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Early vascular damage from smoking and alcohol in teenage years: The ALSPAC study

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Abstract

Aims: To determine the impact of smoking and alcohol exposure during adolescence on arterial stiffness at 17 years.

Methods and Results: Smoking and alcohol use were assessed by questionnaires at 13, 15 and 17 years in 1266 participants (425 males and 841 females) from the ALSPAC study.

Smoking status (smokers and non-smoker) and intensity (“high” ≥ 100 , “moderate” 20-99, and “low or never” < 20 cigarettes in lifetime) were ascertained. Participants were classified by frequency (low or high) and intensity of drinking (light (LI < 2), medium (MI 3-9), and heavy (HI > 10 drinks)). Carotid to femoral pulse wave velocity (PWV) was assessed at 17 years (mean \pm standard deviation and/or mean difference [95% confidence intervals]).

Current smokers had higher PWV compared to non-smokers ($p=0.003$). Higher smoking exposure was associated with higher PWV compared to non-smokers (5.81 ± 0.725 versus 5.71 ± 0.677 m/s, mean adjusted difference $0.211 [0.087, 0.334]$ m/s, $p=0.001$). Participants who stopped smoking had similar PWV to never smokers ($p=0.160$). High intensity drinkers had increased PWV (HI: 5.85 ± 0.8 versus LI: 5.67 ± 0.604 m/s, mean adjusted difference $0.266 [0.055, 0.476]$ m/s, $p=0.013$). There was an additive effect of smoking intensity and alcohol intensity, so that “high” smokers who were also HI drinkers had higher PWV compared to never-smokers and LI drinkers (mean adjusted increase $0.603 [0.229, 0.978]$ m/s, $p=0.002$).

Conclusion: Smoking exposure even at low levels and intensity of alcohol use were associated individually and together with increased arterial stiffness. Public health strategies need to prevent adoption of these habits in adolescence to preserve or restore arterial health.

Key words: smoking; alcohol; arterial stiffness; adolescence.

Introduction

Cigarette smoking and consumption of alcohol are associated with increased cardiovascular (CV) risk in adult life^{1, 2}. Smokers are twice as likely to suffer a myocardial infarction compared to people who have never smoked. For alcohol, a J-shaped association has been reported, with CV benefit for those consuming small or moderate amount of alcohol daily. This has however been questioned in recent studies³ which showed that higher intake or binge drinking are associated with increased cardiovascular morbidity and mortality⁴. Most adult users of alcohol or tobacco first start in their early teens^{5, 6}. In the United States, each day approximately 6,000 adolescents, aged 12 to 18 years, smoke a cigarette for the first time, and 3,000 adolescents become daily smokers⁷. A large body of research suggests that adolescents who participate in one health-risk behavior are more likely to engage in additional risk behaviors⁷. According to the Center of Disease Classification (CDC), 75% of high school students report drinking alcoholic beverages at least once⁷. The early impact of unhealthy behaviors on contemporary arterial disease is not well documented.

The Avon Longitudinal Study of Parents and Children was established in 1991 to provide environmental information on participants from childhood to adolescence and young adulthood and to study the impact on their health (<http://www.alspac.bris.ac.uk>)⁸. The cohort has been followed with questionnaires through childhood and at regular annual clinics since age of 7 years. Detailed information about alcohol and smoking is available for participants through adolescence from questionnaires, and vascular phenotyping was performed at age 17 years. This provided a unique opportunity to assess the impact of exposure to these substances on arterial phenotype and CV risk factor profile in young adulthood.

Methods

Vascular study population

We studied adolescents who attended the ALSPAC clinics in Bristol at 17 years (Figure 1). The study was approved by the ALSPAC Ethics and Law Committee and written informed consent was obtained from all participants.

Tobacco use in adolescence

Information about tobacco use was obtained from questionnaires at ages 13, 15 and 17 years. Participants were classified as smokers or no-smokers at each period. Smoking exposure over the 5-year period was assessed. Participants who stopped smoking were also identified.

Numbers of cigarettes smoked over lifetime were assessed by questionnaire at 17 years and participants were classified in three groups to reflect smoking intensity: “high” (≥ 100 cigarettes), moderate (20-99 cigarettes) and low/never smokers (< 20 cigarettes). Cotinine levels were not measured. Exposure to parental smoking (passive smoking) was also assessed by questionnaires.

Alcohol consumption in adolescence

Information about alcohol consumption was obtained from questionnaires at the ages of 13, 15 and 17 years and participants were classified as drinkers or non-drinkers at each period. At 17 years, more detailed information about patterns of alcohol use was obtained. The participants were asked to report the age when they started drinking alcohol, frequency of alcohol consumption/ month and intensity of alcohol consumption (number of drinks on a typical drinking day, with one drink equating to 8 g of alcohol). Heavy (HI), medium (MI) and light (LI) intensity drinkers were defined as subjects consuming > 10 drinks, 3-9 drinks and < 2 drinks respectively on a typical day that they were drinking alcohol. Preferences for

different beverages (i.e. beer, wine and spirits) were evaluated at 17 years by questionnaires, which assessed the number of each of the aforementioned drinks consumed. Participants were classified as never, light, moderate and heavy beer, wine or spirit-drinking if they reported no consumption or consumption of 1-5, 6-20 and over 20 drinks in the last 30 days.

Aortic stiffness

Pressure-pulse waveforms were obtained using the Vicorder device by placing a 100 mm wide blood pressure cuff around the upper thigh to measure the femoral pulse pressure, and a 30 mm partial cuff around the neck at the level of the carotid artery. To measure carotid to femoral pulse wave velocity (PWV), high quality waveforms were recorded simultaneously for 3 seconds with the subject in the supine position, and the foot-to-foot transit time was determined using an in-built cross-correlation algorithm centred around the peak of the second derivative of pressure. All measurements were performed independently by one of two trained vascular technicians (inter-observer mean difference (standard deviation of difference) 0.2 (0.1) m/s).

Cardiovascular risk factors (Confounders and mediators)

Three seated right arm blood pressure measurements were made (Omron 705 IT oscillometric BP monitor) after a 10min rest and the mean of the last 2 were analyzed. Simultaneous heart rate was measured. Waist circumference, weight and height were measured and body mass index (BMI) was calculated. At 17 years, fasting blood samples were taken; all samples were immediately centrifuged and stored at -80°C for lipid profile (total cholesterol (TC), high density lipoprotein cholesterol (HDL-C), triglycerides), inflammatory markers (C-reactive protein (CRP)) and liver function tests⁹. Socioeconomic status (SES) was designated from 1 to 5 according to National Readership Survey (NRS) grading criteria based on father's occupation, with class 5 denoting unskilled workers. (<http://www.nrs.co.uk/nrs-print/lifestyle->

and-classification-data/social-grade). Physical activity (PA) was assessed by actigraph accelerometer at 15 years. Time spent in moderate to vigorous PA (MVPA) like cycling, swimming, running was calculated, the cut-point being four times resting metabolic rate (equivalent to brisk walking). Minutes of MVPA was calculated as the average minutes of such activity/valid day of measurement.

Statistical analysis

Standard analytical approaches to normally and non-normally distributed measures were used and values are expressed as **mean± standard deviation (SD) and** median (interquartile range), respectively. Categorical variables are expressed as N, percentage. Unadjusted comparisons for continuous variables between groups of interest were performed using analysis of variance (ANOVA), with a test for linear trend carried out across pre-specified categories. Categorical variables were compared using the chi-squared test. Multivariable linear regression analysis was performed to assess the association between smoking, alcohol and cardiovascular risk factors and PWV. **Numeric estimates for comparisons of interest are provided as mean difference in PWV along with 95% confidence intervals [CIs] around the mean difference.** Multivariable models were built through an unbiased method of a priori variable selection, based on previous medical literature and conventional knowledge with adjustment for established CV risk factors and exposure to variables previously associated with increased PWV (Supplementary file). An interaction effect between gender and smoking/alcohol consumption behaviour was tested as well as a potential additive or multiplicative adverse effect of combination of bad behaviours on PWV at 17 years (Supplementary file).

To assess smoking and alcohol exposure across the range of 13-17 years, adolescents with complete questionnaires for smoking behaviour and alcohol consumption were included in longitudinal analyses (Supplementary file).

We replaced missing data for all variables of interest by multiple imputation using the MCMC method¹⁰. Variables with < 5% missing values were not imputed. Statistical analysis was performed by STATA package, version 11.1 (StataCorp, College Station, Texas USA). We deemed statistical significance at alpha=0.05.

Results

Participant characteristics (Table 1)

There was no difference in either smoking or alcohol use between males and females. At 17 years, 23.8% of participants were smokers. One hundred and fifty-four (14.2%) participants drank 0-2 drinks/typical day, 822 (75.6%) 3-9/typical day and 111(10.2%) > 10 drinks/typical day). Seven hundred and twenty-four (66.6%) participants were classified as low frequency drinkers (10 never drinkers, 203 monthly or less, 511 (2-4 times/ month) and 363 (33.4%)) were high frequency drinkers (316 drank 2-3 times/ week and 47 \geq 4 times/week).

Smoking rates (p=0.012) but not alcohol consumption (p=0.130) in adolescence increased progressively from social class I (high status) to V (manual unskilled). Parental smoking was associated with smoking in adolescence (p=0.046). Physical activity did not differ across smoking and drinking intensity groups. Participants with higher alcohol intensity had increased weight but normal BMI, increased TC and mildly deranged liver function (Table 1). Following adjustment, drinking intensity was still related to increased ALT (p=0.014).

Patterns of smoking behaviour during adolescence and arterial stiffness

Current smokers had increased arterial stiffness compared to non-smokers (mean difference 0.176 [0.058, 0.293] m/s, $p=0.003$). Number of cigarettes smoked over lifetime (smoking intensity) was positively associated with PWV, with “high” intensity smokers having higher PWV compared to low/never-smokers (5.81 ± 0.725 versus 5.71 ± 0.677 m/s, mean difference 0.104 [0.01, 0.199] m/s, $p=0.032$). This association remained after adjustment for other CV risk factors (mean increase in PWV for high smokers 3.7% or 0.211 [0.087, 0.334] m/s, $p=0.001$ compared to low/never smokers) (Table 2) and passive smoking ($p=0.004$).

Following imputation for missing values in covariates of interest (i.e. LDL, CRP, family history of CAD, physical activity and passive smoking), the association of smoking intensity and increased PWV remained significant (mean increase 0.122 [0.032, 0.212], $p=0.008$).

There was no interaction ($p_{\text{for interaction}}=0.308$) between gender and smoking exposure on vascular profile.

Of 661 participants with measurements of smoking status at 13, 15 and 17 years, longitudinal analysis indicated that never smokers ($n=269$) had lower PWV at 17 years compared to those who had been smoking since 13 years (-0.313[-0.01, -0.618] m/s, $p=0.044$) and to current smokers (i.e. at 17 years) (-0.196 [-0.034, -0.357] m/s, $p=0.018$). The longitudinal effect of smoking across the period of 13 to 17 years on PWV was consistent across categories of increased duration (mean increase in PWV 0.143 [0.047, 0.239] m/s per category, $p_{\text{for linear trend}}=0.004$) (Figure 2) and when adjusted for passive smoking (mean increase in PWV 0.211[0.083, 0.340] m/s per category, $p_{\text{for linear trend}}=0.002$) compared to never smokers (Table 2). Subjects ($n=91$) who smoked between 13 and 17 years but who subsequently stopped, had comparable PWV to never smokers (mean difference -0.152 [-0.364, 0.06], $p=0.160$). Finally, when missing values for longitudinal smoking status as well as for confounders were imputed, the association of increased duration of smoking with PWV at 17

years remained significant (mean expected increase 0.047[0.01, 0.089] m/s per category, $p=0.027$) after adjustment. Adolescents who smoked since 13 or 15 years, presented an adjusted increase of 0.157 [0.01, 0.308] m/s in PWV compared to participants who had never smoked ($p=0.042$) ($n=1225$) (Table 2).

Patterns of alcohol consumption during adolescence and arterial stiffness

There was no association between age of starting drinking alcohol or frequency of drinking and PWV, whereas HI drinking was associated with increased PWV (HI: 5.85 ± 0.8 versus LI: 5.67 ± 0.604 m/s, mean difference 0.182 [0.019, 0.346] m/s, $p=0.029$). This association remained after adjustment for CV risk factors (relative mean increase 4.7% or 0.266 [0.055, 0.476] m/s, $p=0.013$) (Table 2). Complete analysis for imputed observations of drinking intensity at 17 years and additional exposure variables, including physical activity, revealed a similar association with increased PWV ($p=0.048$) but additional adjustment for family history of CAD and parental smoking attenuated this effect ($p=0.059$). There was no interaction between gender and alcohol consumption ($p=0.230$). Increased drinking intensity as a proxy to binge drinking (≥ 10 drinks/ typical drinking day) correlated with increased arterial stiffness (5.85 ± 0.8 versus 5.7 ± 0.625 m/s, mean increase 0.147 [0.016, 0.279], $p=0.028$), even after controlling for gender, SBP, SES, LDL, BMI, CRP (mean increase 0.231 [0.057, 0.405] m/s, $p=0.01$). In longitudinal analysis, drinking intensity was not associated with PWV ($p>0.05$ for all categories) (Table 2).

Over a month period, adolescents consumed more beer than wine ($p<0.001$) with no difference between consumption of beer- and spirit-based drinks ($p=0.426$). Three hundred twenty-seven (26.7%) adolescents did not drink beer while 414 (33.8%), 371 (30.3%) and 112 (9.15%) were light, moderate and heavy beer-drinkers. Almost half of participants, 558 (46.5%) did not consume wine, 458 (38.2%), 158 (13.16%) and 26 (2.17%) were light,

moderate and heavy wine drinkers respectively. Finally, 264 (21.48%) participants abstained from spirits in the last month, while 518 (42.14%), 372 (30.27%) and 75 (6.1%) adolescents were light, moderate and heavy spirit-drinkers. Light and moderate wine drinking were associated, in univariate analysis, with decreased arterial stiffness (5.67 ± 0.677 m/s for light and 5.61 ± 0.649 m/s for moderate versus 5.77 ± 0.684 m/s for no consumption, $p=0.02$ and $p=0.008$ respectively). Moderate and heavy consumption of beer were related to increased PWV (5.66 ± 0.672 m/s for moderate and 5.79 ± 0.690 m/s for heavy versus 5.62 ± 0.597 m/s for non-consumers, $p=0.001$ and $p<0.001$, respectively) as compared to non-consumption. However, these associations lost their significance following adjustment for confounding exposure variables ($p>0.05$ for all categories). Spirit drinking pattern was not associated with arterial stiffness at 17 years.

Higher alcohol intensity and smoking intensity had additive effects on arterial stiffness (high alcohol and smoking versus never smokers and low alcohol; 5.89 ± 0.857 versus 5.61 ± 0.589 , mean increase $0.277 [0.028, 0.525]$ m/s, $p=0.029$) compared to never smoking and low alcohol consumption. After adjustment, the combined index of alcohol and smoking intensity remained an independent predictor of PWV (mean increase 10.8% or $0.603 [0.229, 0.978]$ m/s in PWV, for adolescents with both high alcohol and smoking versus never smokers and low alcohol, $p=0.002$) (Table 2) (Figure 3). The association of the combined index of alcohol and smoking intensity with increased PWV remained significant after additional adjustment for parental smoking ($p<0.001$) or imputation for missing values in confounders at 17 years (mean increase $0.331 [0.094, 0.568]$ m/s, $p=0.006$) (Table 2). There was a non-multiplicative combined effect of these unfavorable behaviors for the vascular profile of adolescents (p for interaction >0.1 in both unadjusted and adjusted models, likelihood ratio test $p>0.1$ for the addition of the interaction terms smoking*drinking intensity over the core model).

Discussion

This study demonstrates that smoking and alcohol use up to age 17 years have both independent and additive associations with arterial stiffness, a marker of vascular damage that predicts later CV disease and events. Smoking in youth, even at low levels, was associated with increased arterial stiffness, but stopping during adolescence could restore arterial health. In addition, patterns of alcohol use had a significant impact on arterial stiffness with higher intensity, rather than frequency of consumption, showing the greatest adverse effect on PWV. These data demonstrate the importance of public health measures, which focus on preventing the establishment of unhealthy behaviours in children and adolescents.

Impact of smoking and excessive alcohol use on adverse CV outcomes in adults is well established^{11, 12}. While most adult users of alcohol or tobacco first tried these “drugs” during their early teens, the impact of smoking and alcohol consumption on the atherosclerotic process at this early stage of the life course is less clear. To evaluate the development of early atherosclerosis, we measured carotid to femoral PWV in a well-characterised cohort of 17 year olds. Previous studies have demonstrated that PWV is reproducible and, in adults, predicts CV outcomes independently from conventional risk factors¹³.

Epidemiological studies have consistently demonstrated that acute and chronic cigarette use adversely affects vascular health in adulthood and promotes atherosclerosis progression¹⁴.

We quantified exposure to cigarettes during adolescence and also assessed smoking frequency. Both current cigarette use and chronic smoking exposure had an adverse effect on arterial stiffness. This finding is consistent with reports in adults which show that the longer and earlier a person starts smoking, the higher the incidence of coronary artery disease and hypertension and the worse the impact on life expectancy¹⁵. Passive smoking has

consistently been shown to adversely affect arterial health in the young, however no association with aortic stiffness in adolescence was demonstrated in our cohort¹⁶. Exposure to parental smoking at home was assessed as binary variable which precluded evaluation of potential differences in the degree in passive smoking.

The pathophysiological mechanisms linking smoking to vascular disease are still not fully elucidated^{17, 18}. Tobacco contains many toxic and vasoactive compounds, which can exert damage on vascular endothelium and can activate inflammatory and thrombotic pathways relevant to CV events¹⁷. Although cigarette smoking is discouraged in many countries with legislation and other initiatives, our findings confirm that smoking continues to be prevalent in adolescence in both sexes in the UK. It was interesting that only a small percentage of our cohort was in the highest smoking category of >100 cigarettes in total. This is considerably less exposure than that of typical adult smokers, in whom life time exposure is measured in pack-years (\equiv 20 cigarettes/day for 1 year). These data are consistent with a recent NHS survey, which demonstrated that the number of children trying cigarettes has fallen by three quarters since 2003. However, even at these low levels of smoking exposure, we could detect an adverse effect on arterial stiffness even when adjusted for other CV risk factors. Quitting smoking in adolescence could restore aortic stiffness, emphasizing the benefit and opportunity from implementing interventional and educational strategies in the young to preserve arterial health consistent with the **recent European CV prevention guidelines**¹².

There are conflicting findings on the impact of alcohol consumption on atherosclerosis. Alcohol intake has been shown to prevent atherosclerosis in some animal studies, but not in all,^{19, 20} and results from clinical studies are also inconsistent^{21, 22}. High alcohol intake (>34g/day) is associated with higher blood pressure, but observational evidence does not support an association of alcohol intake with blood pressure below this level²³. Mild alcohol

consumption (≤ 2 alcoholic beverages/ day), can independently improve endothelial function both in young healthy subjects and in those with type 2 diabetes²⁴. In contrast, a Finnish study reported a direct linear adverse effect of alcohol consumption on carotid intima media thickness in the young, from as little as 2 alcoholic drinks per day²⁵. In support of this, a recent Mendelian randomization meta-analysis implicated alcohol consumption as a causal factor for CV disease¹¹.

We used a combination of frequency and intensity questionnaires to describe better patterns of alcohol use. The age at which participants started consuming alcohol was not associated with vascular stiffness, suggesting that duration of exposure might not be that important at this young age and this was confirmed in our longitudinal analysis. In contrast, higher intensity rather than frequency of alcohol consumption had the greatest adverse relationship with arterial stiffness. This finding is of particular concern since excessive drinking, with the aim of getting drunk, is increasingly the norm for teenagers²⁶.

The mechanistic link between alcohol and arterial stiffness is not well explored. Light to moderate alcohol consumption is associated with an increase in HDL cholesterol, a decrease in inflammatory mediators and improvement in metabolic pathways^{27,28}. In contrast, excess alcohol consumption has been associated with elevation in blood pressure, autonomic dysregulation and derangements in coagulation and fibrinolytic pathways²⁷. We did not find any beneficial effect of alcohol consumption on arterial stiffness even at lower consumption levels. When we separated different alcoholic beverages, light and moderate wine drinking groups and moderate to heavy beer drinkers were associated with lower and higher PWV, respectively as compared to non-consumers. However, these associations were not significant in multivariable analysis, implying that drinking intensity rather than type of alcoholic beverage may be more important. The association between alcohol use and CV risk factors

was modest and only mild derangements in liver function tests were noted in participants with high alcohol intensity²⁹. Interestingly, lower heart rate was noticed in adolescents with high drinking intensity and this might represent autonomic dysregulation³⁰.

Our study has limitations as it is observational, so that causal associations between smoking, alcohol exposure and arterial stiffness cannot be established. We relied on self-reported confidential questionnaires, collected every 2 years through adolescence, without any biomarker-based assessment of smoking or alcohol exposure. Although self-report of smoking and alcohol behaviour has been shown to be a valid measure compared to biochemical measures, we cannot exclude the possibility that some of our participants may have been misclassified, particularly those from the heavier exposure categories. This however, would be likely to result in underestimation of the effect sizes observed. The presence of unmeasured or residual confounders on our results cannot be excluded. In addition, a number of missing data were imputed in order not to reduce the power of our multivariable longitudinal analysis. This is a well- established statistical approach.

Nevertheless, despite these limitations, we were able to demonstrate important associations between patterns of smoking and drinking use in adolescence with arterial stiffness.

In summary, in this large contemporary British cohort of adolescents, we have demonstrated that drinking intensity and smoking in adolescence, even at lower levels compared to those reported in adult studies, is associated with arterial changes relevant to atherosclerosis progression. The effect of these unhealthy behaviours was independent of one another and additive. Smoking cessation in adolescence was associated with normalization of aortic stiffness. These findings have significant public health implications and provide further support for public health measures to discourage young adults adopting smoking and drinking habits and the benefit of discontinuing these unhealthy behaviours.

Summary illustration

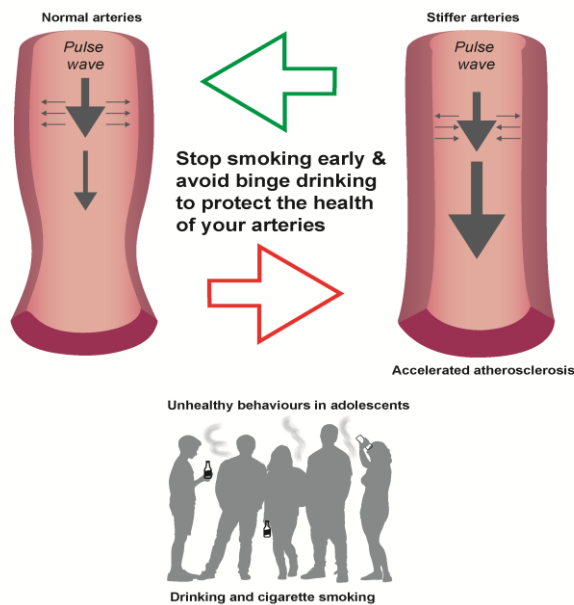


Illustration legend: Unhealthy behaviours in adolescents (drinking and cigarette smoking) are associated with increased carotid to femoral pulse wave velocity (stiffer arteries) and accelerated atherosclerosis. Stopping smoking in adolescence and reducing binge drinking has potential for reversibility of arterial stiffening.

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Figure 1: Study population.

Flow chart shows the number of participants who responded to questionnaires exploring smoking and alcohol use from 13-17 years.

Figure 2: The longitudinal association between smoking exposure and arterial stiffness

Increased smoking exposure was associated with higher aortic pulse wave velocity (PWV) compared to those who had never smoked. Participants who quit smoking had similar PWV compared to those who never smoked. * $p < 0.05$

Figure 3: The combined effect of smoking over lifetime and intensity of drinking on arterial stiffness.

The combination of high intensity drinking with lifetime smoking exposure is shown. Pulse wave velocity (PWV) measurements are expressed as mean values and 95% confidence intervals around the mean on the X axis. The participants who had “high” drinking intensity and “high” smoking exposure had the highest pulse wave velocity compared to the “low lifetime smoking exposure” and “low drinking intensity”. *: $p < 0.05$