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Blood pressure during adolescence: A study among Belgian adolescents selected from a high cardiovascular risk population

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Abstract. *Introduction*: the Belgian province of Luxembourg has a high incidence of cardiovascular (CV) disease according to the MONICA register. Surveys conducted in adults and children have also found high CV risk factor levels in this province. *Design*: cross-sectional study. *Objective of the present study*: to collect data about blood pressure (BP) and its determinants in adolescents from this high CV risk population and to analyse their relationship. *Participants*: 1526 adolescents (12–17 years) in 24 secondary schools of the province. *Results*: mean systolic BP levels were 125 mm Hg (sd = 12 mm Hg) and 122 mm Hg (sd = 11 mm Hg) for boys and girls, respectively. Mean diastolic BP was equal to 74 mm Hg (sd = 10 mm Hg) in both genders. Systolic BP increased with age and differed significantly between genders from 15 years onwards. Body fatness indices increased with age except waist-to-hip ratio in girls and triceps skinfold in boys. Regression models including age, anthropometric indices and physical activity explained a small percentage of BP variance (for systolic BP, $r^2 = 0.21$ and 0.12 for boys and girls, respectively). Weight was the first parameter related to BP in correlation and regression analyses. *Conclusions*: this study showed high BP and body fatness indices in adolescents from a high CV risk population. The model under study showed a moderate relationship between body fatness and BP. This finding suggests other influences as a genetic component to account for the high levels observed.

Key words: Adolescence, Blood pressure, Body fatness, Body mass index, Weight

Introduction

Blood pressure (BP) during adolescence is a major determinant of the level recorded in later adulthood. Blood pressure tracking from childhood to adulthood has been widely documented in the literature and the strength of tracking increases with increasing age at first measurement [1–5]. Follow-up studies have also supported the major role of ponderosity indices changes in adult blood pressure level prediction. Therefore the emergence of an association between body fatness and blood pressure in youth takes on particular importance [6–12]. The aim of this study was to determine the nature of factors associated with blood pressure in adolescents and in particular to analyse the relationship with body fatness indices. A major interest of this work was the choice of the population study. The Belgian province of Luxembourg has a high cardiovascular disease morbidity and mortality burden in comparison with neighbouring regions. MONICA surveys have shown that adults and children of this province exhibited high levels of cardiovascular risk factors and in particular high body fatness indices [13–14]. The current study was therefore the missing link between observations made in adults and children from the same population.

Subjects and methods

Survey population

This cross-sectional survey was conducted in Belgium, in the Southern province of Luxembourg. Eligibility criteria were age (12–17 years), Belgian nationality and residence in the province. The participants were recruited by a multi-clustered sampling technique. Firstly, twenty-four secondary schools were randomly selected out of the 48 schools in the province. Secondly, a learning option was assigned to each school with probability proportional to the distribution recorded in the province. The Belgian school system has indeed three learning options. The classical curriculum has mainly theoretical courses. The technical curriculum involves some practical courses and the vocational curriculum includes mainly manual courses. The choice of a learning option early on determines thereby the professional orientation and perhaps its corresponding lifestyle. The ultimate phase of the sampling was the random selection of classes as final cluster units. The eligible population had 1826 subjects. A response rate of 83.6% resulted in a total of 1526 participants. Characteristics of the participants are given in Table 1. Seven hundreds and forty-two boys (n = 742) and 784 girls participated. Age distributions of the

Table 1. Participants: age and gender distribution (number and percentage)

Age (years)	Boys		Girls	
	N	%	N	%
12	86	12	96	13
13	155	21	145	18.5
14	138	18.5	119	15
15	130	17	147	18.5
16	139	18.5	139	17.5
17	94	13	138	17.5
All	742	100	784	100

participants was homogeneous in middle age groups with fewer participants in the youngest and oldest ones. Of the 300 non-respondents, 108 were not at school during the survey and 192 subjects refused to participate. The first reasons put forward were recent medical examination (n = 31), omission of the appointment (n = 24), and parental refusal (n = 19). Ethical approval was secured before hand. Information letters were sent to directors, parents and adolescents. All participants and their parents wrote their consent.

Methods
The survey was carried out in the schools' premises. The interviewers had a peaceful classroom at their disposal for the survey. All interviewers had a medical background (i.e. physiotherapy). They underwent a specific training during one week at the beginning of the study. A new training week was scheduled in the middle of the survey period. The adolescents had an individual appointment during the courses period. They filled in first a self-administered questionnaire on their smoking and physical activity habits. Smokers were classified as regular smokers (at least one cigarette a day), occasional smokers (at least one cigarette a week) or ex-smokers (smoked but stopped more than one month ago). Details were also obtained on the duration and on the usual consumption. Questions on usual leisure time physical activity related to sports, to recreational activities and to the journey to school. For each activity the usual weekly frequency and duration was determined and the consequent energy expenditure was calculated. Physical examination included blood pressure (BP), heart rate and anthropometric indices measurement. Blood pressure (mm Hg) was measured following the recommendations of the second Task Force on Blood Pressure in Children and Adolescents [15]. Two observers were in charge of the BP measurement. An inflation peak based on the radial pulse was determined by a first cuff inflation. The blood pressure level was subsequently recorded twice with a standard mercury sphygmomanometer (left arm, subject sitting). The size of the cuff depended on the size of the upper arm. The fifth Korotkoff sound was used for diastolic blood pressure. Anthropometric indices included height, weight, skinfolds and circumferences. Measurements were performed by two interviewers according to the guidelines of the World Health Organisation [16]. Height was measured to the nearest centimetre and weight was recorded to the nearest 0.5 kg, with underwear. The body mass index (BMI) was obtained by dividing the weight by the square of the height. Triceps and subscapular skinfolds were measured with a Harpenden calliper to the nearest 0.1 mm. Hip and waist circumferences were measured to the nearest centimetre with a plastic tape. Hip circumference was recorded at the point yielding the maximum circumference over the buttocks. Waist circumference was measured at the point yielding the smaller circumference between the lower rib margin and the iliac crest. Assessment of pubertal status with Tanner staging was not performed given the adverse effect on participation rate. However, girls were asked about menarche and contraceptive use. Quality control procedures for blood pressure and anthropometric indices included three types of procedures. First, quality assurance measures included the observers' training, an instruction manual and the daily calibration of equipment. Secondly, inter-rater reliability was studied by double measurements performed by an external observer on a sub-sample of participants (n = 31). Differences were analysed using paired t tests. For systolic and diastolic double measurements, all mean differences between the external and the survey observers were non significant. For anthropometric variables, all but one measurement (i.e. subscapular skinfold) did not differ significantly between the external and the survey observers. Thirdly, the blood pressure records were also analysed to detect ending digit preferences, occurrence of odd numbers, frequency of very low digits and abnormally high differences between two readings made by the same observers. Finally, the quality of the data collected was controlled by a check at data entry and further controls during data processing.

Statistical analyses
Statistical analyses were performed using SAS® statistical package [17]. Means and standard deviations were computed for continuous parameters and frequencies were used for qualitative data. t tests were applied for comparing means of two subgroups and analysis of variance was used for more than two groups. χ^2 tests were used to test the association between categorical variables. Associations between continuous variables were analysed by correlation and multiple regression analyses. Tests for normality were performed and skewed values were log-transformed to obtain normal distributions. Models were selected by R-Square and Forward selection procedures. Final regression models were computed with the significant variables selected by the stepwise procedures. The relation between a binary dependent

variable and explanatory variables was analysed with logistic regression models.

Results

Mean systolic blood pressure (SBP) levels were 125 mm Hg (sd = 12 mm Hg) and 122 mm Hg (sd = 11 mm Hg) for boys and girls, respectively. Mean diastolic blood pressure (DBP) was equal to 74 mm Hg (sd = 10 mm Hg) in both genders. The quartiles and range of SBP and DBP in both genders are presented in Table 2. Eleven percent of the adolescents (11.4%, n = 180) had hypertension according to adult criteria (i.e. exceeding 140 mm Hg for systolic blood pressure or 90 mm Hg for diastolic blood pressure). Blood pressure values by age and gender are illustrated in Figure 1. Systolic blood pressure level differed significantly between genders (mean difference = 3.4 mm Hg; 95% confidence interval (CI): 2.2–4.6 mm Hg). This difference appeared from 15 years onwards, with mean difference values equal to 5 mm Hg in 15 and 16 year-olds and equal to 9 mm Hg in 17-year olds. Mean diastolic blood pressure level did not differ significantly between genders, neither in separate age groups nor for all ages combined. Systolic blood pressure increased with age as shown by significantly positive correlation coefficients (Table 3). The rise was more marked for boys than for girls ($r = 0.32$ and $r = 0.07$, respectively). DBP increase with age was less important but correlation coefficients were also statistically significant ($r = 0.07$ and $r = 0.12$ for girls).

Mean BMI values were 20.5 and 21.0 for boys and girls, respectively (95% CI for the difference: 0.15–0.85). BMI increased also significantly with age in both genders (Figure 2). The stabilisation of girls'

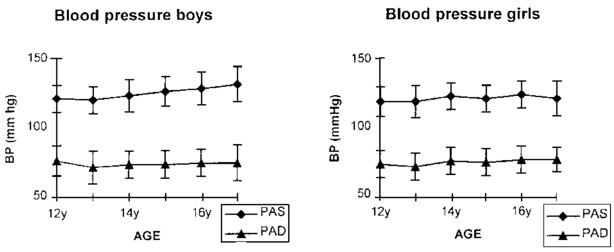

Figure 1. Blood pressure: pattern with age.

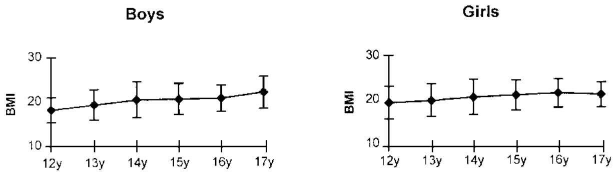

Figure 2. BMI: pattern with age.

weight at 16 years coupled with their slower growth velocity gave a flat curve in the oldest age groups. Conversely, for boys, height and especially weight were still increasing at 17 years and a larger increment was noted at the end of their BMI curve. Subscapular and triceps skinfolds assessed central and peripheral fatness, respectively. Mean triceps skinfolds values were 11.6 mms for boys and 16.3 mms for girls (mean difference = 4.7 mms; 95% CI: 4.1–5.3 mms). Mean subscapular skinfolds values were 9.1 mms and 12.5 mms for boys and girls, respectively (mean difference = 3.4 mms; 95% CI: 2.9–3.9 mms). In girls, both skinfolds increased significantly with age ($r = 0.19$ and $r = 0.11$ for triceps and subscapular skinfolds, respectively). For boys, triceps skinfold decreased and subscapular skinfold increased with age significantly ($r = -0.11$ and $r = 0.07$, respectively). Waist-to-hip ratio (WHR) according to age exhibited also a different pattern in boys and girls. For boys, waist and hip girths increased in parallel and their ratio did not change much during puberty (0.81 to 0.83). For girls, a highly significant decrease with age in the ratio was explained by the waist circumference increase, inferior to the hip circumference change. Mean WHR at the end of puberty was more favourable in girls than in boys (0.73 versus 0.81).

One fifth of the adolescents (19.8%, n = 302) were occasional or regular smokers. Smoking prevalence

Table 2. Systolic and diastolic blood pressure quartiles (mm Hg)

	Min	P25	P50	P75	Max
SBP boys	90	118	124	130	204
SBP girls	90	114	122	130	162
DBP boys	0	68	74	82	102
DBP girls	42	68	74	80	102

Table 3. Correlations between blood pressure and body fatness indices (r values)

	Age	Heart rate	Weight	Height	BMI	Triceps	Subscap	WHR
SBP boys	0.32***	0.09**	0.41***	0.34***	0.33***	0.08*	0.19***	ns
SBP girls	0.07*	0.25***	0.25***	0.16***	0.22***	0.14***	0.16***	ns
DBP boys	0.07*	0.10**	0.09**	ns	0.12***	0.14***	0.14***	0.17***
DBP girls	0.12***	0.13***	0.14***	0.11**	0.12***	0.14***	0.16***	ns

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; ns = non-significant results.
SBP = systolic blood pressure; DBP = diastolic blood pressure; BMI = body mass index; Triceps = triceps skinfold; Subscap = subscapular skinfold; WHR = waist-to-hip ratio.

was similar in both genders. Conversely, leisure time physical activity differed between genders. Boys and girls spent a mean of 8.2 and 5.2 hours every week in physical activity (including light activities as walking).

Relationships between BP and anthropometric indices were analysed by correlation analyses (Table 3). Correlation analyses were performed firstly in smokers and non-smokers separately as the smoking status could have influenced the relation between blood pressure and the other variables. However, results in both subgroups were similar and the figures presented in the table refer therefore to the whole sample. Significant associations were found between SBP and age, heart rate, DBP and anthropometric indices (except WHR). Diastolic blood pressure was similarly positively associated with age, heart rate and anthropometric variables.

Stepwise regression analyses were computed with systolic and diastolic blood pressure as dependent variables. Age, heart rate, anthropometric indices and physical activity were independent parameters. The final SBP models are presented in Table 4. The models under study explained a small proportion of the BP variance. For SBP in boys, positive significant associations were found for weight, age and heart rate whereas physical activity exhibited a negative relationship. Similar results were found for girls except for age and physical activity. DBP models are displayed in Table 5. In boys, significant associations were found with WHR and triceps skinfold whereas weight did not enter the model. The variables significantly associated with DBP in girls were age and subscapular skinfold. Models were computed separately with other body fatness indices as explanatory variables (e.g. BMI). None of them improved the final characteristics of the model and in particular the final multiple R^2 value (Table 6). Finally, the association between hypertension and other determinants was also analysed using a logistic regression analysis. The outcome variable was the presence or absence of hypertension as defined above. In both genders, the variables significantly associated with hypertension were age (odds ratio (OR): 1.33 for boys and 1.22 for girls), heart rate (OR:1.10 for boys and 1.12 for girls) and body fatness (weight for boys, OR: 1.16 and BMI for girls, OR: 1.08).

The influence of menarche and contraceptive use on blood pressure was analysed in girls from the same age group. In 12–13-year olds, systolic blood pressure level was higher for menstruating than for non-menstruating girls. However, the difference disappeared after taking into account their higher weight (54 kg versus 45 kg) and BMI (21.2 versus 18.7). In the 15–17-year old age group, systolic and diastolic blood pressure did not differ between oral contraceptive users and non-users after taking into account body fatness.

Table 4. Multiple regression analyses for systolic blood pressure (SBP)

Variable	Final slope	Standardized coefficient of regression	Significance (p)
Boys (multiple R^2 = 0.21)			
Constant	4.489		
Weight	0.002	0.391	0.0001
Heart rate	0.002	0.125	0.0002
Age	0.007	0.132	0.0008
Physical activity	−0.0003	−0.091	0.0099
Girls (multiple R^2 = 0.12)			
Constant	4.12		
Weight	0.125	0.258	0.0001
Heart rate	0.004	0.245	0.0001

Table 5. Multiple regression analyses for diastolic blood pressure (DBP)

Variable	Final slope	Standardized coefficient of regression	Significance (p)
Boys (multiple R^2 = 0.04)			
Constant	5.549		
Waist/hip ratio	0.410	0.137	0.0002
Triceps skinfold	0.040	0.119	0.001
Girls (multiple R^2 = 0.04)			
Constant	5.743		
Subscapular skinfold	0.379	0.152	0.0001
Age	0.056	0.093	0.001

Table 6. Final multiple R^2 values of models including other body fatness indices

Body fatness variables	SBP Boys	SBP girls	DBP boys	DBP girls
Weight	0.21	0.13	0.03	0.03
BMI	0.20	0.12	0.02	0.03
BMI > P90	0.15	0.09	0.04	0.03
Triceps skinfold	0.13	0.08	0.04	0.02
Subscapular skinfold	0.15	0.10	0.03	0.04

Discussion

Blood pressure levels recorded in adolescents from the province of Luxembourg were higher than those observed in adolescents from the USA or other European countries, although similar to those recorded in another sample of Belgian adolescents [18–24].

Methodological problems are unlikely given the concordance between internal and external observers during quality control procedures. The second and most plausible explanation for high blood pressure levels observed is the current body fatness increase in young people. High BP level in adolescents from the province of Luxembourg might be explained by a worsening of the cardiovascular risk profile in youth during the last decade. This observation is not specific to Belgium. In comparison with a few years ago, the adolescents from the Young Finns Study exhibit a worse lipoprotein profile, higher obesity indices exercise less and have a worse diet [25]. The Bogalusa Study similarly observed an increase in participants' body fatness between successive young cohorts [26]. The available comprehensive data on blood pressure of European adolescents come from studies conducted in the eighties. The blood pressure level of these populations might have also increased during the last decade as far as their body fatness indices have also increased. Finally, specific genetic characteristics of the population are a plausible explanation for the high BP recorded in this sample. This point is corroborated by similar results in adults and children from the same province [13–14].

High anthropometric indices were recorded in this survey. BMI values of adolescents in the province of Luxembourg were compared to British and French percentiles [27–28]. One quarter of the Belgian adolescents (27% of the boys and 24% of the girls) had a higher BMI than the 90th percentile of the French distribution. The percentages were somewhat lower when compared to British percentiles (i.e. respectively 20% of boys and 18% of girls were above the 90th British percentile). In any case, the population from the Belgian province of Luxembourg had about twice as many adolescents exceeding the upper percentile. The choice of a cut-off point based on a percentile to define adolescent obesity (as suggested by the WHO) raises therefore a problem in the province of Luxembourg where fatness indices are high [29]. A high prevalence of obesity was also found in adults and children from the same province [13, 14]. As an illustration, the prevalences of overweight or obesity were 45% and 59% in male and female adults, respectively.

The correlation analysis showed a significant relationship between blood pressure and body fatness indices. However, in the regression analysis, the small size of regression coefficients highlighted the fact that a large part of blood pressure variability was unexplained by age, body fatness and physical activity. A first hypothesis is that weight was not an appropriate parameter for assessing body fatness. Introducing other anthropometric indices in the models tested this hypothesis but these changes did not improve the final equation characteristics. The second hypothesis is that genetic and family factors contributed to the high blood pressure levels found in this young population as suggested by the high incidence of cardiovascular disease in adults of the province. The Muscatine, Dunedin and Nottingham studies [30–32] demonstrated the role of a positive family history in the child blood pressure level. A study conducted in families with natural and adopted children estimated that shared genes accounted for 61% of the variance whereas a shared environment explained the remaining 38% [33]. Further studies should be useful to identify family and genetic components that contribute to the elevated blood pressure level in the province of Luxembourg.

Blood pressure was associated with body fatness in both genders. The positive relationship between body fatness variables and blood pressure has been widely demonstrated in cross-sectional and longitudinal surveys [10–12, 23, 32]. In regression analyses, weight was the first SBP determinant as in other surveys conducted in Belgium and in the USA [23, 34]. For DBP, skinfolds were first selected. The selection of body fatness variables other than BMI is explained by the fact that BMI not only reflects body fatness but also lean body mass index [35]. In the longitudinal Amsterdam Growth and Health survey, correlation analyses showed indeed that BMI (but not skinfolds) had a significant correlation with lean body mass in all age and gender groups from 13 to 27 years of age [36].

Heart rate was significantly positively related to blood pressure level, especially in girls. This positive association was found in some other studies but few hypotheses were suggested to explain this phenomenon [37–38]. In the Bogalusa study, participants were categorised according to their heart rate: hyperdynamic status was significantly associated with high levels of systolic blood pressure, body fatness, insulin and low HDL-cholesterol levels. The authors suggested that a hyperdynamic state could be an early feature of an insulin resistance syndrome. An alternative explanation could be the sympathetic nervous response to examination stress, particularly in girls.

A weak negative association between physical activity and blood pressure was found in boys only. For girls, the negative correlation found between diastolic blood pressure and physical activity disappeared in the regression analysis. Age acted as a confounder, positively associated with girls' diastolic blood pressure and negatively with physical activity. In boys, the inverse relationship between physical activity and systolic blood pressure was similar to observations in adult populations [39, 40]. In adolescents, the beneficial effect of physical activity on blood pressure was demonstrated in intervention studies but the evidence was more difficult to show in population studies where effects were moderate or non-significant [41–44].

A significant correlation was also found between blood pressure and height. The Panel of the Task Force on Blood Pressure in Children specified that their recommendations based on age were not applicable for children whose height exceeded the 90th percentile of the distribution [15]. However, in the multiple regression analysis, influence of height disappeared after taking into account body fatness. St George [21] and A. Saint-Remy [37] found also a non significant association between blood pressure and height after controlling for age and weight.

WHR did not show any relationship with blood pressure, except with DBP in boys [45, 46]. This observation corroborated the negative outcomes of other adolescent studies [5, 7]. This lack of agreement might be explained by four factors. First, technical variability induces variations in anthropometric measurements [47]. However, the greatest differences found among interviewers related to skinfolds measures. Secondly, body fat distribution 'types' are not so well defined in youth as in adults. Thirdly, the variables used to define central fatness might differ in children and in adults. In younger subjects, visceral fatness is mainly retroperitoneal and techniques valid in older populations are not applicable [48]. Finally, a time lag is needed before the onset of a link between body fat distribution and cardiovascular risk factors.

Conclusion

This study confirmed the underlying suspicion of high blood pressure and body fatness indices in adolescents selected from a Belgian high cardiovascular risk population. Adolescence is a key period where cardiovascular risk factors emerge, as well as differences between genders. Lifestyle, physical and physiological changes during puberty entail gender differences in cardiovascular risk factor levels, e.g. a lower blood pressure and a more favourable body fatness pattern in girls than in boys. These differences might be the first step towards the well-known later differential cardiovascular morbidity.

The present data showed a clear but moderate role of body fatness in the level of blood pressure in youth. Unfortunately, no reliable criterion exists today for defining the blood pressure and body fatness levels above that the risk of future cardiovascular disease significantly increases. Follow-up studies are therefore needed to elucidate this question.

A further problem is to establish which adolescents will effectively become adults at risk and ultimately, who will suffer from cardiovascular disease. The question clearly does not have an easy answer, but the inescapable conclusion that emerges from the known tracking of blood pressure and body fatness is that from a public health point of view, high risk adolescents are the first candidates for becoming tomorrow's adults with atherosclerotic disease. One of the most effective ways to improve the future is to foster health promotion interventions in youth. Interventions in children and adolescents have been found effective for improving lifestyle habits, i.e. diet and physical activity. However, the results on cholesterol and blood pressure level differ between studies [49–51]. Further research should confirm the fact that the changes induced by the interventions will persist in adulthood. The challenge is the early introduction of a lifelong healthy lifestyle susceptible to decrease the cardiovascular disease incidence in the long run.

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