Short Communication

Plasma alkylresorcinol metabolites as potential biomarkers of whole-grain wheat and rye cereal fibre intakes in women

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(Received 18 February 2009 – Revised 29 July 2009 – Accepted 3 August 2009 – First published online 29 October 2009)

It has been demonstrated that intact plasma alkylresorcinols (AR) and urinary AR metabolites could be used as biomarkers of whole-grain intake. Thereafter, we developed the method for the plasma AR metabolites, which is more convenient and requires less sample pretreatment than the analysis of intact plasma AR. The aim of the present study is to evaluate whether AR metabolites measured in plasma, in the same population, could also be considered as useful biomarkers of cereal fibre. Fifty-six women were recruited in a cross-sectional and observational study. Dietary intake (5-d record) and plasma AR metabolites (3,5-dihydroxybenzoic acid, DHBA; 3-(3,5-dihydroxyphenyl)-1-propanoic acid, DHPPA) were measured. The relationship between plasma AR metabolites and cereal fibre intake was examined using partial correlation and stepwise regression. Cereal fibre intake correlated significantly with plasma DHBA (r=0.411; P=0.002) and DHPPA (r=0.463; P=0.000) even after adjustment for BMI and age. Thus, plasma AR metabolites correlate with cereal fibre intake as noted with plasma intact AR and urinary AR metabolites. We observed that plasma DHPPA was the independent predictor of cereal fibre intake, explaining 18% of the variance (adjusted r²=0.176; P=0.002). In epidemiological screening, it might be easier to obtain and to collect plasma than urine samples. In addition, the plasma AR metabolites half-life seems longer than those of intact plasma AR, and their measurements are more convenient, and faster. Thus, sum of plasma AR metabolites and more specifically plasma DHPPA seems to be good and specific biomarkers of cereal fibre intake.

Biomarkers: Alkylresorcinol metabolites: Cereal fibre: Rye: Nutrition

Abbreviations: AR, alkylresorcinols; DHBA, 3,5-dihydroxybenzoic acid; DHPPA, 3-(3,5-dihydroxyphenyl)-1-propanoic acid.

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DHPPA have been proposed to be useful biomarkers for whole-grain wheat and rye intakes and indicators of the cereal type consumed. Alkylresorcinol metabolites are possibly formed via β-oxidation of intact plasma AR\(^9\).

We have recently published an article showing that intact AR measured in plasma and the AR metabolites measured in urine could be used as biomarkers of whole-grain intake\(^{22}\). Thereafter, we developed the method for the plasma AR metabolites\(^{23}\). The aim of the present study is to evaluate whether AR metabolites measured in plasma in the same population\(^{22}\) could also be considered as useful biomarkers of whole-grain rye and wheat cereal fibre. This question is relevant because: (1) in epidemiological studies, the fasting blood collection is easier and more often available than the collection of urine; and (2) the analysis of plasma AR metabolites is more convenient and requires less sample pretreatment than the analysis of intact plasma AR.

Subjects and methods

Subjects

Fifty-six women living in the Helsinki area were recruited. Subjects with a history of cancer or any major diseases, or using drugs like oral contraceptives, hormone replacement therapy or antibiotics were excluded. The subjects included also vegetarians (\(n = 20\)) to obtain a broad range of cereal intake. All subjects agreed to consume the diet as before the recruitment during the study. Age, weight, height, BMI (kg/m\(^2\)), age at menarche, type of diet, number of children, menopausal status, smoking status and physical activity level were recorded during the screening visit by questionnaire and published in details previously (Table 1)(22). All subjects gave their written informed consent and were initially interviewed by a doctor who explained the study. The present study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures involving human subjects/patients were approved by the ethics committee of the Helsinki University Central Hospital.

Data collection

All subjects were studied for 5 d during the same year on two occasions with 6 months between collections. The 5-d food record was initiated 2 d before the 3-d plasma collection.

**Table 1. Anthropometric characteristics**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean</th>
<th>SD</th>
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<tbody>
<tr>
<td>Age (years)</td>
<td>46</td>
<td>13</td>
</tr>
<tr>
<td>BMI (kg/m(^2))</td>
<td>22.5</td>
<td>2.7</td>
</tr>
<tr>
<td>Plasma DHBA (nmol/l)</td>
<td>94</td>
<td>82</td>
</tr>
<tr>
<td>Plasma DHPPA (nmol/l)</td>
<td>90</td>
<td>59</td>
</tr>
<tr>
<td>Plasma DHBA + DHPPA (nmol/l)</td>
<td>185</td>
<td>135</td>
</tr>
<tr>
<td>Cereal fibre intake (g/d)</td>
<td>10-02</td>
<td>3-05</td>
</tr>
<tr>
<td>Total fibre intake (g/d)</td>
<td>19-84</td>
<td>6-27</td>
</tr>
</tbody>
</table>

More details for anthropometric characteristics are in Aubertin-Leheudre et al.\(^{22}\).

Dietary intake

All subjects agreed to maintain their habitual diet throughout the whole study. Each subject was provided with a letter balance and was instructed on how to complete the dietary records. A 3-d dietary record has been demonstrated to be valid for estimating dietary intakes in adults without cognitive impairments\(^{24}\). Dietary analyses were completed by a nutritionist using the tables of Southgate for the fibre data (total, cereal, vegetables and fruit and berry)\(^{25}\). For some typical Finnish food (e.g. rye products), we used the fibre data given by the manufacturers. The vegetable fibre values include also the legume fibre values.

Plasma alkylresorcinol metabolites

The two plasma AR metabolites, DHBA and DHPPA, were analysed by HPLC with coulometric electrode array detection (ESA Biosciences, Chelmsford, MA, USA) as described by Koskela et al.\(^{23}\).

Briefly, to 100 \(\mu\)l plasma, syringic acid was added as the internal standard. The enzymatic hydrolysis was carried out overnight at 37°C. The sample was acidified to reach pH about 3, and thereafter extracted thrice with diethyl ether. Separation of diethyl ether and water phase was done by freezing. The combined organic phases were evaporated to dryness. The sample was reconstituted in 50 \(\mu\)l methanol, and 100 \(\mu\)l HPLC mobile phase was added. The sample was filtered through Gelman GHP 0.2 \(\mu\)m filter and analysed with HPLC–coulometric electrode array detection\(^{23}\).

The intra-assay CV for DHBA was 3.9\% and for DHPPA 3.8\%. The inter-assay CV for DHBA was 7.4\% and for DHPPA 10.7\%. This method is considered as accurate, specific and reproducible\(^{23}\).

Statistical analysis

Normality of distribution was determined using the Skewness test. All AR and diet variables were log transformed for statistical analysis. First, we used Pearson correlation test to examine the relationship between plasma AR metabolites and dietary fibre intake (total, cereal, vegetables or/and fruit and berry). We performed partial correlations between plasma AR metabolites and dietary fibre intake using BMI and age as covariables, which could be confounding variables. Finally, stepwise regression analysis was used to determine the independent predictors of cereal fibre intake. The variables plasma AR (C17:0, C21:0 and sum of intact AR), plasma DHBA, plasma DHPPA, sum of plasma AR metabolites, weight, BMI, age and enterolactone were entered in this order in the model. \(P\) values of \(< 0.05\) were considered...
statistically significant. Analyses were performed using SPSS 15.0 software (SPSS Inc., Chicago, IL, USA).

Results
Cereal fibre intake correlated significantly with plasma DHBA (r 0·411; P=0·002) and DHPPA (r 0·463; P=0·000; Table 2) even after adjustment for BMI and age. No significant association was detected between plasma AR metabolites and vegetable or berry/fruit fibre intake (Table 2).

Because our sample included omnivores and vegetarians, we evaluated whether the present results were influenced by the type of diet. We observed a significant correlation between plasma DHPPA and cereal fibre intake in both vegetarians (r 0·514; P=0·019) and omnivores (r 0·404; P=0·038), respectively, even after adjustment for BMI and age. Thus, the type of diet does not seem to influence the relationship between the plasma DHPPA level and the cereal fibre intake.

Finally, as a means of examining a greater depth of the relationship between cereal fibre intake and alkylresorcinols, we performed a stepwise linear regression analysis with plasma AR (C17:0, C21:0 and sum of intact AR), plasma DHBA, plasma DHPPA, sum of plasma AR metabolites, weight, BMI, age and enterolactone in the model. We observed an absence of intercorrelation between residuals (Durbin–Watson statistic = 1·8), showing that the model presented no outliers (leverage = 0·005; Cook’s distance = 0·001), no problem of multicollinearity between variables (variance inflation factor < 10; tolerance = 1) and that the residuals were normally distributed. Thus, the model respected the postulates of a stepwise linear regression. We observed that plasma DHPPA was the independent predictor of cereal fibre intake, explaining 18% of the variance (adjusted r² 0·176; P=0·001; unstandardised coefficients: β = 0·24; standardised coefficients: β = 0·43).

Discussion
The aim of the present study was to evaluate whether plasma AR metabolites could be used as biomarkers of whole-grain rye and wheat cereal fibre intakes in women.

We observed that rye/wheat cereal fibre intake in women during their habitual diet correlates significantly with plasma AR metabolites but not with plasma enterolactone (P=0·995) even after adjustment for BMI and age, which could be confounding variables (Table 2). This result agrees with other recent studies19,26 showing the non-specificity of enterolactone as biomarker of whole-grain intake. Furthermore, the present results are not influenced by the diet status of our subjects because, both in omnivores and vegetarians, rye/wheat cereal fibre intake correlates significantly with plasma DHPPA (r 0·404 and 0·514, respectively) even after adjustment for BMI and age. This indicates that plasma AR metabolites are good biomarkers of rye/wheat cereal fibre intake in Finnish women. At present, there are no accepted biomarkers of whole-grain cereal fibre intake. We demonstrated earlier that plasma intact AR and urinary AR metabolites could be used as biomarkers27. In addition, we showed that plasma AR metabolites correlate with intact plasma AR and urinary AR metabolites23. Thus, intact plasma AR and AR metabolites (in urine and plasma) could be used as biomarkers in free-living population independently of the type of diet.

Because of some commonly known weaknesses of FFQ in epidemiological studies4,7, the precise estimation of the intake of various food components is difficult. The use of a quantifiable biomarker could confirm and strengthen the conclusions in such studies and correct for the measurement errors5,7.

The lack of significant correlation between plasma AR metabolites and the other fibres confirmed the specificity of plasma AR metabolites as biomarkers for cereal rye and wheat fibre intakes. The present results are not influenced by age or BMI, which are known as confounding variables26. Studies have reported that with ageing, people tend to change their dietary habits by increasing the amount of whole-grain cereal intake28 causing the differences in consumption of AR. Moreover, we have previously shown that in free-living women or after a dietary intervention, the plasma intact AR concentration and urinary AR metabolites appeared to be useful biomarkers of whole-grain cereal intake19,20,27. In the present study, we found that a higher coefficient of correlation between cereal fibre intake and plasma DHPPA (r 0·463) than with plasma AR C17:0 (r 0·368), plasma AR C21:0 (r 0·416), urinary DHPPA (r 0·408) or urinary DHBA (r 0·372)22. In addition, we carried out a stepwise regression with plasma AR (C17:0, C21:0 and sum of intact AR), plasma DHBA, plasma DHPPA, sum of plasma AR metabolites, weight, BMI, age and enterolactone in the model. Plasma DHPPA was found to be the only independent predictor of cereal fibre intake in this population.

The present study has some limitations. It has been carried out in Finnish women who are known to consume a high daily amount of cereal fibre rich in AR, mainly from whole-grain rye and wheat. Finland and Denmark have the highest intake of AR compared with other European countries, the estimated average daily intake of AR in free-living population being about 11 mg/d in United Kingdom and about 40 mg/d in Finland28,29. Moreover, the coefficients of correlation are

<table>
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<th>Table 2. Partial correlation between fibre intake and plasma alkylresorcinol metabolites with BMI and age as covariables (n 56)</th>
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<tr>
<td>Cereal fibre intake (g/d)</td>
</tr>
<tr>
<td>--------------------------</td>
</tr>
<tr>
<td>0·463***</td>
</tr>
<tr>
<td>0·024</td>
</tr>
<tr>
<td>0·117</td>
</tr>
<tr>
<td>0·376**</td>
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DHBA, 3,5-dihydroxybenzoic acid; DHPPA, 3-(3,5-dihydroxyphenyl)-1-propanoic acid.

r (coefficient of correlation) obtained using log values.

* P<0·05, ** P<0·01, *** P<0·001.
significant, but the r-values are clinically moderate (r < 0.750). However, these values are in agreement with the values expected in epidemiological studies and in free-living populations [30].

To our knowledge, this is the first study demonstrating that plasma AR metabolites (DHBA, DHPPA and sum of plasma AR metabolites) correlate significantly with whole-grain rye/wheat cereal fibre intake as noted with plasma intact AR and urinary AR metabolites. Cereal fibre intake correlated highly with plasma DHPPA, and plasma DHPPA is the only independent predictor of cereal fibre intake in this population. We believe that in epidemiological screening, it might be easier to obtain and collect fasting blood samples than urine samples. In addition, according to the present preliminary kinetic results, it seems that the half-life of plasma AR metabolites (mean approximately 12 h; data not shown) is longer than the half-life of intact plasma AR (mean approximately 5 h [31]). Finally, the method for analysing the plasma AR metabolites is more convenient, faster and requires less sample pretreatment compared with the method for plasma intact AR. Thus, sum of plasma AR metabolites and more specifically plasma DHPPA could better reflect the amount of AR intake than the intact plasma AR.

In conclusion, sum of plasma AR metabolites and more specifically plasma DHPPA seems to be good and specific biomarkers of whole-grain rye and wheat cereal fibre intakes. Further research in larger free-living populations in other countries is needed to generalise and confirm the present findings.

Acknowledgements
The present study was supported by the Medical Research Council in the Academy of Finland, the Sigrid Jusélius Foundation and Samfundet Folkhälsan. M. A.-L. is supported by the Canadian Institutes of Health Research (CIHR). There were no conflicts of interest. M. A.-L. did the study concept and design, analysis and interpretation of data and preparation of manuscript. A. K. did the acquisition and preparation of manuscript. A. S. did the acquisition and analysis of the samples and revision of manuscript. A. S. did the acquisition and analysis of the samples and revision of the manuscript; H. A. did the study concept and design and revision of the manuscript.

References


