Food Omega-3 Fatty Acid Intake of Individuals (Total, Linolenic Acid, Long-Chain) and Their Blood Pressure
INTERMAP Study

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Abstract—Findings from short-term randomized trials indicate that dietary supplements of omega-3 polyunsaturated fatty acids (PFA) lower blood pressure of hypertensive persons, but effect size in nonhypertensive individuals is small and nonsignificant. Data are lacking on food omega-3 PFA and blood pressure in general populations. The International Study of Macro- and Micro-nutrients and Blood Pressure (INTERMAP) is an international cross-sectional epidemiologic study of 4680 men and women ages 40 to 59 from 17 population-based samples in China, Japan, United Kingdom, and United States. We report associations of food omega-3 PFA intake (total, linolenic acid, long-chain) of individuals with blood pressure. Systolic and diastolic blood pressure were measured 8 times at 4 visits. With several models to control for possible confounders (dietary, other), linear regression analyses showed inverse relationship of total omega-3 PFA from food (percent kilocalories, from four 24-hour dietary recalls) to systolic and diastolic blood pressures. With adjustment for 17 variables, estimated systolic blood pressure/diastolic blood pressure differences with 2 standard deviation higher (0.67% kcal) omega-3 PFA were −0.55/−0.57 mm Hg (Z-score −1.33, −2.00); for 2238 persons without medical or dietary intervention, −1.01/−0.98 mm Hg (Z −1.63, −2.25); for 2038 nonhypertensive persons from this sub-cohort, −0.91/−0.92 mm Hg (Z −1.80, −2.38). For linolenic acid (largely from vegetable foods), blood pressure differences were similar eg, for the 2238 “nonintervened” individuals, −0.97/−0.87 mm Hg (Z −1.52, −1.95); blood pressure differences were −0.32/−0.45 mm Hg for long-chain omega-3 PFA (largely from fish). In summary, food omega-3 PFA intake related inversely to blood pressure, including in nonhypertensive persons, with small estimated effect size. Food omega-3 PFA may contribute to prevention and control of adverse blood pressure levels. (Hypertension. 2007;50:313-319.)

Key Words: blood pressure ■ nutrition ■ food ■ omega-3 polyunsaturated fatty acids ■ population study

Unclear persists concerning efficacy of omega-3 (ω-3) polyunsaturated fatty acid (PFA) intake for prevention and control of the cardiovascular diseases (CVD) and their major risk factors. This is particularly the case for population-wide ω-3 PFA from foods. As to ω-3 PFA supplements for secondary prevention of CVD, recent reviews/meta-analyses come to diverse conclusions.1,2 Inconsistencies also prevail on influences of supplemental ω-3 PFA on blood pressure (BP). Meta-analyses of randomized clinical trials (RCTs) on ω-3 PFA supplements reported significant BP reduction overall and in hypertensive participants; significant heterogeneity in systolic BP (SBP) outcomes across trials; only small nonsignificant systolic and diastolic BP (DBP) lowering in nonhypertensive individuals.3–8 Almost no population-based observational data exist on relation of food ω-3 PFA of individuals to their BP.9 Possible reasons for the heterogeneous RCT findings on ω-3 PFA supplements and BP are: actual effect size is small, particularly in nonhypertensive individuals, hence false-negative findings are probable unless sample sizes are large, and BP is measured repeatedly by high-quality techniques.

In observational studies, data on nutrient intakes and other variables must be extensive and high-quality, enabling characterization of ω-3 PFA intake by individuals and control for...
multiple possible confounders. The population-based Interna-
tional Study of Macro- and Micro-nutrients and Blood Pressure
(INTERMARP) Study on nutrients and blood pressure was
designed to cope with such problems. Its basic premises are:
multiple nutrients have small independent influences on BP of individuals that in combination yield
sizeable effects. To detect impact of single nutrients on BP of
individuals, it is essential to collect standardized, high-quality
data on large samples of diverse populations. Accordingly, INTERMARP surveyed in-depth 4680 men and women ages
40 to 59 from 17 population samples in Japan, People’s
Republic of China, United Kingdom, United States, enabling
it to address main unanswered questions on ω-3 PFA intake
and BP: (1) Does food ω-3 PFA intake of individuals relate
independently to their SBP/DBP? (2) Is this the case through-
out the population, including nonhypertensive individuals?
(3) Are both linoleic and long-chain ω-3 PFA intake indepen-
dently associated with their SBP/DBP? INTERMARP hypothesized that dietary ω-3 PFA intake of individuals is
inversely related to their blood pressure. Findings on food
ω-3 PFA and BP are reported here.

Methods
INTERMARP included men and women ages 40 to 59 years from population random samples in Japan (4 samples), People’s Repub-
iclue of China (PRC, 3), United Kingdom (UK, 2), and United States (US, 8). Staff were trained and certified for BP measurement by
international/national senior colleagues based on a common stan-
dardized protocol. Each participant attended 4 times, visits 1 and 2
on consecutive days, visits 3 and 4 on consecutive days on average
3 weeks later. For BP measurement, each participant—having
emptied his/her bladder—was seated comfortably for 5 minutes, feet
flat on the floor, in a quiet room, with no physical activity in the
preceding half hour. Korotkoff sounds I and V were criteria for SBP
and DBP. BP was measured twice at each visit with a random zero
sphygmomanometer; BP at each visit was the average of the 2
readings. Measurements of height and weight, and questionnaire data
on daily alcohol consumption over the previous 7 days were obtained
at 2 visits. Dietary data were collected at each visit by a trained
interviewer with use of the in-depth multi-pass 24-hour recall
method. All foods and drinks consumed in the previous 24 hours,
including dietary supplements, were recorded. Questionnaire data
were obtained on demographic and other possible confounders.
Quality control was extensive.

Each participant provided 2 24-hour urine collections, start and
time at the research center (visits 1 to 2 and 3 to 4); measure-
ments included urinary volume, sodium, potassium, creati-
ine, urea; 10% of samples were split locally and sent to the
Central Laboratory with different identification number to estimate
interindividual variability. Mean BMI and energy intake were lower for Japanese and
PRC; average DBP, from 73.2 (PRC) to 77.3 (UK) mm Hg.

Descriptive Statistics
Detailed data are tabulated in the online supplement to this
paper (please see Table S1 at http://hyper.ahajournals.org).
Average SBP ranged from 117.2 (Japan) to 121.3 mm Hg
(PRC); average DBP, from 73.2 (PRC) to 77.3 (UK) mm Hg.
Mean BMI and energy intake were lower for Japanese and
PRC participants, highest for American. Mean total ω-3 PFA

Results

Statistical Methods
Food data of individuals were converted into nutrient intakes (83
nutrients) with use of enhanced country-specific food tables, stan-
dardized across countries by the Nutrition Coordinating Center,
University of Minnesota. For nutrients supplying energy, intake was calculated as percent total energy; for others, as intake/1000
kcal; nutrients were calculated also as amounts/24 hours. Food data
were used to estimate main food groups supplying ω-3 PFA—
linolenic acid (largely from vegetable sources), long-chain ω-3 PFA
(largely from fish; eicosapentaenoic acid [EPA], docosapentaenoic acid [DPA]). Urinary values/24 hours were calculated as products of urinary concentrations and timed
volume standardized to 24 hours. Measurements/person were aver-
aged, for BP and nutrient variables, across the 4 visits; for the urinary
excretions, across the 2 24-hour collections. For descriptive statis-
tics, means, standard deviations, numbers, and percentages were
calculated by country and study-wide. Reliability of SBP, DBP, and
ω-3 PFA intakes from the mean of the 4 visits was estimated from the
formula 1/[(1+(ratio/4))×100], where the ratio is interindividual
variance/interindividual variance, estimated separately for 8 gender/
country strata and pooled by weighting each stratum-specific esti-
mate by (sample size minus one). This gives a first approximation of
reliability, ie, an estimate of the size of an observed coefficient as a
per cent of the true coefficient in a univariate regression analysis.
Associations among nutritional variables were explored by partial
correlation, adjusted for sample, age, gender; pooled across coun-
tries, weighted by sample size. Multiple regression analyses were
used to examine relationships of food ω-3 PFA (percent kcal) of
individuals—total, linoleic acid, long-chain—to their SBP and
DBP. These analyses were done for four cohorts: all 4680 partici-
pants; 2238 “nonintervened” persons not on a special diet, not
consuming nutritional supplements, not with diagnosed CVD/diabe-
tes (DM); not taking medication for high BP, CVD, diabetes; ie,
exclusion of people whose data might bias the food ω-3 PFA-BP
relationship; nonhypertensive individuals—SBP <140, DBP
<90 mm Hg, not taking antihypertensive medication—from the total
cohort (n = 3671) and from the “nonintervened” subcohort (n = 2038).
Adjustment for confounders was done sequentially: for sample, age,
gender, weight, height (Model 1); plus reported special diet, dietary
supplement intake, moderate/heavy physical activity (hours/d), his-
tory of CVD/DM, family history of hypertension (Model 2); plus
24-hour urinary sodium, potassium, (or urinary sodium/creatinine,
potassium/creatinine) and 7-day alcohol intake (Model 3); plus
dietary cholesterol, saturated fatty acids (SFA), calcium (Model 4);
plus dietary fiber or magnesium or phosphorus, separately because of
collinearity (Models 5a, 5b, 5P).

Regression models were fitted by country and cohorts pooled
across countries, weighted by inverse of variance, to estimate overall
association; cross-country heterogeneity was tested; interactions
were assessed for age, gender, and body mass index (BMI, weight/
height$^{2}$ [kg/m$^{2}$]). Regression coefficients were expressed as mHg for 2 standard deviation (SD) higher food ω-3 PFA, from pooled
within-country standard deviations weighted by sample size.

Sensitivity analyses involved: inclusion of energy intake with
nutrient densities; use of g/d intake adjusted for energy; addition to
regression models of other nutrients (monounsaturated fatty acids,
oleic acid, ω-6 PFA, linoleic acid, arachidonic acid, trans fatty
acids, vegetable protein, animal protein, estimated total sugars,
vitamin E); exclusion from the “nonintervened” subcohort of people
taking nonsteroidal antiinflammatory drug (NSAID); ex-
clusion of people with marked intra-individual variability in
nutrient intake or SBP, DBP.

Analyses were with SAS version 8.02 by Q.C. and I.J.B.
TABLE 1. Estimated Mean Difference in Blood Pressure (mm Hg), Dietary Total ω-3 PFA (% kcal) Higher by Two Standard Deviations,* Sequential Regression Models, All Men and Women (n=4680)

<table>
<thead>
<tr>
<th>Model</th>
<th>Other Variables, Added Sequentially†</th>
<th>Systolic Blood Pressure</th>
<th>Diastolic Blood Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sample, age, gender, height, weight</td>
<td>−0.54</td>
<td>−0.63‡</td>
</tr>
<tr>
<td>2</td>
<td>Special diet, supplement intake, CVD-DM diagnosis, physical activity, family history of high BP</td>
<td>−0.58</td>
<td>−0.61‡</td>
</tr>
<tr>
<td>3</td>
<td>Urinary Na, urinary K, alcohol</td>
<td>−0.38</td>
<td>−0.48‡</td>
</tr>
<tr>
<td>4</td>
<td>Dietary cholesterol, SFA, calcium</td>
<td>−0.56</td>
<td>−0.55</td>
</tr>
<tr>
<td>5a</td>
<td>Dietary fiber or,</td>
<td>−0.53</td>
<td>−0.54</td>
</tr>
<tr>
<td>5b</td>
<td>Dietary magnesium, or</td>
<td>−0.51</td>
<td>−0.54</td>
</tr>
<tr>
<td>5P</td>
<td>Dietary phosphorus</td>
<td>−0.55</td>
<td>−0.57</td>
</tr>
</tbody>
</table>

Units are mmol/24 hours (urinary Na, urinary K), g/24 hours (alcohol), mg/1000 kcal (calcium, magnesium, phosphorus, cholesterol), %kcal (ω-3 PFA, SFA).

*Two standard deviation difference is 0.669 %kcal for total omega 3 PFA; as grams/24 hours, 1.929.
†Variables listed are added to each prior model, so that for example, Model 5P contains all variables listed in Models 1–4 and dietary phosphorus.
‡P-value for cross-country heterogeneity = 0.05.

Table 1 shows the estimated mean difference in blood pressure (mm Hg) due to dietary total ω-3 PFA (% kcal) higher by two standard deviations, using sequential regression models for all men and women (n=4680). The differences are presented for systolic and diastolic blood pressure.

Partial Correlation Data
Food total ω-3 PFA (% kcal) was correlated directly with food linoleic acid (partial r=0.48) and total ω-6 PFA (0.48), arachidonic acid (0.23), total monounsaturated fatty acids (MFA; 0.34), oleic acid (0.27), Vitamin E (0.35); inversely with total available carbohydrate (−0.34) and total sugars (−0.21). ALA was correlated similarly with the foregoing variables; it was not correlated with EPA, DHA, DPA, or their sums. EPA, DHA, DPA were highly intercorrelated (r values 0.65 to 0.84). Sum EPA+DHA was correlated with total protein (0.30), arachidonic acid (0.36), phosphorus (0.18), vitamin E (0.16), as was sum EPA+DHA+DPA.

Relation of Food Total Omega-3 PFA to Blood Pressure

All 4680 Participants
Consistently, dietary total ω-3 PFA was inversely related to SBP and DBP (Table 1). With 2 standard deviation higher total ω-3 PFA (0.669% kcal=about 1.9 g/d), estimated difference in SBP was about −0.4 to −0.6 mm Hg; in DBP, about −0.5 to −0.6 mm Hg (DBP Z-scores −1.71 to −2.23).

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TABLE 2. Estimated Mean Difference in Blood Pressure (mm Hg), Dietary Total ω-3 PFA (% kcal) Higher by 2 Standard Deviations,* Model 5P, All Persons, “Nonintervened” Persons, Nonhypertensive Persons

<table>
<thead>
<tr>
<th>Group</th>
<th>No. of Persons</th>
<th>Systolic Blood Pressure</th>
<th>Diastolic Blood Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Difference mm Hg</td>
<td>Z-Score</td>
</tr>
<tr>
<td>All persons</td>
<td>4680</td>
<td>−0.55</td>
<td>−1.33</td>
</tr>
<tr>
<td>“Nonintervened” persons</td>
<td>2238</td>
<td>−1.01</td>
<td>−1.63</td>
</tr>
<tr>
<td>Nonhypertensive persons from total cohort</td>
<td>3671</td>
<td>−0.74</td>
<td>−2.05</td>
</tr>
<tr>
<td>Nonhypertensive persons from “Nonintervened” subcohort</td>
<td>2038</td>
<td>−0.91</td>
<td>−1.80</td>
</tr>
</tbody>
</table>

PFA indicates polyunsaturated fatty acids.

*Nonintervened” persons: individuals not on a special diet, not consuming nutritional supplements, not with diagnosed CVD/DM, not taking medication for high BP/CVD/DM.

Other variables in Model 5P: Sample, age, gender, height, weight, physical activity, family history of high BP, urinary sodium and potassium, alcohol intake, dietary cholesterol, saturated fatty acids, calcium, phosphorus; also, for all persons and all nonhypertensive persons, special diet, supplement intake, CVD/DM diagnosis.

Nonhypertensive persons: individuals with SBP <140 mm Hg and DBP <90 mm Hg and not reporting use of medication for high BP.

All tests for cross-country heterogeneity were nonsignificant.

A. %kcal with inclusion of energy intake (kcal/24 hours)
B. g/24 hours adjusted for energy intake (kcal/24 hours)
C. %kcal with exclusion from the “Nonintervened” subcohort of people taking NSAID
D. %kcal with exclusion of people with high day-to-day variability of SBP, DBP, and/or nutrient intakes

TABLE 3. Sensitivity Analyses: Estimated Mean Difference in Blood Pressure (mm Hg), Dietary Total ω-3 PFA (% kcal) Higher by Two Standard Deviations,* Men and Women Combined

<table>
<thead>
<tr>
<th>Modification of Model 5P</th>
<th>No. of Persons</th>
<th>Systolic Blood Pressure</th>
<th>Diastolic Blood Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Difference mm Hg</td>
<td>Z-Score</td>
</tr>
<tr>
<td>A. %kcal with inclusion of energy intake (kcal/24 hours)</td>
<td>4680</td>
<td>−0.53</td>
<td>−1.30</td>
</tr>
<tr>
<td>B. g/24 hours adjusted for energy intake (kcal/24 hours)</td>
<td>4680</td>
<td>−0.80</td>
<td>−1.61</td>
</tr>
<tr>
<td>C. %kcal with exclusion from the “Nonintervened” subcohort of people taking NSAID</td>
<td>2131</td>
<td>−0.90</td>
<td>−1.42</td>
</tr>
<tr>
<td>D. %kcal with exclusion of people with high day-to-day variability of SBP, DBP, and/or nutrient intakes</td>
<td>3473</td>
<td>−0.76</td>
<td>−1.63</td>
</tr>
</tbody>
</table>

All tests for cross-country heterogeneity were nonsignificant.

*2 SD difference in dietary total ω-3 PFA is 0.669 %kcal (analyses A, C, D) or 1.929 g/24 hours (analysis B).
TABLE 4. Estimated Mean Difference in Blood Pressure (mm Hg), Dietary Linolenic Acid and Dietary Long-chain ω-3 PFA (Sum, EPA+DHA) (% kcal) Higher by 2 Standard Deviations, * Linolenic Acid and Sum, EPA+DHA in Same Regression Model (Model 5P), All Participants, “Nonintervened” Persons, Nonhypertensive Persons

<table>
<thead>
<tr>
<th>Group</th>
<th>No. of Persons</th>
<th>Linolenic Acid</th>
<th></th>
<th>Sum, EPA+DHA</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
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<td>Systolic Blood Pressure</td>
<td>Diastolic Blood Pressure</td>
<td>Systolic Blood Pressure</td>
<td>Diastolic Blood Pressure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Diff. mm Hg</td>
<td>Z-Score</td>
<td>Diff. mm Hg</td>
<td>Z-Score</td>
</tr>
<tr>
<td>All persons</td>
<td>4680</td>
<td>−0.60</td>
<td>−1.43</td>
<td>−0.50†</td>
<td>−1.71</td>
</tr>
<tr>
<td>“Nonintervened” persons</td>
<td>2238</td>
<td>−0.97</td>
<td>−1.52</td>
<td>−0.87‡</td>
<td>−1.95</td>
</tr>
<tr>
<td>Nonhypertensive persons from total cohort</td>
<td>3671</td>
<td>−0.77</td>
<td>−2.05</td>
<td>−0.61‡</td>
<td>−2.16</td>
</tr>
<tr>
<td>Nonhypertensive persons from “Nonintervened” cohort</td>
<td>2038</td>
<td>−0.73</td>
<td>−1.39</td>
<td>−0.73</td>
<td>−1.89</td>
</tr>
</tbody>
</table>

PFA indicates polyunsaturated fatty acids; EPA, eicosapentaenoic acid; DHA, docosahexaenoic acid.
See footnotes for Tables 1–3.

*Two standard deviation difference is 0.566 %kcal for linolenic acid and 0.318 %kcal for sum, EPA+DHA, similar for the 3 subcohorts; 2 SD differences in gram/24 hours are 1.623 and 0.789.

†P value for cross-country heterogeneity =<0.01; ‡P value for cross-country heterogeneity ≤0.05.

Long-Chain ω-3 PFA From Foods and BP

Findings for the relation to BP of Sum EPA+DHA+DPA and Sum EPA+DHA were similar: For the 4 groups, DBP differences with 2 SD higher EPA+DHA (0.318% kcal, ≈about 0.79 g/d) ranged (model 5 P) from −0.28 mm Hg to −0.54 mm Hg; SBP differences were generally smaller (Table 4).

Corresponding analyses were done on the relation to BP of EPA and DHA considered separately. Results were qualitatively similar to the foregoing: eg, Model 5P, with 2 SD higher EPA, DBP lower by −0.21 to −0.56 mm Hg; for DHA, −0.31 to −0.61 mm Hg. Findings were similar from regressions of SBP, DBP on EPA, DHA, EPA+DHA ingested only from fish/shellfish and their products.

In multiple regression models with these 2 highly correlated variables considered together in the same model, the relation of EPA to SBP and DBP varied across cohorts, ie, was nonsignificantly positive for all 4680 participants and the 2238 “nonintervened” persons, nonsignificantly inverse for the 3671 nonhypertensive persons and the subcohort of 2038 nonhypertensive persons. DHA-BP relations also varied in sign across cohorts and all had low-order Z-scores.

Discussion

Main findings of this population-based study on food ω-3 PFA intake of individuals and their blood pressure are: (1) Consistent independent inverse relations of total ω-3 PFA to systolic and diastolic pressure; (2) estimated effect size small, <1.0 mm Hg with 2 SD higher ω-3 PFA intake (about 1.9 g/d); (3) estimated effect size larger for nonhypertensive persons and for persons not reporting lifestyle modification (eg, special diet, use of nutritional supplements), diagnosed CVD or diabetes, prescribed medication for major chronic disease; (4) similar inverse relations also of linolenic acid to SBP/DBP; (5) for long-chain ω-3 PFA (sum EPA+DHA, EPA separately, DHA separately) qualitatively similar weaker inverse relation to DBP.

To the best of our knowledge these INTERMAP data indicating low-order independent inverse relations of food ω-3 PFA (total, linolenic acid, long-chain) to BP are the first comprehensive population-based findings on this matter. The Finnish Kuopio Study of 722 middle-aged men reported a significant independent cross-sectional relation of dietary ALA to SBP and mean arterial pressure, but not to DBP; no data were given on long-chain ω-3 PFA.

These INTERMAP observational data on food ω-3 PFA and BP are concordant with results from metaanalyses of randomized trials assessing whether ω-3 PFA supplements (mostly fish oil capsules) influence BP; in particular, our data are similar qualitatively and quantitatively in indicating a low-order favorable BP effect, including in nonhypertensive persons, and are also compatible with the small nonsignificant differences (−0.4/−0.6 mm Hg) reported recently from the Kanwu Study Group RCT on 162 healthy nonhypertensive adults.

As to BP influences of ALA per se, Wendland et al9—based on 3 RCTs involving 348 persons—reported small nonsignificant effect sizes (−0.72/−0.17 mm Hg). Similarly, for long-chain ω-3 PFA per se, the 1993 metaanalysis of RCTs estimated effect sizes overall (ie, for all participants, hypertensive and nonhypertensive) for DHA of −1.50/−0.77 mm Hg/gram, and for EPA of −0.93/−0.53 mm Hg/gram. Given limitations in statistical power, it is consistent with the foregoing that no significant influences of EPA supplements on BP were noted in a recent overview of 4 small RCTs in nonhypertensive people.7 For DHA supplements (4 g/d), that article reported sizable BP effects on 24-hour and day-time ambulatory BP of 56 overweight hypercholesterolemic adults.7 High order collinearity of EPA and DHA intakes from foods limits ability to estimate their separate influences on BP. Our separate regression analyses on EPA-BP and DHA-BP relations yielded similar low-order associations for each. Because dietary ALA is a metabolic precursor of EPA and DHA, it is a reasonable expectation that all these dietary ω-3 PFA relate to BP.

Limitations of the INTERMAP findings include: their cross-sectional nature, but they are the only available population-based data on food ω-3 PFA (total, linolenic acid,
long-chain) and BP, and their results are consistent with those from RCTs; underestimation of effect size attributable to limited reliability in measurement of nutrients (regression dilution bias); possible confounding of the overall data on food ω-3 PFA and BP by special diets, dietary supplements, and drug treatment for high BP/CVD/diabetes, but the findings prevailed with multivariate control for those and other possible confounders for the 4680 participants. In addition, the data indicating larger influences of ω-3 PFA on BP for persons not experiencing such interventions are coherent with the inference that the ω-3 PFA–BP relation may be etiologically significant.

Possible mechanisms whereby ω-3 PFA may favorably influence BP are, based on animal experimental data: enhanced endothelial vasodilator function,19,20 reduced reactivity of resistant vessel vascular smooth muscle,20,21 increased vascular compliance.22

As noted, if feasible intakes of food ω-3 PFA do indeed influence BP favorably for people in the general population, effect size is apparently small, based on INTERMAP and RCT results. This finding, anticipated by INTERMAP, needs to be kept in perspective: First, with multiple nutrients having “small” independent influences, combined effect becomes sizable, ie, improved nutrition is capable of preventing or lowering unfavorable BP levels for most people, as the Dietary Approaches to Stop Hypertension and Optimal Macro-Nutrient Intake Heart feeding trial results indicate.23–25 Second, long-term effects of habitual eating patterns, from early life into middle-age, may be greater, as data on salt intake and BP indicate.26,27 Third, estimates indicate that lowering of population average SBP by “small” amounts (eg, 2 mm Hg) can result in reduction of mortality rates of 6% for stroke and 4% for coronary heart disease (CHD).28 Fourth, enhanced ω-3 PFA intake from foods may contribute to decreased risk of CHD/CVD not only by modestly lowering BP, also by favorably influencing dyslipidemia, by anticoagulant, and antiarrhythmic effects.28–32 Population-wide feasibility of greater ω-3 PFA intake from foods, vegetable and marine sources is indicated by findings for INTERMAP Japanese—compared with Chinese, U.K., U.S.A.—participants, ie, linolenic acid and long-chain ω-3 PFA both substantially higher, especially the latter. As to specific food sources, ω-3 PFA in 100 g cooked fatty fish (175 kcal) is 2.70g; 100 g canned pink salmon (unsalted) (134 kcal), 1.90g; 20g walnuts (unsalted) (134 kcal), 1.36g; 10g flax seed (45 kcal), 1.83g; 5g canola oil (45 kcal), 0.46g; 5g soy bean oil (45 kcal), 0.34g.

In conclusion, there was a weak inverse relationship to BP of ω-3 polyunsaturated fat intake from foods (total, linolenic acid, long-chain) with control for multiple possible confounders. This finding was stronger for nonhypertensive people and persons not experiencing dietary/medical intervention, ie, was stronger after removing sources of possible bias, a result consistent with the inference that the ω-3 PFA–BP relationship may be etiologically significant, albeit low-order.

**Perspectives**

Recent research data indicate that multiple improvements in food intake lower BP levels of adults, both prehypertensive and hypertensive. Nutrients possibly accounting for these favorable effects include greater intake of minerals (calcium, magnesium, phosphorus); vegetable protein; polyunsaturated fatty acids including omega-3; and reduced intake of total fat, saturated fatty acids, cholesterol, sugars—over and above known favorable effects on BP of reduced sodium chloride, increased potassium, and prevention/correction of overweight/obesity and excess alcohol intake. The findings of the present study indicating a low-order favorable influence of food ω-3 fatty acid intake on BP of individuals from general population samples are consistent with metaanalytic data of RCTs on this matter. Thus, these results on a major CHD/CVD risk factor lend modest support to current recommendations for increased ingestion of ω-3 fatty acids from marine and vegetable sources.

**Acknowledgments**

It is a pleasure to express appreciation to all INTERMAP staff at local, national, and international centers for their invaluable efforts; a partial listing of these colleagues is given in Reference 10 of this paper. We note with sadness the recent passing of Professor Beifan Zhou, Principal Investigator for INTERMAP in China; we dedicate this paper to her memory.

**Sources of Funding**

This research is supported by grant 2-R01-HL50490 from the US National Heart, Lung, and Blood Institute, National Institutes of Health, Bethesda, Md; by the Chicago Health Research Foundation; and by national agencies in China, Japan (the Ministry of Education, Science, Sports, and Culture, Grant-in-Aid for Scientific Research [A], No. 090357003), and the UK.

**Disclosures**

None.

**References**


Table S1. Descriptive Statistics, Mean (sd) or Number (%), Selected Variables by Country, Men and Women Combined, INTERMAP, 1996-1999

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<thead>
<tr>
<th>Variable</th>
<th>Japan (n=1,145)</th>
<th>P. R. China (n=839)</th>
<th>UK (n=501)</th>
<th>USA (n=2,195)</th>
<th>All (n=4,680)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (sd)</td>
<td>Mean (sd)</td>
<td>Mean (sd)</td>
<td>Mean (sd)</td>
<td>Mean (sd)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>49.4 (5.3)</td>
<td>49.0 (5.8)</td>
<td>49.1 (5.6)</td>
<td>49.1 (5.4)</td>
<td>49.2 (5.5)</td>
</tr>
<tr>
<td>Systolic BP (mm Hg)</td>
<td>117.2 (13.8)</td>
<td>121.3 (17.4)</td>
<td>120.4 (14.6)</td>
<td>118.6 (13.9)</td>
<td>118.9 (14.7)</td>
</tr>
<tr>
<td>Diastolic BP (mm Hg)</td>
<td>73.6 (10.3)</td>
<td>73.2 (10.2)</td>
<td>77.3 (9.9)</td>
<td>73.4 (9.7)</td>
<td>73.8 (10.0)</td>
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<tr>
<td>Total Omega-3 PFA (% kcal)</td>
<td>1.35 (0.38)</td>
<td>0.55 (0.37)</td>
<td>0.73 (0.26)</td>
<td>0.75 (0.31)</td>
<td>0.86 (0.44)</td>
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<tr>
<td>Linolenic acid (% kcal)</td>
<td>0.81 (0.26)</td>
<td>0.54 (0.37)</td>
<td>0.57 (0.20)</td>
<td>0.67 (0.27)</td>
<td>0.67 (0.30)</td>
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<tr>
<td>Sum, EPA+DHA+DPA (% kcal)</td>
<td>0.50 (0.29)</td>
<td>0.01 (0.02)</td>
<td>0.15 (0.17)</td>
<td>0.08 (0.13)</td>
<td>0.18 (0.26)</td>
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<tr>
<td>Sum, EPA + DHA (% kcal)</td>
<td>0.46 (0.26)</td>
<td>0.01 (0.02)</td>
<td>0.12 (0.15)</td>
<td>0.07 (0.12)</td>
<td>0.16 (0.24)</td>
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<tr>
<td>EPA (% kcal)</td>
<td>0.17 (0.11)</td>
<td>0.01 (0.02)</td>
<td>0.05 (0.07)</td>
<td>0.02 (0.04)</td>
<td>0.06 (0.09)</td>
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<tr>
<td>DHA (% kcal)</td>
<td>0.29 (0.16)</td>
<td>0.002 (0.007)</td>
<td>0.06 (0.08)</td>
<td>0.04 (0.08)</td>
<td>0.10 (0.15)</td>
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<tbody>
<tr>
<td>DPA (%kcal)</td>
<td>0.05</td>
<td>(0.03)</td>
<td>0.0004</td>
<td>(0.001)</td>
<td>0.04</td>
<td>(0.02)</td>
<td>0.01</td>
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<td>Total Omega-3 PFA (g/24hr)</td>
<td>3.07</td>
<td>(1.12)</td>
<td>1.25</td>
<td>(0.92)</td>
<td>1.76</td>
<td>(0.80)</td>
<td>1.87</td>
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<tr>
<td>Linolenic acid (g/24hr)</td>
<td>1.84</td>
<td>(0.73)</td>
<td>1.23</td>
<td>(0.91)</td>
<td>1.39</td>
<td>(0.64)</td>
<td>1.69</td>
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<tr>
<td>Sum, EPA+DHA+DPA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(g/24hr)</td>
<td>1.15</td>
<td>(0.73)</td>
<td>0.02</td>
<td>(0.05)</td>
<td>0.36</td>
<td>(0.38)</td>
<td>0.18</td>
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<tr>
<td>Sum, EPA+DHA (g/24hr)</td>
<td>1.04</td>
<td>(0.66)</td>
<td>0.02</td>
<td>(0.04)</td>
<td>0.27</td>
<td>(0.34)</td>
<td>0.15</td>
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<tr>
<td>EPA (g/24hr)</td>
<td>0.39</td>
<td>(0.28)</td>
<td>0.02</td>
<td>(0.04)</td>
<td>0.12</td>
<td>(0.16)</td>
<td>0.05</td>
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<tr>
<td>DHA (g/24hr)</td>
<td>0.66</td>
<td>(0.39)</td>
<td>0.01</td>
<td>(0.02)</td>
<td>0.15</td>
<td>(0.20)</td>
<td>0.10</td>
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<tr>
<td>DPA (g/24hr)</td>
<td>0.10</td>
<td>(0.08)</td>
<td>0.001</td>
<td>(0.003)</td>
<td>0.09</td>
<td>(0.06)</td>
<td>0.02</td>
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<td>Height (m)</td>
<td>1.61</td>
<td>(0.09)</td>
<td>1.59</td>
<td>(0.08)</td>
<td>1.69</td>
<td>(0.09)</td>
<td>1.68</td>
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<td>Weight (kg)</td>
<td>61.2</td>
<td>(10.2)</td>
<td>58.9</td>
<td>(10.0)</td>
<td>78.2</td>
<td>(15.3)</td>
<td>82.3</td>
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<td>Body Mass Index (kg/m²)</td>
<td>23.4</td>
<td>(2.9)</td>
<td>23.1</td>
<td>(3.4)</td>
<td>27.5</td>
<td>(4.6)</td>
<td>28.9</td>
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<tr>
<td>Energy (kcal/24hr)</td>
<td>2038.6</td>
<td>(449.0)</td>
<td>2035.8</td>
<td>(576.8)</td>
<td>2168.0</td>
<td>(631.8)</td>
<td>2244.2</td>
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<tr>
<td>Total protein (% kcal)</td>
<td>16.0</td>
<td>(2.3)</td>
<td>12.4</td>
<td>(1.9)</td>
<td>15.8</td>
<td>(3.1)</td>
<td>15.5</td>
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<td>Vegetable protein (% kcal)</td>
<td>7.1</td>
<td>9.9</td>
<td>6.1</td>
<td>5.2</td>
<td>6.6</td>
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<tr>
<td>Total fat (% kcal)</td>
<td>24.9</td>
<td>20.0</td>
<td>32.8</td>
<td>32.9</td>
<td>28.6</td>
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<tr>
<td>Total SFA (% kcal)</td>
<td>6.6</td>
<td>5.0</td>
<td>12.1</td>
<td>10.7</td>
<td>8.8</td>
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<tr>
<td>Total MFA (% kcal)</td>
<td>9.0</td>
<td>8.1</td>
<td>11.0</td>
<td>12.2</td>
<td>10.5</td>
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<tr>
<td>Oleic acid (% kcal)</td>
<td>8.0</td>
<td>6.7</td>
<td>10.0</td>
<td>11.6</td>
<td>9.6</td>
<td></td>
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<tr>
<td>Total PFA (% kcal)</td>
<td>6.4</td>
<td>5.8</td>
<td>6.2</td>
<td>7.0</td>
<td>6.5</td>
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<tr>
<td>Omega-6 PFA (% kcal)</td>
<td>5.0</td>
<td>5.3</td>
<td>5.5</td>
<td>6.3</td>
<td>5.7</td>
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<td>Linoleic acid (% kcal)</td>
<td>4.9</td>
<td>5.3</td>
<td>5.4</td>
<td>6.2</td>
<td>5.7</td>
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<tr>
<td>Arachidonic acid (% kcal)</td>
<td>0.07</td>
<td>0.02</td>
<td>0.08</td>
<td>0.06</td>
<td>0.06</td>
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<td>Trans fatty acids (% kcal)</td>
<td>0.44</td>
<td>0.18</td>
<td>1.36</td>
<td>1.94</td>
<td>1.20</td>
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<tr>
<td>Cholesterol (mg/1,000kcal)</td>
<td>197.2</td>
<td>89.0</td>
<td>120.4</td>
<td>131.4</td>
<td>138.7</td>
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<tr>
<td>Total available carbohydrate (% kcal)</td>
<td>54.2</td>
<td>65.0</td>
<td>44.5</td>
<td>49.4</td>
<td>52.9</td>
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Table S1 continued, page 4

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<tr>
<th>Estimated total sugars (%kcal)</th>
<th>18.7 (4.7)</th>
<th>8.5 (5.2)</th>
<th>20.3 (6.0)</th>
<th>26.7 (8.2)</th>
<th>20.8 (9.5)</th>
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<tbody>
<tr>
<td>7-Day alcohol* (g/24hr)</td>
<td>17.0 (22.6)</td>
<td>8.6 (21.4)</td>
<td>14.7 (19.2)</td>
<td>7.0 (13.7)</td>
<td>10.5 (18.8)</td>
</tr>
<tr>
<td>7-Day alcohol among drinkers* (g/24hr)</td>
<td>18.8 (23.0)</td>
<td>18.9 (28.4)</td>
<td>16.6 (19.6)</td>
<td>9.9 (15.4)</td>
<td>14.5 (20.7)</td>
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<tr>
<td>Dietary calcium (mg/1,000 kcal)</td>
<td>305.6 (108.7)</td>
<td>149.3 (56.2)</td>
<td>445.4 (118.7)</td>
<td>363.0 (142.0)</td>
<td>319.5 (149.2)</td>
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<tr>
<td>Dietary magnesium (mg/1,000 kcal)</td>
<td>134.4 (25.2)</td>
<td>154.6 (46.6)</td>
<td>153.8 (35.2)</td>
<td>148.1 (40.0)</td>
<td>146.5 (38.5)</td>
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<tr>
<td>Dietary phosphorus (mg/1,000 kcal)</td>
<td>562.6 (94.4)</td>
<td>438.9 (113.2)</td>
<td>662.0 (125.9)</td>
<td>591.0 (124.6)</td>
<td>564.4 (132.8)</td>
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<tr>
<td>Vitamin E (mg/1,000 kcal)</td>
<td>4.95 (1.41)</td>
<td>5.29 (1.62)</td>
<td>4.48 (1.59)</td>
<td>4.48 (1.80)</td>
<td>4.74 (1.69)</td>
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<tr>
<td>Fiber (g/1,000 kcal)</td>
<td>7.9 (2.3)</td>
<td>14.2 (3.8)</td>
<td>12.2 (3.8)</td>
<td>9.0 (3.4)</td>
<td>10.0 (4.0)</td>
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<tr>
<td>Urinary sodium (mmol/24hr)</td>
<td>198.3 (56.2)</td>
<td>227.5 (100.3)</td>
<td>145.2 (49.1)</td>
<td>162.6 (59.4)</td>
<td>181.1 (72.4)</td>
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<th>Urinary potassium (mmol/24hr)</th>
<th>48.9 (13.6)</th>
<th>38.3 (12.7)</th>
<th>68.2 (20.1)</th>
<th>57.7 (20.9)</th>
<th>53.2 (20.0)</th>
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<td>Urinary Creatinine (mmol/24hr)</td>
<td>11.09 (2.99)</td>
<td>9.20 (2.62)</td>
<td>12.58 (3.45)</td>
<td>13.36 (4.11)</td>
<td>11.97 (3.89)</td>
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<tr>
<td>Ratio of Urinary Na to Creatinine (mmol/mmol)</td>
<td>18.74 (5.95)</td>
<td>25.70 (11.09)</td>
<td>12.03 (4.05)</td>
<td>12.60 (4.07)</td>
<td>16.39 (8.12)</td>
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<tr>
<td>Ratio of Urinary K to Creatinine (mmol/mmol)</td>
<td>4.67 (1.67)</td>
<td>4.38 (1.70)</td>
<td>5.62 (1.51)</td>
<td>4.51 (1.58)</td>
<td>4.64 (1.66)</td>
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<tr>
<td>Family history of hypertension in any first degree relative</td>
<td>n (%)</td>
<td>n (%)</td>
<td>n (%)</td>
<td>n (%)</td>
<td>n (%)</td>
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<tr>
<td>-Yes</td>
<td>528 (46.1)</td>
<td>298 (35.5)</td>
<td>242 (48.3)</td>
<td>1,491 (67.9)</td>
<td>2,559 (54.7)</td>
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<tr>
<td>-Unknown</td>
<td>406 (35.5)</td>
<td>188 (22.4)</td>
<td>188 (37.5)</td>
<td>489 (22.3)</td>
<td>1,271 (27.2)</td>
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<tr>
<td>Current alcohol drinkers</td>
<td>1,039 (90.7)</td>
<td>382 (45.5)</td>
<td>444 (88.6)</td>
<td>1,533 (69.8)</td>
<td>3,398 (72.6)</td>
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Table S1 continued, page 6

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<tr>
<th>Special diet: weight loss, weight gain, vegetarian, salt reduced, diabetic, fat modified, or any other</th>
<th>76</th>
<th>(6.6)</th>
<th>45</th>
<th>(5.4)</th>
<th>106</th>
<th>(21.2)</th>
<th>401</th>
<th>(18.3)</th>
<th>628</th>
<th>(13.4)</th>
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<tr>
<td>Taking dietary supplement</td>
<td>243</td>
<td>(21.2)</td>
<td>34</td>
<td>(4.1)</td>
<td>191</td>
<td>(38.1)</td>
<td>1,136</td>
<td>(51.8)</td>
<td>1,604</td>
<td>(34.3)</td>
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<td>High blood pressure†</td>
<td>153</td>
<td>(13.4)</td>
<td>145</td>
<td>(17.3)</td>
<td>116</td>
<td>(23.2)</td>
<td>595</td>
<td>(27.1)</td>
<td>1,009</td>
<td>(21.6)</td>
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<td>History of heart attack, other heart disease, stroke, or diabetes</td>
<td>131</td>
<td>(11.4)</td>
<td>59</td>
<td>(7.0)</td>
<td>54</td>
<td>(10.8)</td>
<td>343</td>
<td>(15.6)</td>
<td>587</td>
<td>(12.5)</td>
</tr>
<tr>
<td>Taking lipid lowering drugs</td>
<td>37</td>
<td>(3.2)</td>
<td>6</td>
<td>(0.7)</td>
<td>15</td>
<td>(3.0)</td>
<td>146</td>
<td>(6.7)</td>
<td>204</td>
<td>(4.4)</td>
</tr>
<tr>
<td>Taking prescribed drug treatment for high BP/CVD</td>
<td>85</td>
<td>(7.4)</td>
<td>66</td>
<td>(7.9)</td>
<td>82</td>
<td>(16.4)</td>
<td>518</td>
<td>(23.6)</td>
<td>751</td>
<td>(16.0)</td>
</tr>
<tr>
<td>Taking diuretic for other reason</td>
<td>3</td>
<td>(0.3)</td>
<td>1</td>
<td>(0.1)</td>
<td>5</td>
<td>(1.0)</td>
<td>25</td>
<td>(1.1)</td>
<td>34</td>
<td>(0.7)</td>
</tr>
<tr>
<td>Taking prescribed drug treatment for diabetes</td>
<td>18</td>
<td>(1.6)</td>
<td>11</td>
<td>(1.3)</td>
<td>6</td>
<td>(1.2)</td>
<td>128</td>
<td>(5.8)</td>
<td>163</td>
<td>(3.5)</td>
</tr>
</tbody>
</table>

continued on next page
Table S1 continued, page 7

| Taking non-steroidal anti-inflammatory drug (NSAID) | 48    | (4.2) | 17    | (2.0) | 41    | (8.2) | 235   | (10.7) | 341   | (7.3) |

PFA is polyunsaturated fatty acids; EPA is eicosapentaenoic acid; DHA is docosahexaenoic acid; DPA is docosapentaenoic acid, SFA is saturated fatty acids, MFA is monounsaturated fatty acids

*Average daily alcohol intake, from two histories per person of daily alcohol intake during the preceding 7 days

†SBP ≥140 mm Hg or DBP ≥90 mmHg or reporting use of medication for high BP