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# Associations between Dietary Patterns and Post-Bronchodilation Lung Function in the SAPALDIA Cohort

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**Keywords**
Dietary pattern · Factor analysis · Lung function · Food frequency questionnaire · Epidemiological studies

**Abstract**
***Background:*** Chronic obstructive pulmonary disease (COPD) is not restricted to smokers. Dietary habits may contribute to the disease occurrence. Epidemiological studies point to a protective effect of fruit and vegetable intake against COPD. ***Objective:*** To investigate the associations between dietary patterns and parameters of lung function related to COPD in the Swiss Cohort Study on Air Pollution and Lung and Heart Diseases in Adults (SAPALDIA). ***Methods:*** Data were included from the second follow-up assessment of the SAPALDIA cohort in 2010–2011 using a food frequency questionnaire. Principal component factor analysis was used to derive dietary patterns, whose association with FEV1, FEV1/FVC, FEF2575, and COPD was investigated by applying multivariate regression analyses. ***Results:*** After adjustment for potential confounders, the "prudent dietary pattern" characterised by the predominant food groups vegetables, fruits, water, tea and coffee, fish, and nuts was positively associated with FEV1 (increase of 40 mL per SD, $p < 0.001$). Also for factor 3 ("high-carbohydrate diet"), we found a significant positive association with FEV1 (with an increase per SD of 36 mL, $p = 0.006$). ***Conclusions:*** The main results are consistent with a protective effect of a diet rich in fruits, vegetables, fish, and nuts against age-related chronic respiratory disease. If confirmed in prospective cohorts, our results may guide nutritional counselling towards respiratory health promotion.



## Introduction

Worldwide, the prevalence of chronic obstructive pulmonary disease (COPD) is dramatically increasing. COPD will account for the third leading cause of death by 2020, thus representing a major public health issue [1–3].

Members of the SAPALDIA Team are listed in the Appendix.

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Cigarette smoking has been established as the predominant risk factor for COPD, but not all smokers develop COPD. Furthermore, COPD also affects many never smokers. While environmental tobacco smoking, occupational inhalants and air pollutants originating from biomass burning and traffic exhaust are established COPD risk factors [4], dietary habits may also contribute importantly to disease aetiology. Epidemiological research points to a benefit of a diet rich in antioxidants and omega-3 fatty acids for protecting from loss of lung function and from COPD symptoms [5–12]. Protective effects of fruit and vegetable intake have been shown in several cohort studies [13–19]. In their review, Boeing et al. [20] also reported a preventive effect of COPD with increasing vegetable and fruit intake. In addition, in a case-control study from Japan, a significantly lower risk of COPD was observed with increasing total vegetable intake [21].

The independent effects of individual foods on health are difficult to establish because diets are eaten in specific combinations and contexts, i.e. strong correlations can exist between nutrients, foods, and also other lifestyle aspects. In order to get a broader picture of dietary behaviour, the authors suggested to assess dietary patterns rather than focus on nutrients [15, 22–24]. Apart from hypothesis-driven approaches, the application of "data-driven approaches," i.e. exploratory approaches based on statistical dimension-reduction methods have been widely used to derive dietary patterns. In this case, dietary patterns are derived directly from the data and do not consider researchers assumptions. Principal component analysis and factor analysis are the most frequently applied dimension-reduction techniques in nutritional epidemiology [25–28].

The aim of this study was to derive dietary patterns for Swiss adults and to assess their association with lung function and COPD in the Swiss Cohort Study on Air Pollution and Lung and Heart Diseases in Adults (SAPALDIA). To focus on irreversible airway obstruction characterising COPD, we used data from post-bronchodilation measurements of lung function being used in the GOLD definition of COPD (i.e., requiring the ratio FEV1/FVC to be lower than 0.7 after bronchodilation).

## Material and Methods

*Study Population*

The data used for the present analysis derive from the second follow-up assessment of the SAPALDIA study, the largest epidemiological cohort in Switzerland that integrates physiological assessments and bio samples. SAPALDIA was initiated in 1991 with a baseline survey (SAPALDIA 1) to investigate the relationship between air pollution and lung diseases in adults recruited as random samples from inhabitant registries (18–60 years, $n$ = 9,651). The multi-centre cohort study includes 8 distinct urban and rural areas representing the demographic and environmental diversity of Switzerland (Aarau, Basel, Davos, Geneva, Lugano, Montana, Payerne, Wald). A first follow-up assessment of participants (SAPALDIA 2) was conducted in 2002. The methods and participation of SAPALDIA 1 and 2 have been described elsewhere [29, 30]. In SAPALDIA 3, which was conducted in 2010–2011, detailed information about dietary intake and physical activity (PA) was obtained in a random subset of participants.

Study approval was given by the central Ethics Committee of the Swiss Academy of Medical Sciences and the Cantonal Ethics Committees for each of the study areas. Written informed consent was obtained from all participants prior to the execution of any of the health examinations.

For the current analysis, 2,178 SAPALDIA 3 participants with complete data on lung function, smoking history, PA, and dietary intake were considered.

*Assessment of Dietary Intake and Identification of Dietary Patterns*

Dietary intake was collected using a paper form food frequency questionnaire (FFQ) designed to assess average food intake over the previous 4 weeks (www.ernaehrungserhebung.ch). The validated, 127-item, semi-quantitative paper form FFQ was handed out to SAPALDIA 3 participants after the conduct of a spirometry during an in-persons health examination. The FFQs were self-administered (detailed written instructions on how to handle the questionnaire were handed out to participants) [31].

Subjects were asked to indicate their consumption of each of the 127 food items during the past 4 weeks in terms of average frequency, portion size, and number of portions. The frequency was asked in 9 categories from "never" to "daily," and the number of portions could be specified. The amounts of food were in gram or decilitre/centilitre, and as a measurement aid for estimating portion size, 3 pictures of each food item were shown. The FFQ additionally obtained information on preparation and cooking methods (using specific types of oil, butter and/or margarine), consumption of take-out foods, and the frequency of use of dietary supplements.

To prepare for dietary pattern analysis, the 127 food items listed in the FFQ were grouped into 25 predefined food groups on the basis of similarity of type of food and nutrient composition. The classification corresponded to a similar grouping already used in the National Nutritional Survey II in the Federal Republic of Germany [32, 33]. To identify food factors, principal component factor analysis was performed on the predefined food groups. Food group consumption (originally given in g/day) was expressed as a function of body weight (g food/kg body weight per day). To achieve better interpretability, the factors were transformed using Varimax rotation. Subsequently, the number of factors retained was based on the eigenvalues and interpretability. There were 6 factors with eigenvalues >1; however, the 3 strongest factors were retained because of their clear interpretability. Their structure is summarised below in Table 1. The "predominant" food groups in factor 1 were vegetables, fruits, water, tea and coffee, fish, and nuts, in contrast to factor 2 where the dominant groups were meat, sausage, egg, fish, and alcohol. Factor 3 was characterised by sweet spreads, bread, dessert, and potatoes.

**Table 1.** Factor loadings estimated by factor analysis after extraction of three factors on 25 food groups

| Food group | Factor loading | | |
|---|---|---|---|
| | factor 1 | factor 2 | factor 3 |
| Dairy products | 0.0219 | 0.0977 | 0.1955 |
| Cheese | 0.1242 | 0.2350 | 0.2797 |
| Meat | 0.1005 | 0.7112 | 0.0245 |
| Sausage | –0.2611 | 0.4973 | 0.2180 |
| Fish | 0.425 | 0.4269 | –0.1444 |
| Egg | 0.0565 | 0.4595 | –0.0194 |
| Meat alternatives | 0.1395 | –0.1942 | 0.0402 |
| Bread | 0.0592 | 0.0769 | 0.6326 |
| Cereals and grains | 0.3725 | 0.1711 | 0.3331 |
| Potato | 0.1284 | 0.3286 | 0.4222 |
| Legumes | 0.1828 | 0.0899 | –0.0564 |
| Vegetables | 0.7106 | 0.1761 | 0.0558 |
| Fruits | 0.6302 | –0.1226 | 0.0892 |
| Soup | 0.3517 | 0.1188 | 0.0301 |
| Sauce | 0.2997 | 0.3631 | 0.2147 |
| Dessert | 0.2932 | 0.0525 | 0.4329 |
| Nuts | 0.3967 | –0.1637 | 0.0966 |
| Salty snacks | –0.0166 | 0.1788 | 0.0938 |
| Composite foods | –0.1257 | 0.1157 | 0.3341 |
| Water, tea and coffee | 0.5271 | –0.1110 | 0.1635 |
| Soft drinks with sugar | –0.1151 | 0.0726 | –0.0628 |
| Soft drinks without sugar | –0.0215 | 0.0228 | –0.1633 |
| Alcohol | –0.2423 | 0.4183 | –0.0780 |
| Preparation fats and savoury spreads | 0.2259 | 0.2196 | 0.3484 |
| Sweet spreads | 0.0545 | –0.1028 | 0.6661 |

Factors were interpreted based on variables with a factor loading of 0.40 or more. Factor 1: vegetables, fruits, water, tea and coffee, fish, nuts → "prudent pattern." Factor 2: meat, sausage, egg, fish, alcohol → "traditional Western diet." Factor 3: sweet spreads, bread, dessert, potato → "high-carbohydrate diet."

Factor 1 seemed to represent vegetable foods and fish consumption, while factor 2 seemed to represent consumption of animal foods and alcohol. The characteristic features of factor 3 were foods rich in carbohydrates.

*Assessment of Lung Function and Other Variables*

In SAPALDIA 3, lung function was measured using the portable, ultrasonic EasyOne spirometer (ndd Medizintechnik AG, Zürich, Switzerland), which is widely used in epidemiological studies. In order to ensure strict quality control, field workers were trained to a standardised protocol, and the accuracy of the device was recorded and verified daily by using a 3-L syringe. Recalibrated lung function parameters were used for this analysis as previously described [34].

Spirometry was done before and after inhalation of a bronchodilator. For the present analysis, we considered lung function parameters that were assessed after the inhalation of salbutamol, focusing on the lung function parameters FEV1 (forced expiratory volume in 1 s), the ratio between FEV1 and FVC (forced vital capacity), and FEF25–75% (mean of the flow between the 25th and the 75th percentile of exhaled volume). In addition, we defined COPD as FEV1/FVC <0.7.

Other covariates considered for the present analysis were anthropometric data such as height and weight. Both were measured in the study centres, the latter by using calibrated scales (SECA 877, SECA GmbH & Co, Hamburg, Germany). In addition, several parameters were gathered in a computer-assisted interview based on a standardised questionnaire and led by trained field workers: sociodemographic variables such as educational level (low, medium, high), civil status (married, divorced, widowed, single) and employment status (employed, home, training/military/long vacation/unemployed, pension); detailed information on smoking status (never, former, current) and total amount of pack-years smoked, and the number of cigarettes per day, on exposure to environmental tobacco smoke in the last 12 months (yes/no), and on parental smoking in childhood (yes/no). Based on 4 short questions from the Swiss Health Survey questionnaire in 2012 [35] which concerned the frequency and duration of weekly PA, 2 PA variables were derived: one for the weekly number of minutes of moderate PA and the other one for the weekly time of vigorous PA.

*Statistical Analyses*

Data Pre-Processing

Prior to data entry, the FFQ paper forms were checked for completeness and possible errors. After scanning the FFQ paper forms, each questionnaire was checked for completeness, missing values, and structurally impossible answers (e.g., 2 boxes checked where only one was selectable). The following data management procedures were applied. If indications of frequency, portion size and number of portions were completely missing, the frequency information "never" was assigned to the respective food item. If at least one of frequency, portion size or number of portions was indicated, the following strategy was applied. Missing values of frequency or number of portions were imputed by the respective mean value for the given food item. Missing values of portion sizes were imputed by pre-set standard portion sizes.

In order to avoid bias from clearly wrongly reported food habits in the FFQ, the distribution of the total energy intake computed from the FFQ reports was considered. Upper and lower cut-offs for exceedingly high and low energy intakes, respectively, were defined at the 75th percentile plus 1.5 times the interquartile range (3,868.3 kcal) and the 25th percentile minus 1.5 times the interquartile range (242.3 kcal) [36]. Out of a total of 2,991 FFQs, 118 FFQs (3.9%) were excluded due to implausible energy intakes.

Statistical Methods

In the descriptive analyses, quantitative variables were described by their mean and standard deviation, and categorical variables by their frequency distribution. Principal component factor analysis was performed to identify dietary patterns.

In order to analyse the relationships between dietary patterns and lung function outcomes, multiple mixed linear and logistic regression models with random intercepts by study area were applied. All models contained the variables sex, age, and age squared as well as interactions between sex and the 2 age variables, and

**Table 2.** Characteristics of study participants in SAPALDIA 3 with food frequency questionnaire ($n$ = 2,178)

| Variable | All | Men | Women |
|---|---|---|---|
| Participants, *n* (%) | 2,178 (100.0) | 1,011 (46.4) | 1,167 (53.6) |
| Age, years | 58.6 (10.6) | 58.5 (10.7) | 58.7 (10.6) |
| Height, cm | 168.8 (9.1) | 175.6 (6.5) | 162.8 (6.4) |
| Weight, kg | 74.3 (15.0) | 82.9 (12.3) | 66.8 (13.0) |
| Body mass index[a] | | | |
| Underweight | 28 (1.3) | 2 (0.2) | 26 (2.2) |
| Normal weight | 963 (44.2) | 334 (33.0) | 629 (53.9) |
| Overweight | 825 (37.9) | 496 (49.1) | 329 (28.2) |
| Obesity class I | 289 (13.3) | 152 (15.0) | 137 (11.7) |
| Obesity class II | 51 (2.3) | 19 (1.9) | 32 (2.7) |
| Obesity class III | 22 (1.0) | 8 (0.8) | 14 (1.2) |
| Study area, *n* (%) | | | |
| Basel | 310 (14.2) | 147 (14.5) | 163 (14.0) |
| Wald | 391 (18.0) | 188 (18.6) | 203 (17.4) |
| Davos | 238 (10.9) | 113 (11.2) | 125 (10.7) |
| Lugano | 182 (8.4) | 76 (7.5) | 106 (9.1) |
| Montana | 263 (12.1) | 119 (11.8) | 144 (12.3) |
| Payerne | 274 (12.6) | 126 (12.5) | 148 (12.7) |
| Aarau | 338 (15.5) | 156 (15.4) | 182 (15.6) |
| Geneva | 182 (8.4) | 86 (8.5) | 96 (8.2) |
| Education, *n* (%) | | | |
| Low | 130 (6.0) | 32 (3.2) | 98 (8.4) |
| Medium | 1,452 (66.7) | 622 (61.5) | 830 (71.2) |
| High | 596 (27.4) | 357 (35.3) | 239 (20.5) |
| Employment status, *n* (%) | | | |
| Employed | 1,287 (59.1) | 647 (64.0) | 640 (54.8) |
| Home | 138 (6.3) | 11 (1.1) | 127 (10.9) |
| Training, military, long vacation, not work | 28 (1.3) | 16 (1.6) | 12 (1.0) |
| Pension | 725 (33.3) | 337 (33.3) | 388 (33.3) |
| Civil status, *n* (%) | | | |
| Married | 1,517 (69.7) | 787 (77.8) | 730 (62.6) |
| Divorced | 268 (12.3) | 98 (9.7) | 170 (14.6) |
| Widowed | 127 (5.8) | 17 (1.7) | 110 (9.4) |
| Single | 266 (12.1) | 109 (10.8) | 157 (13.5) |
| Smoking status, *n* (%) | | | |
| Never | 1,085 (49.8) | 448 (44.3) | 637 (54.6) |
| Former | 749 (34.4) | 398 (39.4) | 351 (30.1) |
| Current | 344 (15.8) | 165 (16.3) | 179 (15.3) |
| Pack years | 11.7 (18.6) | 14.6 (20.8) | 9.1 (15.9) |
| Cigarettes per day | 2.0 (5.9) | 2.2 (6.6) | 1.8 (5.2) |
| ETS/12 m[b], *n* (%) | | | |
| No | 1,925 (88.4) | 890 (88.0) | 1,035 (88.7) |
| Yes | 253 (11.6) | 121 (12.0) | 132 (11.3) |
| Parental smoking, *n* (%) | | | |
| No | 993 (45.6) | 447 (44.2) | 546 (46.8) |
| Yes | 1,185 (54.4) | 564 (55.8) | 621 (53.2) |
| Lung function (post-bronchodilatation) | | | |
| FEV1 | 3.1 (0.8) | 3.6 (0.8) | 2.7 (0.6) |
| FEV1/FVC | 0.8 (0.1) | 0.8 (0.1) | 0.8 (0.1) |
| FEF2575 | 2.7 (1.2) | 3.1 (1.3) | 2.4 (1.0) |
| COPD[c], *n* (%) | | | |
| No | 1,812 (83.2) | 820 (81.1) | 992 (85.0) |
| Yes | 366 (16.8) | 191 (18.9) | 175 (15.0) |

**Table 2** (continued)

| Variable | All | Men | Women |
|---|---|---|---|
| Dietary intake | | | |
| Energy, kcal | 2,038.8 (630.8) | 2,172.3 (637.9) | 1,923.1 (601.3) |
| Protein, g/day | 97.6 (34.5) | 106.1 (35.6) | 90.2 (31.7) |
| Carbohydrates, g/day | 268.2 (102.4) | 281.7 (106.2) | 256.5 (97.5) |
| Fat, g/day | 76.2 (29.4) | 81.6 (31.1) | 71.5 (27.0) |
| Fibres, g/day | 29.0 (12.3) | 27.9 (11.4) | 29.8 (12.9) |
| Physical activity | | | |
| Moderate physical activity, min/week | 276.9 (303.9) | 286.1 (314.5) | 268.8 (294.4) |
| Vigorous physical activity, min/week | 70.4 (91.9) | 84.3 (101.5) | 58.4 (80.8) |

Data are presented as mean (SD) or as stated. [a] Underweight ≤18.5, normal weight = 18.5–24.9, overweight = 25.0–29.9, obesity class I = 30.0–34.9, obesity class II = 35.0–39.9, obesity class III ≥40.0. [b] Exposure to environmental tobacco smoke in the last 12 months. [c] Defined as FEV1/FVC <0.7.

those for quantitative lung function variables also included height and an interaction between sex and height. The basic model (referred to as model 1) included these basic variables and the 3 dietary factors along with a priori selected potential confounder variables (smoking status, pack-years smoked, daily number of cigarettes smoked, exposure to passive smoking in the last 12 months, parental smoking in childhood, educational level, civil status, employment status, and PA, as described in the previous section). Model 2 (referred to as "main model") was further adjusted for total energy intake, and model 3 additionally included body mass index (BMI). BMI was not included in the basic model because it may be both a confounder and an intermediate endpoint of dietary habits.

Results are expressed as mean change in the outcome per unit increment in the respective factor. As factors are z-standardised, one unit is equivalent to one standard deviation.

We conducted several sensitivity analyses. As the effects of smoking on lung function might not have been fully captured in our final model, we repeated all analyses in lifetime non-smokers. Moreover, to assess potential confounding by seasonal variations in diet and in lung function, we ran models, which additionally included the month of interview as categorical variable. Given previous findings suggesting a protective effect of omega-3 fatty acids [7] and fibre [37] on the risk of COPD, we added the 4 separate consumption variables for fatty and lean fish, and for whole grain and refined bread as additional covariates to the models to see whether associations with the 3 dietary patterns were robust to adjustment for these specific dietary items.

To address potential participation bias, additional analyses using inverse probability weighting were conducted [38]. For this purpose, the probability of being included in the present analysis was modelled using predictor variables assessed in the entire SAPALDIA 3 sample.

All statistical analyses were performed using the statistical software STATA (Release 13.1 Statistical Software; StataCorp, College Station, TX, USA).

## Results

*Study Population*

The characteristics of the study population included in this analysis and answering an FFQ with complete data on all covariates in SAPALDIA 3 ($n$ = 2,178) are given in Table 2. Age ranged from 37.3 to 80.8 years, with a mean of 58.6 years; 53.6% were women. Considering anthropometric data of the participants, the mean height was 168.8 cm and mean weight was 74.3 kg. Their BMI ranged from 15.9 to 54.9, with a mean of 26.0. 82.1% had a BMI between 18.5 and 30 (Table 2). Two-thirds had a medium and 27.4% a high educational level. The majority of the subjects were employed at this period (59.1%) and one-third was retired. 69.7% of the study participants were married, followed by 12.1% singles, 12.3% divorced, and 5.8% widowed persons. Concerning smoking status, half of the participants were never smokers (49.8%), one-third were former smokers and 15.8% were current smokers at the time of the assessment. Males were more likely to have smoked than females (39.4 vs. 30.1%), and to smoke more heavily (14.6 vs. 9.1 mean pack years). 88.4% of the study group did not show an exposure to passive smoking in the last 12 months, but more than half of the participants (54.4%) affirmed parental smoking in childhood. In terms of lung function parameters, the study population showed a mean FEV1 of 3.1 L, a mean FEV1/FVC of 0.8 and a mean FEF2575 of 2.7 L/s. Males had higher levels in FEV1 and FEF2575 than females (3.6 vs. 2.7 and 3.1 vs. 2.4). 16.8% of the study participants had COPD according to the FEV1/FVC <0.7 cut-off. The prevalence of COPD was higher

**Table 3.** Independent associations between dietary patterns and FEV1, FEV1/FVC, and FEF2575, adjusted for different covariates ($n$ = 2,178)

| | Factor 1 | | | Factor 2 | | | Factor 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Coeff | 95% CI | $p$ value | Coeff | 95% CI | $p$ value | Coeff | 95% CI | $p$ value |
| FEV1, mL | | | | | | | | | |
| Model 1[a] | 28.84 | 8.66 to 49.02 | 0.005 | –10.06 | –29.06 to 8.94 | 0.30 | 16.48 | –2.83 to 35.79 | 0.09 |
| Model 2[b] | 39.65 | 17.36 to 61.94 | <0.001 | 3.56 | –18.89 to 26.02 | 0.76 | 35.71 | 10.04 to 61.38 | 0.006 |
| Model 3[c] | 22.52 | –2.53 to 47.58 | 0.08 | –11.17 | –35.52 to 13.18 | 0.37 | 12.23 | –18.93 to 43.38 | 0.44 |
| FEV1/FVC, % | | | | | | | | | |
| Model 1 | 0.08 | –0.22 to 0.39 | 0.60 | –0.09 | –0.38 to 0.20 | 0.56 | –0.28 | –0.57 to 0.01 | 0.06 |
| Model 2 | 0.03 | –0.31 to 0.37 | 0.87 | –0.15 | –0.49 to 0.19 | 0.38 | –0.38 | –0.76 to 0.01 | 0.06 |
| Model 3 | 0.26 | –0.12 to 0.63 | 0.19 | 0.03 | –0.34 to 0.40 | 0.86 | –0.02 | –0.49 to 0.45 | 0.94 |
| FEF2575, mL/s | | | | | | | | | |
| Model 1 | 28.60 | –12.77 to 69.97 | 0.18 | –7.13 | –46.25 to 31.99 | 0.72 | –19.61 | –59.35 to 20.13 | 0.33 |
| Model 2 | 30.22 | –15.48 to 75.93 | 0.20 | –5.10 | –51.18 to 40.99 | 0.83 | –16.73 | –69.37 to 35.90 | 0.53 |
| Model 3 | 39.73 | –11.70 to 91.17 | 0.13 | 2.44 | –47.64 to 52.52 | 0.92 | 1.63 | –62.54 to 65.81 | 0.96 |

All three factors were included in the same model. The coefficients give the mean change in the outcome per unit increment in the respective factor. As factors are z-standardised, one unit is equivalent to one standard deviation. [a] Mixed linear regression models with random intercepts by study areas and adjusting for sex and interactions of sex with age, age$^2$ and height, for smoking status (never, former, current), pack-years smoked, daily number of cigarettes smoked, exposure to passive smoking in the last 12 months, parental smoking in childhood, educational level, civil status, employment status, and physical activity. [b] Further adjustment for total energy intake. [c] Model 2 with additional adjustment for body mass index as a categorical variable with 6 levels.

in males (18.9% vs. 15.0% in females). The mean energy and macronutrient intake was higher in males, except for fibres (29.8 g in females vs. 27.9 g in males). Male participants also tended to show a higher mean PA level than female participants (e.g., for moderate PA: 286.1 vs. 268.8 min/week).

The distributions of educational level, civil status, occupational categories, smoking categories, age, and BMI were comparable between participants included in the present analysis and SAPALDIA 3 participants not included due to incomplete data (e.g., because they were not randomly selected for answering the FFQ or did not have lung function testing ($n$ = 2,574) (see online suppl. Table S1; for all online suppl. material, see www.karger.com/doi/10.1159/000488148). Women were over-represented in our analysis sample, and there was some heterogeneity in inclusion rates across study areas.

*Dietary Patterns and Lung Function Measurements*

Table 3 provides a summary of models 1–3 for the associations of lung function outcomes FEV1, FEV1/FVC, and FEF2575 with the 3 dietary factors combined. Factor 1 was positively associated with FEV1 in the models 1 and 2 (with increases per SD ranging between 29 and 40 mL, all $p < 0.006$). After further adjustment for BMI, the association decreased to 23 mL and was no longer significant ($p = 0.08$).

Associations of FEV1/FVC with factor 1 were slightly positive but clearly non-significant. Regarding the relationship with the lung function parameter FEF2575, we found consistent positive associations with factor 1 (with estimated increases in FEF2575 between 29 and 40 mL/s per SD), but none of these associations was statistically significant. In contrast to FEV1, additional adjustment for BMI even increased the association of factor 1 with FEF2575 (to 40 mL/s per SD).

Factor 3 also showed a significant positive association with FEV1 in model 2 (with an increase per SD of 36 mL, $p = 0.006$), whereas the associations were considerably smaller in model 1 (17 mL per SD, $p = 0.09$) and in model 3 (12 mL per SD, $p = 0.44$).

When analysing the independent relationship of factor 3 with FEV1/FVC, there was a borderline significant negative association in models 1 and 2 (–0.3 and –0.4% per SD, respectively).

Unlike in the case of FEV1, associations with factor 3 were negative across models 1 and 2 of FEF2575, without however reaching statistical significance. We found no association of factor 2 with any of the 3 lung function parameters.

**Table 4.** Independent associations between dietary patterns and COPD adjusted for different covariates ($n$ = 2,178)

| | COPD Gold | | |
|---|---|---|---|
| | odds ratio | 95% CI | $p$ value |
| Factor 1 | | | |
| Model 1[a] | 0.98 | 0.86–1.13 | 0.82 |
| Model 2[b] | 0.97 | 0.84–1.13 | 0.70 |
| Model 3[c] | 0.90 | 0.77–1.06 | 0.21 |
| Factor 2 | | | |
| Model 1 | 1.03 | 0.91–1.17 | 0.61 |
| Model 2 | 1.02 | 0.88–1.18 | 0.83 |
| Model 3 | 0.95 | 0.81–1.11 | 0.52 |
| Factor 3 | | | |
| Model 1 | 1.05 | 0.93–1.20 | 0.44 |
| Model 2 | 1.03 | 0.87–1.21 | 0.76 |
| Model 3 | 0.90 | 0.74–1.10 | 0.31 |

COPD defined as FEV1/FVC <0.7. All three factors were included in the same model. [a] Mixed logistic regression models with random intercepts by study areas and adjusting for sex and interactions of sex with age, age$^2$, for smoking status (never, former, current), pack-years smoked, daily number of cigarettes smoked, exposure to passive smoking in the last 12 months, parental smoking in childhood, educational level, civil status, employment status, and physical activity. [b] Further adjustment for total energy intake. [c] Model 2 with additional adjustment for body mass index as a categorical variable with 6 levels.

In the subsample of never smokers, the effect estimates reported above tended to be larger (see online suppl. Table S2) and the estimated effect of factor 1 on FEV1 in model 3 was almost twice as high as in the entire sample and reached statistical significance ($p$ = 0.02).

Significant effect estimates did not show major changes when inverse probability weighting was applied (cf. see online suppl. Table S3). Most estimates of the effects of the 3 dietary factors were comparable between men and women (cf. see online suppl. Table S4).

*Dietary Patterns and COPD*

Table 4 presents the results of the multiple mixed logistic regression models estimating the independent associations of the 3 dietary factors with COPD. Associations with factor 1 were consistently negative, which is in line with the corresponding coefficients for FEV1. However, none of these associations was statistically significant.

Associations between COPD and factors 2 and 3 were positive in models 1 and 2 and negative in model 3, but highly non-significant throughout.

## Discussion

In the present study, we assessed the relation between dietary patterns and lung function outcomes. Three prominent food factors (dietary patterns) were derived by principal component factor analysis. Factor 1 reflected a "prudent pattern," described by the predominant food groups vegetables, fruits, water, tea and coffee, fish, and nuts. Factor 2 could reflect a rather contrasting pattern, i.e. a traditional Western pattern characterised by a high intake of meat, sausage, egg, fish, and alcohol and thus likely representing a rather "unhealthy" diet. Factor 3 was characterised by a "high-carbohydrate diet," i.e. a high intake of sweet spreads, bread, dessert, and potatoes.

Our major finding was the positive association of the "prudent pattern" (vegetables, fruits, water, tea and coffee, fish, and nuts) with FEV1. Associations with FEV1/FVC, FEF2575, and COPD were not statistically significant, but consistent with the FEV1 results.

In the case of FEV1, the statistical significance was lost, and the coefficient decreased after further adjustment for BMI. To what extent BMI is a confounder and/or a mediator of the associations between dietary habits and lung function could only be determined in a longitudinal study.

The findings are in line with other studies analysing the relationship of dietary patterns and dietary intake with lung function or COPD. Similar to our analysis, Shaheen et al. [13] showed in their cross-sectional cohort study a positive association between a prudent dietary pattern and FEV1. Our "prudent" pattern was very similar to theirs and differed only in terms of its wholemeal cereals content. Another recently published study found a lower risk of COPD with a higher intake according to a healthy diet [16]. In that prospective cohort study, associations between the risk of COPD and dietary patterns were analysed. A high Alternate Healthy Eating Index 2010 (AHEI-2010) diet score was reflecting a rather healthy diet, described by high intakes of whole grains, polyunsaturated fatty acids, nuts and long-chain omega-3 fats. In contrast to our "prudent pattern," this pattern consisted of other food groups that are rich in dietary fibres, polyunsaturated fatty acids and long-chain omega-3 fats. Moreover, a cross-sectional study by Watson et al. [39] showed a specific protective effect of fruit and vegetable consumption on COPD. Other data of a prospective study of diet and decline in lung function in a general population also suggested a beneficial effect of a prudent pattern on the FEV1 level [40]. Finally, our findings add to the general evidence of a protective effect of antioxi-

dant intake in COPD, evidenced in part by previously reported negative associations of vitamin C with the prevalence of COPD. Cross-sectional studies have consistently shown that subjects with a high level of vitamin C intake have larger FEV1 than their counterparts [41, 42]. Oxidative stress and associated inflammation in the respiratory tract of COPD patients is well established [5].

A novel finding of our study was the positive association of factor 3 ("high-carbohydrate diet") with FEV1, which disappeared though upon BMI adjustment. Given the opposite direction of the association with FEV1 and FEF2575, in the absence of previous evidence and in the light of the inconsistency of associations with other respiratory health indicators, this finding needs to be interpreted with caution, however.

Our results were consistent in men and women, but they tended to be stronger in never smokers. This may indicate the presence of some residual confounding from imperfect control of smoking effects or a stronger effect of nutritional factors in persons who had never smoked.

The strengths of this analysis include a large sample size ($n$ = 2,178) with rich information on lifestyle and environmental factors. Lung function data were obtained in the context of stringent spirometry protocols with well-trained field workers. Studying dietary patterns rather than single food items or nutrients has the advantage of addressing the influence of food habits in their lifestyle context. Knowledge of the effects of dietary patterns can be beneficial in designing preventive measures directed to stimulate alteration of dietary habits in specific subgroups of the population.

However, we need to address some potential limitations of these analyses. First, the dietary pattern analysis was based on a food group categorization of the 127-item FFQ into 25 food groups, which was done a priori and further evaluated with experts (see methods under assessment of dietary intake and identification of dietary patterns). Food attribution and categorization are influenced by cultural agreements and therefore differ, e.g. between European countries. Thus, despite being in accordance with cultural practice, food group categorization may be arbitrary to some extent, and this can pose limitations. Furthermore, the quality of the FFQ data is challenged by imperfect recall and difficulties in estimating portion size [43]. Despite the use of a validated FFQ, the study participants may have had difficulty recalling frequency and food portion size accurately. An additional challenge in the estimation of food intake could derive from the high level of detail in the food groups and the seasonality aspect, which could result in a tendency for over-reporting or under-reporting of specific food groups. Yet, additional adjustment for seasonality aspects did not materially alter the reported associations.

Regarding social desirability, it is well known that women may be more likely to over-report food items related to a positive health image, e.g. fruits and vegetables, whereas sweets and cakes are usually associated with a rather negative health image and thus tend to be under-reported [44]. Moreover, for this analysis, dietary intake was measured only at one point in time, which introduces some random misclassification. However, this will affect intake of specific nutrients more than general dietary patterns. Also, it is well known that diet does track throughout a lifetime [45]. Despite these limitations, nutrition epidemiology presents an important research area because diet is a modifiable risk factor.

We also recognise that our study population could represent a group of people who differ from the general population in terms of health awareness, socioeconomic status and smoking behaviour. We therefore reran our models using inverse probability weighting. As all main findings could be confirmed, we think that these are unlikely affected by major selection bias.

The most important limitation is the cross-sectional study design as a result of the availability of detailed dietary information from the last SAPALDIA follow-up only, which limits our ability to infer a causal relationship between dietary intake and lung function and to differentiate between the 2 possible roles of BMI as a confounder and a mediator of this relationship.

In conclusion, our results are in line with a protective effect of a "prudent dietary pattern" against chronic respiratory disease. Apart from potential prevention benefits for cardiovascular diseases, diabetes, and cancer, a higher fruit and vegetables intake might also play a protective role in the pathogenesis of COPD through anti-inflammatory effects. For COPD prevention, smoking cessation is still the most relevant public health message. But our results point to diet as a modifiable potential risk factor of lung function decrease. Recommendations for high fruit and vegetable intake and low meat and alcohol intake may become an important pillar of respiratory disease prevention.

## Appendix

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All authors declare that they have no conflict of interest.


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## Author Contributions

N.S., C.B., and N.P.H. designed the research, N.S., L.G., and N.P.H. conducted the research, N.S., L.G., and C.S. performed the statistical analysis and N.S., L.G., C.S. and N.P.H. wrote the paper. C.B., M.P., T.R., A.T., and D.S. provided guidance in drafting the manuscript. All authors read and approved the final manuscript.

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