findings is quite low. The purpose of present study is to review the existing evidences in this regard.

Materials and Methods: First of all, the phrases: "Glycaemic index", "Glycaemic load", "Glycemic index" OR "Glycemic load" accompanied by one of the words: "Adolescent", "Young", "Youth" "Children" OR "Child" were searched in texts of articles existing in ISI and PUBMED databases which were obtained out of 1001 articles. Among these, some articles, which reviewed the relationship of obesity with glycemic index and glycemic load, were selected. Finally, 20 articles were studied in current review study.

Results: The majority of cross-sectional studies have found children's obesity directly linked with glycemic index and glycemic load; however, cohort studies found controversial results. Also, the intervention studies indicate the negative effect of glycemic index and glycemic load on obesity in children.

Conclusion: Published evidences reported inconsistent results. It seems that existing studies are not sufficient and more studies are needed in this regard.

Key Words: Children, glycemic index, glycemic load, obesity

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INTRODUCTION

Obesity is defined as the increase of body fat more than the ideal range.[1] Previous studies have demonstrated that childhood obesity is usually accompanied by complications in the same period and increased risk of mortality during adulthood.[2] Besides, a direct relationship between the body mass index and blood pressure among Iranian adolescents has been reported.[3] During the recent three decades, the incidence of obesity has increased two folds among American children and adolescents.[4] According to the previous studies, the incidence of obesity and overweight among Iranian children is 10.1% and 4.79%, respectively.[5] Genetics and environmental factors are considered as effective indices for the obesity in the children.[6] Some researchers believe that the macronutrient composition of the diet play an important role to achieve ideal body weight.[7-9]

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Some studies have investigated the effect of dietary fat on obesity.[10] Previous studies have shown that both quantity and quality of carbohydrates should be assessed in respect to weight control.[11] Jenkins *et al*. used the term "glycemic index" for the first time to define carbohydrate quality.[12] The glycemic index (GI) of each food is defined as the ability of that food to increase blood glucose 2 hours after eating that kind of food.[12] Glycemic load (GL) was define in order to the quality and quantity of carbohydrates.[13] For calculating glycemic load, the amount of GI is multiplied by carbohydrate amount in gram.[13] Several studies have been conducted on the relationship of these two indices with obesity in adults and have reported a direct, neutral or reverse relationship, and their results were controversial.[14-19] DASH diet is one of the investigated topics that appear to have a low level of GI due to having high fruit, vegetable and whole grain ingredients.[20] The studies conducted on adults have shown that adhering to this diet is usually followed by reduction in weight.[21,22] and waist circumference.[21] Also, some studies were conducted to evaluate the relationship of GI and GL with cancer,[23] athletic performance[24] diabetic indices[25-29] and cognitive performances[30-32] among children. Because there are no review studies in this regard recently, the present review study deals with evaluating the findings on glycemic index and glycemic load with obesity in the children.

MATERIALS AND METHODS

In order to search the related articles, ISI and PUBMED databases were used. First of all, articles having one of the words "glycemic index", "glycemic load", glycaemic index" OR glycaemic load" is accompanied by one of words "Child", "Children", "Youth", "Young" OR "Adolescent" were searched in both databases and they were summed up to 1001 articles. Then, some articles were chosen in which the obesity in children and/or one of the obesity-related factors as the dependent variable and glycemic index and glycemic load and/or both of them as the main independent variable. Those studies written by a language other than English were also omitted. Finally, 20 articles which had the required conditions will be assessed in present review study [Table 1].

OBSERVATIONAL STUDIES

Cross-sectional studies

The cross-sectional studies cannot express the cause and effect relationship due to simultaneous evaluation of the exposure and outcome.[49] According to searches, three cross-sectional studies on the relationship of GI and GL with obesity in children have been published. In 2007, a study conducted on 140 overweight children aged 10-17 years old showed that there is no significant relationship between GI and GL with the body fat.[33] For dietary assessment, two 24-h recalls were used. To justify his findings, the researcher stated that GI was not high enough in the study population. Small sample size and using 24-h dietary recall may disturb the results. One of the strengths of this study is the measurement of body composition by DXA method. However, during another study by Nielsen *et al*. the total of four skin folds was used as a dependent variable.[2] This study was conducted over 485 10-year-old children and 364 16-year-old children. The findings do not show any relationship between GI and GL and total of four skin folds among 10-year-old girls and boys and 16-year-old girls. In contrast, GI and GL in 16-year-old boys have a direct relationship with total of four skin folds ($P = 0.006$, $P = 0.009$, respectively). The researcher identifies high under-reporting among individuals as the reason of observing no relationship among 16-year-old girls. The important point of this study is the dietary assessment, where one 24-h recall and one quality food record were used. This method does not seem to find people's usual intake. Dietary assessment method in Barba *et al*.[6] study published in 2010 is stronger than the two previous studies. In this study conducted on 3734 children aged 6-11, the subjects completed a food frequency questionnaire which can better reflect the individuals' usual intake than two previous methods. Also, validation study for this questionnaire showed that all correlation coefficients were >0.5 for macronutrients ($P < 0.01$). The results of this study shows that GI has a direct relationship with waist circumference and BMI Z-score ($P < 0.001$ for both). Besides, a significant upward trend for waist circumference and energy intake were observed across quartiles of GI ($P = 0.001$).

As previously mentioned, the cross-sectional studies are not reliable due to having major weaknesses and we should refer to cohort studies for better reviewing the issue.

COHORT STUDIES

Due to the exposure prior to the outcome occurrence, cohort studies have more validity in compared to cross-sectional studies.[49] There are few cohort studies on children in this topic. Firstly, we review a retrospective cohort study on 10-11-year-old children.[34] In 1998, an intervention was run in which 64 people had received a diet with low glycemic index (LGI) and 43 people received low fat diet. The low-fat diet contained 55-60% of carbohydrates, 15-20% of protein and 25-30% of fat, with 250-500 kilocalories less than usual energy

Table 1: The studies reviewed in the present article

Reference	Study design	Explanation of study	Main finding
Davis *et al.*[33]	Cross sectional	140 overweight or obese people between 10 and 17 years old	Lack of relationship of GI and GL with body fat
Nielsen, *et al.*[2]	Cross sectional	485 10 years old children and 364 sixteen years old children	Direct relationship of GI and GL with the total of four skin folds only in 16 years old boys
Barba *et al.*[6]	Cross sectional	3734 children with age ranges of 6-11 years old	GI's direct relationship with the waist circumference and BMI Z-score
Spieth *et al.*[34]	Retrospective cohort	107 children with age ranges of 10-11 years old	Reverse relationship between adherence to LGI diet and BMI/Weight
Buyken *et al.*[35]	Prospective cohort	381 people being followed up from the age of 2 to 7 years old	Direct relationship of GI of breakfast with the time for eating next meal and its reverse relationship with intake of energy during the rest of the day
Buyken *et al.*[36]	Prospective cohort	380 people being followed up from ages from 2 to 7 years old	Lack of relationship of GL/GI and bodyfat with body fat percentage andtheBMI Z-score
Boye *et al.*[37]	Prospective cohort	215 people being followed up from puberty until 4 years old	GI's direct relationship with fat percentage and BMI Z score in the obese people
Rovner *et al.*[38]	Intervention by prescribing diet (cross-over)	23 diabetic children with age ranges of 7 to 17 years old	Lack of existence of a significant difference in energy gained by LGI diet
Fajcsak *et al.*[39]	6 weeks of interventions by prescribing diet (before and after)	8 obese children with overweight with mean of age of 11	Body fat percentage significant reduction, waist circumference ratio to hip circumference and level of hunger of people in LGI diet group
Iannuzzi *et al.*[40]	6 months of intervention by prescribing diet	26 obese children with age ranges of 7 to 13 years old	More reduction of BMI in LGI diet group
Ebbeling *et al.*[41]	12 months intervention with prescribing diet (parallel)	16 adolescents affected by obesity with age ranges of 13 to 21 years	Lesser amount of BMI and fat percentage in LGI group diet
Papadaki *et al.*[42]	6 months of intervention with diet prescription (parallel)	827 children with age ranges of 8 to 12	Reduction of percentage of obese & overweight children in HP and LGI diets
Ball *et al.*[43]	Intervention in GI of breakfast & lunch (cross-over)	16 obese children with age ranges of 6 to 12	Energy intakes after consuming several meals did not show a significant difference
Warren *et al.*[44]	Intervention in GI of breakfast meal (cross-over)	37 students with age ranges of 9 to 12	Lesser amount of receipt of lunch and level of hunger in LGI meal in comparison with HGI
Henry *et al.*[45]	10 weeks of intervention in GI of breakfast (cross-over)	23 children with age ranges of 8 to 11	Lack of existence of a significant change for the amount of intake of energy
Ludwig *et al.*[46]	Intervention in GI of breakfast and lunch (cross-over)	12 obese boys with mean age of 15.7	Higher intake of energy in HGI meals compared to LGI ones
LaCombe *et al.*[47]	Intervention in the GL of breakfast and lunch	23 children with age ranges of 4 to 6	Lack of existence of significant relationship in level of intake of energy
Mirza *et al.*[48]	Intervention in the GL of breakfast and Lunch and dinner	88 people with age ranges of 5 to 15	Lack of existence of significant relationship in level of intake of energy

GI=Glycemic index, GL=Glycemic load, HGI=High glycemic index, LGI=Low glycemic index, HGL=High glycemic load, LGL=Low glycemic load, HP=High protein, BMI=Body mass index

intake. In contrast, LGI diet contained 45-50% of carbohydrates, 20-25% of protein, and 30-35% of fat without any calorie restriction. The study population included 107 obese and healthy children and the average follow-up period for each group was 4.25 months. The findings show that in LGI diet group, weight and BMI reduced more as compared with low fat diet group (for both $P < 0.001$). After adjusting for the effect of age, sex, nationality, BMI, and baseline weight and follow-up duration, this reduction still remained significant ($P < 0.01$). Furthermore, more individuals in the LGI diet group were able to decrease their BMI than in the low fat diet group ($P = 0.03$). The prescribed diet compositions differed in two groups and the changes observed may be due to different compositions of macronutrients and not due to the difference in GI. Other limitations of this study include the short follow-up period and lack of assessment of adhering to the prescribed diet. However, during the recent decade, a huge cohort study (DONALD) is being performed in Germany in which the individuals are followed up from neonatal period till adulthood. In order to evaluate the individuals' diet, three-day food records have been applied for different time periods. Native food composition table and food labels of industrial foods were used to analyze nutritional data in this study. A limitation of this study is the lack of evaluation of physical activity. This has led toward the fact that those articles raised from this study are unable to adjust the effect of physical activity in their analytic models. In addition, the socioeconomic status of study population is low or average.

The first article published by Buyken *et al*. assessed the relationship of GI of breakfast and the daily energy intake.[36] To do so, the data of 381 people whose food intake was recorded at ages 2, 4-5, and 7 were assessed. The findings showed that during 4-5 years old and 7 years old, there is a direct association between GI of breakfast and the time of eating next meal (P = 0.01 and P = 0.03, respectively) and also there is a reverse relationship between breakfast GI and the energy intake during the rest of the day (P = 0.0497 and P = 0.03, respectively). To explain the findings, it should be stated that the variations between the tertiles of GI was not sufficient.

The second article published in 2008 examined the relationship of GI and GL with body fat percentage.[36] The findings do not show any relationship of GI and GL with body fat and BMI Z-score. In order to justify these findings, some researchers believe that the skin fold underestimates the level of body fat. However, studies conducted in this population showed that there is a significant relationship between the skin fold and fat free mass.[37]

The latest article from this study was published in 2010, in which the relationship of GI and GL with body fat percentage from the beginning of puberty to 4 years after was studied.[50] When individuals were classified according to their weights into normal and overweight groups, GI had a direct relationship with fat percentage and BMI Z-score (P = 0.05 and P = 0.01, respectively).

INTERVENTIONAL STUDIES

The intervention by food diet prescription

The studies which will be reviewed in this section include interventions in which the whole diet was considered by the researchers in the short or long term. Accordingly, five studies were found on the effect of GI, GL, and obesity in children.

The secondary findings of a cross-over study on the effects of LGI diet as compared to the usual diet of type 1 diabetic children did not show any significant difference in terms of the energy intake.[38] In this study which contained 23 children with age range of 7-17 years old, subjects consumed their usual diets one day and LGI diet on the next day based on the given list of foods. On each day, one food record was taken from individuals. In another study published in 2008, experts prescribed LGI diet.[39] In this before–after designed study, 8 obese children with average age of 11 years old participated for 6 weeks. In order to have access to LGI diet, between 50% and 70% of the carbohydrate intake was provided by LGI foods. Their physical activity was measured. Within 6 weeks of intervention, four food records were taken from each subject. The research findings indicate a significant reduction in body mass percentage, waist circumference to hip circumference ratio and the level of hunger in these individuals ($P < 0.05$), while weight changes were not significant. Despite the fact that confounders were controlled and participants adhered to the diet appropriately, small sample size and before–after design of the study reduced the validity of the findings. However, a study published one year later by Iannuzzi *et al*. had parallel design and a greater sample size.[40] In this 6-month intervention, 26 children with the ages from 7 to 13 years old, who fell on the 95th percentile of BMI for their age and sex, participated. The LGI (GI = 60) diet was prescribed for one group and HGI (GI = 90) was prescribed for another. The energy in both diets was 30% less than required energy for keeping the ideal weight. One 7-day food record was taken from every individual for each month. At the end of the study, the findings indicated the BMI reduction for both groups (for HGI: P =0.032 and for LGI: $P < 0.001$). The important point in this study is the complications arising from diet prescription with 90 glycemic index in children. However, other long-term study conducted in the U.S.A compared the effect of LGL diet on adolescents with that of the low fat diet.[41] In this study, 16 obese adolescents aging 13-21-years-old were assessed. The LGL diet included a complex of LGI foods containing 45-50% carbohydrates and 55-60% fat and lacked any energy restriction. The low-fat diet contained 55-60% carbohydrates and 25-30% fat and it had between 250 and 500 kcal energy restriction. Anthropometric levels were measured at the beginning of study, 6 months later and 12 months later. Findings at the end of month 12 show that BMI and fat mass were lower in LGL diet group than the low fat diet (P = 0.01 and P = 0.02, respectively). Some limitations should also be indicated such as lack of assessment of the individuals' physical activity and low sample size. The last study that is going to be reviewed in this section is the study conducted for six months by Papadaki *et al*. on 827 children aging 8-18-years-old.[42] In this intervention, five different groups were designed, each of which had one of these diets prescribed: LP diet and LGI diet, LP and HGI diets, high protein diet (HP) and LGI, HP and HGI diets and control group. Three-day food records were taken from each. After 6 months, only 645 people (58.1%) completed the study, which may harm data validity. Comparing basic values with the values of week 26 shows that weight, height, hip circumference and fat-free mass of all participants increased (respectively $P < 0.001$, P = 0.041 and $P < 0.001$) which may be due to their natural growth. However, increase of body fat percentage in LP and HGI diet group was more than other groups (P = 0.04). Furthermore, the percent of the obese and overweight people in HP and LGI diet groups was less than that in the remaining groups (P = 0.031).

The intervention during one or multiple meals

The studies made their intervention in form of changing GI and/or changing GL of the meals which we will separately review.

Intervention in GI of one or multiple meals: The design of all the published studies of this group is cross-over and as a result a series of confounders were controlled desirably in all the studies.

In 2003, a study was published in which the effects of three breakfast and lunch with different GIs on the amount of food intake and hunger during the snack times were studied.[43] In this study, 16 people were included during three 24-hour periods. Three types of breakfast and lunch were designed including: LGI, LGI based on whole grains and HGI. At first, the individuals were given breakfast and lunch on the basis of the related group and they were asked to demand evening snack whenever they became extremely hungry. The findings showed consumption of HGI meals made the individuals demand the next meal sooner as compared with LGI diet ($P < 0.01$). In addition, the energy intakes did not have a significant difference with each other after consumption of various meals. Furthermore, no significant difference was observed between the levels of hunger after consumption of different meals. It seems that lack of difference in hunger is because of subjective nature of this variable. In another study by Warren *et al*. the design was similar to the previous study and three breakfast types with different GIs were given to the participants, and the level of the lunch received by them, their satiety and hunger were assessed.[44] The meals in the research included LGI, LGI plus 10% of sucrose and HGI. Within three consecutive days and during each day, one of the various types of breakfasts was given to the participants and he/she was asked to avoid from eating any food until lunch time. The lunch was eaten freely and the amount of intake of lunch for every individual was recorded. In this study, 37 students aging 9-12-years-old participated. The findings of this intervention indicated that lunch intake was reduced followingLGI and LGI plus 10% of sucrose meals as compared with that in HGI diet (for both $P < 0.001$). Also, hunger at lunchtime was higher for HGI group than two others (for both $P < 0.05$). Another study conducted on twenty three 8-11-year-old children.[45] Subjects consumed one of the HGI and/or LGI breakfasts for 10 weeks and 2 days a week, and the lunch intake was studied during the rest of the day. The provided breakfasts were similar in fiber and the macronutrients content. The results of this study demonstrate that there is an insignificant reduction in energy intake at lunch in the LGI breakfast group ($P = 406$). The energy intake during the whole day did not also show a significant difference during consuming two breakfast types. The oldest study in all our searches was conducted in 1999 on 12 obese boys aging 15.7.[46] In this study, one of the three types of breakfast and lunch was eaten by the individuals for three days and (one per day): LGI breakfast and lunch, moderate glycemic index breakfast and lunch (MGI) and HGI breakfast and lunch. The individuals went to the institute from the night prior to conducting study and consumed LGI dinner there. Then, in the next day, the breakfast and lunch related to the same day was given to them and the amount of energy intake was assessed up to 5 h after eating lunch. The findings indicated the higher intake of energy after consumption of HGI meals than the LGI ones ($P = 0.01$). In addition, the average time for demanding food after lunch was lower during consumption of HGI than the LGI meals ($P = 0.01$).

In conclusion, it seems that the effect of GI on satiety and intake of energy becomes significant when studies were made on obese people.

Intervention in GL of one or several meals

Two published studies in this respect will be reviewed here.

The first study was conducted by LaCombe *et al*. on 23 children aging 4-6-years-old.[47] The goal of this intervention was to study the effect of two breakfasts having different GLs (HGL and LGL) on the amount of satiety, hunger and receipt of lunch. The design of the study was cross-over and every breakfast was given in two non-consecutive days to the individuals and the mean values were used for analyzing. The findings of this research show that the level of hunger during receipt of HGL breakfast was more than that for the LGL diet ($P = 0.03$). However, no significant difference was observed regarding the level of energy intake. In order to justify the findings of this study, it should be considered that the composition of the macronutrients, level of fiber and density of energy were different in both breakfasts. The last study is the parallel intervention performed on 88 individuals aging 7-15-years-old.[48] Three meals of dinner, breakfast and lunch with different GLs (HGL and HGL) were given to individuals and their level of energy intake for the evening snack was assessed. This study lasted for 12 weeks, one day per week. The HGL meals included 55-60% of carbohydrates, 15-20% of protein, and 25-30% of fat and the LGL meals included 45-50% of LGI carbohydrates, 20-25% of protein, and 30-35% of fat. The findings of the study indicate the similarity of energy intake from eating snacks after consuming food meals with different GL ($P = 0.5$). In addition, the level of satiety and hunger did not also have a significant difference between the two groups. The energy intake standard deviation was very high in this study. Thus, a high sample size is required in order to find a significant relationship in this population.

Taking two studies into account, we find that the number of conducted studies in field of intervention in GL on one or several meals is highly restricted and performing accurate interventions with higher sample size can be useful.

DISCUSSION

Out of three cross-over studies, only one study reported a significant relationship between GI, GL with childhood obesity and the other two studies did not. Regarding the cohort studies, it should be stated that all the prospective published articles have used one study (DONALD) and a majority of them reported a neutral relationship. However, it should be noticed that no data are available for us regarding other populations especially when it comes to Asian countries. According to clinical trials, there are few studies in which both dependent and independent variables have been identically designed. Therefore, each of the existing findings indicates a part of relationship of GI and GL with obesity in children. It is difficult to justify the findings of the intervention on GL diet in most cases because any change in GL of diet is always accompanied by a change of macronutrient composition; in other words, during an HGL diet, the researcher has to increase the percentage of carbohydrates. The other point is about the interventions made on GI and/or GL of one or several meals. Most of the studies in this field were performed for better controlling of the variables in the institute and/or the schools. This not only can facilitate controlling the variables, but it can also cause changes in nutritional habits and nutritional behaviors. However, it should be mentioned that most of these studies have cross-over design and as a result, there is a very low possibility of error resulting from environmental changes.

Factors that cause less amount of glycemic response to food and are classified as LGI include soluble fiber content, amylose, resistant starch, fructose, protein, fat and.[45] The soluble fibers and pH cause the slower stomach emptying.[45] On the other hand, due to the presence of resistant starch, bioavailability of the enzymes to starch is less and a less amount of glucose is released and absorbed.[45] The consumption of HGI foods causes the increase of the glucose and consequently it will increase the insulin secretion and lowers the glucagon.[6,46] The presence of insulin will lead to activating the Gluconeogenesis and lipolysis and controls their paths.[6,46] As a result, the glucose is rapidly dropped after a while and the processes which are responsible for development of hunger become activated.[46] However, studies that reported a reverse relationship between GI of diet with the level of hunger suggest that the correct functioning of insulin is needed for appropriate function of leptin on satiety.[35] Besides, the HGI foods simultaneously increase the insulin and leptin secretion.[35] As a result, after consumption of HGI breakfast, the levels of insulin and leptin are concurrently increased, and if the person consumes his/her second morning snack, he/she will find a stable satiety.[35] However, a number of the researchers believe that it is possible that oxidation inhibition developed by HGI foods will cause the insulin resistance in the long-term.[36] HGI foods cause more insulin secretion, and the epidemiological studies have demonstrated that the higher insulin levels of the individuals have a direct relationship with obesity in the future.[34] Regarding the GL of diet, it should also be stated that the level of fat and protein is higher in LGL diet than HGL diet.[46] The protein and fat stimulate the secretion of Cholecystokinine from the duodenum and jejunum's I cells. The cholecystokinine activates its own receptors in pyloric sphincter and intensifies this sphincter's contraction. As a result, the stomach of the person will be emptied later and hunger is postponed.[46]

However, as it was previously mentioned, the conducted studies had some limitations. Perhaps, one of the major limitations of observational studies is lack of FFQ for GI and GL in children. So, observational studies especially prospective cohort ones are limited. In addition, most studies were conducted in societies that GI is not high, and the effect of higher GI's have not been yet studied. Interventional studies have their own restrictions. As for the effect of GL on obesity, the design of diets that are only different in the amount of GL is controversial. Another limitation is objective variables like the level of satiety and hunger, which can be erroneous in children.

CONCLUSION

Despite all such limitations, the present findings are unable to report an approved relationship between GI/GL and the children's obesity; however, more precise studies are required to enable us to achieve a reliable result in this respect.

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