Study on Different Sites of Waist Circumference and Its Relationship to Weight-for-Height Index in Thai Adolescents

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Objective: *To compare waist circumference (WC) measured at different sites of trunk region and to determine predictive WC values that were corresponding to weight-for-height index in Thai adolescents.*
Material and Method: *The authors conducted the cross-sectional study in 509 adolescents, aged 10-18 years old. WC was measured at four different sites of trunk region, WC1; at midway between the lowest rib and the iliac crest, WC2; at the narrowest waist, WC3; at immediately above the iliac crest and WC4; at the umbilicus level. Receiver operating characteristic analysis was also performed to determine WC cutoffs to maximize the sensitivity and specificity.*
Results: *WC measured at all four sites provided small different powerful value in prediction of trunk fat and total body fat (TBF) in adolescents and that WC4 provided slightly better predictive value than other WC. In boys, WC provided better prediction of trunk fat than the prediction of TBF, whereas in girls, the prediction of trunk fat and TBF from WC were of similar magnitude. By receiver operating characteristic analysis, WC risk threshold for predicting the overweight adolescents using Thai weight-for-height Z score ≥1.5SD as reference was 73.5 cm for boys (sensitivity 96.8%, specificity 85.7%) and 72.3 cm for girls (sensitivity 96.1%, sensitivity 80.5%). WC threshold was increased to 75.8 cm. (sensitivity 96.3.%, specificity 86.4%) for boys and 74.6 cm for girls (sensitivity 95.1%, specificity 85.7%) in order to detect the obese children.*
Conclusion: *Waist circumference has been proposed as the simple tool for screening the overweight adolescents and when measured at the umbilicus level, it is considered the feasible site for self-evaluation. Further study is needed to investigate the relationship between the increased WC and metabolic risk factors for obesity in adolescents.*

Keywords: *Waist circumference, Adolescents, Weight-for-height Z score, Body fat*

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Several studies in adults have demonstrated that the abdominal adiposity is highly correlated with type 2 DM, hypertension and coronary heart disease(1-3). Increased abdominal adiposity in children is also associated with adverse metabolic and cardiovascular risk factor, whether fat distribution is measured with simple anthropometry(4-6) or with advanced techniques(7,8). Fat distribution in children could be measured directly by trunk skinfolds, by trunk to extremity ratio(4,5,9) or by waist circumference(10). Since waist circumference (WC) is well correlated with trunk fat across wide range of child's BMI, many studies have investigated WC as an index of health risk in children and adolescents and that enlarged WC was found to be associated with hypertriglyceridemia, insulin resistance and hyperlipidemia(11-14). One study in the American prepubertal children showed that children who had WC of 71 cm or more were 14 times more likely to produce adverse

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serum insulin and lipid profile[15]. For Asian children, a study in Japanese girls aged 9-15 years indicated that patients with WC of $\geq$ 77 cm could have adverse lipid profile[16]. Another study in Hong Kong, Chinese children aged 6-12 years proposed the WC value of more than 71 cm for girls and of more than 76 cm for boys as cutoff values for predicting cardiovascular risk condition[17]. Since WC is considered as a simple, practical, and reliable index for abdominal adiposity assessment, but to the authors' knowledge, there is no universally accepted site for WC measurement in adolescents. Therefore, the purpose of this study was to determine the relationship between WC, trunk and total body fat in Thai adolescents and the predictive WC values for identifying the overweight and obese adolescents.

Subjects and Method

Subjects

Five hundred and nine adolescent boys and girls, aged 10-18 years volunteered for the present study. Subjects were randomly enrolled from four primary schools located in Thaweewatana District of Bangkok Metropolitan Area (Thaweewatana, Tungpiruntham, Saladaeng, and Klongbangprom) and five secondary schools in Salaya District of Nakhon Pathom (Khanjanaphisek, Joseph-Upathum, Rattanakosinsompot, Suwanplubpla, and Watpuranawas). The proportion of subjects; i.e., under-nutrition, normal weight, and over-nutrition was 1:3:1. Written informed consent was obtained from the parents and students. The study design was approved by the Committee on Human Rights Related to Human Experimentation, Mahidol University.

Measurements

Anthropometry

All measurements were performed while subjects were wearing light clothes with no shoes. For each subject, body weight was measured to the nearest 0.1 kg using beam balance scale (Weylux; Model 424J, Clarkston, UK) and height was measured to the nearest 0.1cm using a wall-mounted stadiometer (Yamakoshi Seisakusho Co. Ltd., Tokyo, Japan). Subject's nutritional status was categorized using weight-for-height Z score (WHZ), Thai reference, 2000; the wasted adolescent was defined by WHZ $\leq$ 1.5 SD, the normal weight adolescent by WHZ between -1.5 SD and +1.5 SD, the overweight adolescent by WHZ $\geq$ 1.5 SD to +2 SD and the obese adolescent by WHZ $\geq$ 2 SD of median or reference value. The body mass index was also calculated as body weight/height^2 (kg/m^2) for each subject. Waist circumference (WC) was measured at the end of expiration at all four sites with an non-elastic tape placed directly on the skin while the subject stood balanced on both feet touching each other and both arms hanging freely. The measurement was performed by the same researcher throughout the present study. The locations for WC measurement landmarks were as follows, WC1 at midway between the lowest rib and the iliac crest, as suggested by the World Health Organization guidelines (WHO)[18]. WC2 at the narrowest waist, as suggested in the Anthropometric Standardization Report[19]. WC3 at immediately above the iliac crest, as recommended in the National Institute of Health (NIH) guideline[20], and WC4 at the level of umbilicus in the horizontal plane of the subjects. Hip circumference was measured in a horizontal plane at the level of maximum extension of the buttocks without compressing the skin and the measurement was recorded to the nearest 0.1 cm. Measurement of waist and hip circumferences were performed twice and then the average value was used as the data.

Assessment of body fat

Percentage of total body fat (TBF), total body fat mass, and percentage of trunk fat were measured with whole-body dual energy X-ray absorptiometry[21] (DXA, GE LUNAR Model Prodigy; software version 3.50.176, Madison, WI, USA.). Individual subject was scanned in the supine position and in a rectilinear using X-ray at two energy sources (40 and 70 keV) in fast mode. A series of transverse scans were made from head to toe at a 1 cm intervals. Time spent was about 10-12 minutes depending on the height of the subject. Internal calibration of DXA has shown its reliability with a coefficient of variation (CV) of body fat estimation of 0.4%. Average percentage of total body fat was calculated as[(fat mass/fat mass + lean tissue mass + bone mineral content) x 100].

Statistical analysis

All anthropometric and body fat data were presented as mean $\pm$ SD. Statistical analyses was performed with SPSS for WINDOWS (version 13; SPSS Inc., Chicago, USA). Mean comparison of anthropometric indices between male and female adolescents was done using student's t-test. Mann-Whitney test was applied when the data were not normal distribution. Linear regression analysis was used to determine the relationship between WC at different sites and total body fat and trunk fat of subjects. The receiver operating characteristic curve (ROC curve) analysis was used to investigate the ability of WC to distinguish the overweight and obesity from the normal weight subjects. The WC cutoff point was determined based on the combination of sensitivity and specificity of observed data.

Results

The present study included 509 subjects, 238 boys and 271 girls, whose ages ranged between 10-18 years old. The characteristics of the subjects are shown in Table 1. Mean WHZ of male and female subjects were 0.55 ± 1.56 and 0.18 ± 1.48, respectively and were significantly different (p = 0.009). However, when expressed as mean BMI value, there was no significant difference between the two groups. Regarding WC, the values of WC1 and WC2 of girls were significantly lower than that of boys whereas no difference was found between the two groups in WC3 and WC4 values. In terms of body fatness, although there was no difference in mean BMI values whilst mean WHZ-score values of both groups were in the normal range, mean percentage of total body fat and trunk fat of girls were significantly greater (p = 0.001) than those of boys.

Table 2 shows the results of regression analysis to explain the relationship between WC and trunk fat. It was found that all WC measured at four sites of the trunk region were significant determinants for trunk fat in both male and female adolescents. The percentage of variance of % trunk fat explained by WC was between 53%-60% for boys and between 70%-73% for girls. The variance of trunk fat mass that was explained by WC, were between 81%-85% for boys and between 80%-86% for girls. Results from Table 3 showed the significant relationship between WC and TBF. The variance of %TBF explained by WC was between 44%-51% for boys and between 70%-75% for girls. In addition, WC at all sites provided significantly higher correlation with total body fat mass in both genders.

The derived WC cutoff points through ROC analysis to maximize the sensitivity and specificity are shown in Table 4. For boys, by using Thai WHZ ≥ 1.5 SD as criteria for screening the overweight adolescents, the WC cutoff was 73.5 cm (AUC = 0.97; sensitivity 96.8%, specificity 85.7%), which was corresponding to TBF of 28.1%. The WC threshold was increased to 75.8 cm (AUC 0.97; sensitivity 96.3%, specificity 86.4%), the value proposed for classifying the obese adolescents. For girls, the WC cutoff value was lower than that of boys, 72.3 cm (AUC = 0.97, sensitivity 96.1%, specificity 80.5%), which was corresponding to total

Table 1. Anthropometric data of Thai adolescents, by gender

	All subjects		
	Boys	Girls	p-value
No. of subjects	238	271	
Age (y)	13.3 ± 2.3	13.8 ± 2.4	0.015**
Body weight (kg)	48.2 ±12.9	45.6 ±10.9	0.019*
Height (cm)	154.8 ±13.4	152.4 ± 8.6	0.021**
WHZ score	0.55 ±1.56	0.18 ± 1.48	0.009**
BMI (kg/m²)	19.8 ±3.7	19.5 ±3.8	0.243
Waist circumference (cm)			
WC1	69.8 ±10.1	67.4 ± 8.7	0.005*
WC2	67.7 ± 9.0	64.0 ±7.9	0.001*
WC3	72.4 ± 9.9	72.9 ± 9.5	0.541
WC4	70.8 ± 10.4	69.2 ± 9.2	0.076
Total body fat (%)	20.4 ±10.6	28.1±8.1	0.001**
Total body fat mass (kg)	10.1 ± 6.7	13.4 ± 6.6	0.001**
Trunk fat (%)	20.1 ±12.1	27.4 ± 9.7	0.001**
Trunk fat mass (kg)	4.43 ± 4.4	5.85 ± 3.3	0.001**

Data were mean ± SD
* Significantly different between boys and girls subjects, by student's t-test
** Significantly different between boys and girls subjects, by Mann-Whitney test

Table 2. Regression equation to predict trunk fat* from waist circumference measured at different sites

Dependent variable	Waist circumference	Constant	Coefficient	R^2	p-value
% Trunk fat	Boys (n = 238)				
	WC1	-0.250	0.021	0.58	<0.0001
	WC2	-0.315	0.023	0.53	<0.0001
	WC3	-0.270	0.021	0.53	<0.0001
	WC4	-0.243	0.021	0.60	<0.0001
	Girls (n = 271)				
	WC1	0.314	0.016	0.72	<0.0001
	WC2	0.273	0.018	0.70	<0.0001
	WC3	0.321	0.015	0.72	<0.0001
	WC4	0.331	0.016	0.73	<0.0001
Trunk fat mass	Boys (n = 238)				
	WC1	1.292	0.032	0.84	<0.0001
	WC2	1.133	0.035	0.81	<0.0001
	WC3	1.174	0.032	0.82	<0.0001
	WC4	1.310	0.031	0.85	<0.0001
	Girls (n = 271)				
	WC1	1.761	0.029	0.83	<0.0001
	WC2	1.692	0.031	0.80	<0.0001
	WC3	1.733	0.027	0.86	<0.0001
	WC4	1.799	0.027	0.83	<0.0001

WC1 = at midway between the lowest rib and the iliac crest, WC2 = at the narrowest waist,
WC3 = at immediately above the iliac crest, WC4 = at the umbilicus level
* Values as log transformed

Table 3. Regression equation to predict total body fat* from waist circumference measured at different sites

Dependent variable	Waist circumference	Constant	Coefficient	R^2	p-value
% Total body fat	Boys (n = 238)				
	WC1	0.095	0.016	0.49	<0.0001
	WC2	0.059	0.018	0.44	<0.0001
	WC3	0.093	0.016	0.44	<0.0001
	WC4	0.100	0.016	0.51	<0.0001
	Girls (n = 271)				
	WC1	0.555	0.013	0.73	<0.0001
	WC2	0.525	0.014	0.70	<0.0001
	WC3	0.551	0.012	0.75	<0.0001
	WC4	0.564	0.013	0.75	<0.0001
Total body fat mass	Boys (n = 238)				
	WC1	2.065	0.026	0.81	<0.0001
	WC2	1.943	0.029	0.78	<0.0001
	WC3	1.972	0.027	0.79	<0.0001
	WC4	2.079	0.026	0.83	<0.0001
	Girls (n = 271)				
	WC1	2.427	0.024	0.83	<0.0001
	WC2	2.372	0.026	0.80	<0.0001
	WC3	2.394	0.023	0.88	<0.0001
	WC4	2.455	0.023	0.84	<0.0001

WC1 = at midway between the lowest rib and the iliac crest, WC2 = at the narrowest waist,
WC3 = at immediately above the iliac crest, WC4 = at the umbilicus level
* Values as log transformed

Table 4. Predictive waist circumference cutoff values using weight-for-height-index criteria for screening the overweight adolescents

	AUC[a] (95% CI)	WC cut-off[b] (cm)	Sensitivity[c] (%)	Specificity[d] (%)	PPV[e] (%)	NPV[f] (%)	Correspondence to % TBF	Prevalence (%)
Boys								
Thai WHZ ≥ 1.5 SD	0.971 (0.953-0.989)	73.5	96.8	85.7	70.9	98.6	28.1	26.5
Thai WHZ ≥ 2.0 SD	0.968 (0.948-0.988)	75.8	96.3	86.4	67.5	98.8	34.4	22.7
Girls								
Thai WHZ ≥ 1.5 SD	0.969 (0.944-0.993)	72.3	96.1	80.5	53.2	80.4	33.8	18.8
Thai WHZ ≥ 2.0 SD	0.983 (0.970-0.997)	74.6	95.1	85.7	54.2	98.8	40.2	15.1

[a] AUC: Area under the curve indicate the probability that an adolescent with adverse health consequences has a higher value of the WC measurement than an adolescent without adverse health consequences; 95% confidence intervals were given within parentheses, [b] Cut-off producing equal values of sensitivity and specificity, [c] Sensitivity = true positive rate, [d] Specificity = 1-false positive rate, [e] Positive predictive value (PPV) = posttest likelihood of positive results, [f] Negative predictive value = posttest likelihood of negative results

body fat of 33.8% and that WC was increased to 74.6 cm, the cutoff value to define the obese female adolescents.

Discussion

Waist circumference (WC) is now commonly accepted as a practical measure of abdominal adiposity and its value differs in magnitude depending on age and gender. The present results indicated that WC measurements taken at all four sites on abdominal region could be able to predict percentage of trunk fat and total body fat at different magnitude in adolescents. Although the strength of correlation between WC and trunk fat mass and between WC and total body fat mass were similar in both genders, however, in male adolescents, WC measured at all sites provided slightly better prediction on percentage of trunk fat than the prediction of TBF. The study by Wang et al[22] in subjects aged 8-83 years old showed that WC gave the higher predictive values for trunk fat in terms of percentage of trunk fat and trunk fat mass than for TBF in males. Regarding TBF, some studies also revealed that WC is well correlated with TBF in both genders[23,24], which is similar to the present results. The stronger association between WC and trunk fat found in male subjects from the present study may be due to anatomical distribution of intra-abdominal adipose tissue that is different between genders. Generally, the muscle mass and the abdominal fat increase on trunk in boys during adolescence and gluteal-femoral fat increases in girls leading to different phenotypes and these changes are associated with stage of sexual maturity and hormonal change[25,26]. In addition, previous studies in children and adults indicated that WC was proved a better marker of abdominal visceral fat with the correlation coefficient around 0.8-0.9[27,28].

The WC measurement at the four sites provided slightly different powerful performance in prediction of total body fat and the WC measurement at the umbilicus level could be practically performed in adolescents. Therefore, WC4 data was further applied in the ROC analysis to determine proposed WC cutoff value used for screening adolescents who were at risk. In Table 4, by using Thai WHZ as criteria, the authors proposed WC cutoff values was 73.5cm for boys and 72.3 cm for girls indicating overweight condition, and WC was increased to 75.8 cm and 74.6 cm for boys and girls, respectively for obesity. These values were considered based on the maximal area under the curve for ROC analysis that were close to 1.0 with sensitivity of more than 90% and specificity of more than 80% for power of detection. However, considering on low positive predictive value, using these WC cutoff values might perhaps misclassify some of the girls, as that in fact they did not have high adiposity. This could be due to the difference in anatomical site of trunk fat region in girls compared with that of boys and because of the inter-subject variation in WC reflecting variation in body fat and muscle mass have limited utility when applied across a wide age range. In such cases, additional assessment using trunk skinfolds or waist-to-hip ratio might be useful as a selective in detecting excess trunk fat but not affected by total body fat store.

Generally, the WC cutoff value should be derived based on adolescent health-related outcomes. As in adults, increased abdominal adiposity, particularly visceral abdominal fat, was found to be strongly associated with several cardiovascular risk[29,30] because visceral adipose tissue is more lipolytically sensitive and releases more free fatty acids into circulation. In addition, many studies proposed WC as one surrogate index associated with metabolic risk factors[4-6]. A few studies also investigated the appropriate WC cutoff points to detect the presence of one or more cardiovascular risk factors; i.e., fasting insulin, LDL-cholesterol, HDL-cholesterol and triglycerides. Higgins et al[15] indicated that Caucasian prepubertal children with WC $\geq$ 71 cm were more likely to have a negative risk profile, whereas another study in Japanese girls aged 9-15 years old with WC $\geq$ 77 cm would be a good combination of sensitivity and specificity to detect adverse lipid profile[16]. Regarding TBF, the present results showed that adolescents who had WHZ of $\geq$ 1.5 SD would have higher WC values which were corresponding to TBF of $\geq$ 28.1% for boys and of $\geq$ 33.8% for girls. Adolescents who were obese (WHZ $\geq$ 2.0SD) would have TBF of $\geq$ 34.4% for boys and $\geq$ 40.2% for girls. Some previous studies have related percentage of body fat with cardiovascular risk in children and adolescents. A study in 1,289 children aged 9-10 years old demonstrated that the ratio of total cholesterol/HDL-cholesterol was significantly higher with a 23%-25% total body fat in girls by bioelectrical impedance analysis[31]. The study with a large sample of 1,834 school children, aged 9 and 15 year old, showed that total body fat as assessed by trunk skinfolds of $\geq$ 20% for boys and $\geq$ 30% for girls were associated with adverse lipid profiles[32]. Williams et al[33] studied in 3,320 American children aged 5-18 years indicated the cardiovascular risk was evident at $\geq$ 25% total body fat in males and $\geq$ 30% in females. Compared with the amount of TBF from the above studies, the relatively high TBF found in obese girls in the present study had been subjected to criticize. While sexual dimorphism is thought to be emerging during puberty, ethnic difference may be another influencing factor. Malina et al[34] showed their study of adolescent girls that proportionally trunk adipose tissue was more detectable in Asians than in White and Black girls using skinfold measurements.

The limitation of the present study was that the authors did not collect blood samples, so the authors might not be able to convince the increased metabolic risk attributed to this proposed WC cutoff value. The WC cutoff values from the present study, in addition, can be categorized for not being age specific adolescents so that a systematic underestimation of proportion of excess adiposity in younger subjects and overestimation in older subjects might occur. Therefore, further studies are needed to verify these WC values with morbidity in adolescents. Nevertheless, it will be anticipated that the authors' primarily results will provide additional information regarding WC values with an attempt to link these with existing Thai weight-height system used for screening children who were at risk for over nutrition.

Conclusion

The present study showed that waist circumference measurements at four sites on the trunk region were all significantly correlated with trunk fat and total body fat in adolescent children. Among all, waist circumference measured at the level of umbilicus provided reasonable good correlation with trunk fat and total body fat. Based on Thai WHZ reference, the proposed WC cutoff values were also determined. Further studies are needed to verify the association between such WC cutoff values and adverse metabolic risk in adolescents.

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การศึกษาเส้นรอบเอวที่ตำแหน่งต่าง ๆ กับความสัมพันธ์ต่อดัชนีน้ำหนักต่อส่วนสูงในวัยรุ่นไทย

อุรุวรรณ แย้มบริสุทธิ์, กัลยา กิจบุญชู, วันเพ็ญ วิมลพีรพัฒนา, วีรชาติ ศรีจันทร์, วิยะดา ทัศนสุวรรณ

วัตถุประสงค์: *เพื่อศึกษาเปรียบเทียบค่าเส้นรอบเอวที่วัด ณ ตำแหน่งต่าง ๆ บริเวณลำตัว และเพื่อหาค่าจุดตัดเส้นรอบเอวที่สัมพันธ์กับค่าดัชนีน้ำหนักต่อส่วนสูงในวัยรุ่นไทย*

วัสดุและวิธีการ: *การศึกษาภาคตัดขวางในวัยรุ่นไทย จำนวน 509 คน อายุระหว่าง10-18 ปี ทำการวัดเส้นรอบเอว ณ ตำแหน่งต่าง ๆ ที่บริเวณลำตัว, WC1; เส้นรอบเอวที่กึ่งกลางระหว่าง lowest rib และ iliac crest, WC2; เส้นรอบเอวที่แคบที่สุด, WC3; เส้นรอบเอวที่อยู่เหนือต่อ iliac crest และ WC4; เส้นรอบเอวที่วัดผ่านสะดือ วิเคราะห์ผล เพิ่มเติมโดย receiver operating characteristic analysis เพื่อหาค่าทำนายจุดตัดเส้นรอบเอวโดยพิจารณาค่าความไวและค่าความจำเพาะในระดับสูง*

ผลการศึกษา: *เส้นรอบเอวที่วัดได้ ณ ตำแหน่งต่าง ๆ ที่ลำตัวให้ค่าความแตกต่างกันเล็กน้อยในการทำนายปริมาณไขมันลำตัวและไขมันร่างกายในวัยรุ่น โดยพบว่าส่วนใหญ่เส้นรอบเอวที่วัดผ่านสะดือจะทำนายค่าไขมันร่างกายได้ดีกว่าเส้นรอบเอวที่วัด ณ ตำแหน่งอื่น ๆ เล็กน้อย ในวัยรุ่นชายพบว่าเส้นรอบเอวทำนายค่าไขมันลำตัวได้ดีกว่าไขมันร่างกาย ในขณะที่วัยรุ่นหญิงพบว่าเส้นรอบเอวทำนายค่าไขมันลำตัวและไขมันร่างกายได้ใกล้เคียงกัน ผลวิเคราะห์ด้วย receiver operating characteristic curve เมื่อใช้ค่าดัชนีน้ำหนักต่อส่วนสูงเป็นเกณฑ์อ้างอิงจะได้จุดตัดเส้นรอบเอวที่ 73.5 เซนติเมตร ในวัยรุ่นชาย (ค่าความไวร้อยละ 96.8, ค่าความจำเพาะร้อยละ 85.7) และเส้นรอบเอวที่ 72.3 เซนติเมตร ในวัยรุ่นหญิง (ค่าความไวร้อยละ96.1, ค่าความจำเพาะร้อยละ80.5) ใช้เป็นค่าคัดกรองวัยรุ่นที่มีภาวะโภชนาการเกิน นอกจากนั้น ค่าเส้นรอบเอว ที่เพิ่มขึ้นเป็น 75.8 เซนติเมตร ในวัยรุ่นชาย (ค่าความไวร้อยละ 96.3, ค่าความจำเพาะร้อยละ 86.4) และเส้นรอบเอวที่ 74.6 เซนติเมตร ในวัยรุ่นหญิง (ค่าความไวร้อยละ 95.1, ค่าความจำเพาะ ร้อยละ 85.7) ใช้ในการคัดกรองวัยรุ่นที่อ้วน*

สรุป: *การศึกษานี้ชี้ให้เห็นว่า เส้นรอบเอวสามารถใช้เป็นดัชนีคัดกรองวัยรุ่น ที่มีภาวะโภชนาการเกินได้ และการวัดเส้นรอบเอว ในระดับที่ผ่านสะดือนั้นสามารถทำได้ด้วยตนเอง ควรมีการศึกษาเพิ่มเติมความสัมพันธ์ระหว่างค่าเส้นรอบเอวที่เพิ่มขึ้น กับปัจจัยเสี่ยงเมตาบอลิคสำหรับโรคอ้วนในวัยรุ่น*