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Changes in micronutrient intake and factors associated with this change among older Australian men: the Concord Health and Ageing in Men Project

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Abstract

Objectives: To examine changes in micronutrient intake over 3 years and identify any associations between socio-economic, health, lifestyle and meal-related factors and these changes in micronutrient intakes among older men.

Design: Prospective study.

Setting: Dietary adequacy of individual micronutrient was compared to the estimated average requirement of the nutrient reference values (NRV). Attainment of the NRV for twelve micronutrients was incorporated into a dichotomised variable ‘not meeting’ (meeting ≤ 6) or ‘meeting’ (meeting ≥ 7) and categorised into four categories to assess change in micronutrient intake over 3 years. The multinomial logistic regression analyses were conducted to model predictors of changes in micronutrient intake.

Participants: Seven hundred and ninety-four men participated in a detailed diet history interview at the third wave (baseline nutrition) and 718 men participated at the fourth wave (3-year follow-up).

Results: The mean age was 81 years (range 75–99 years). Median intakes of the majority of micronutrients decreased significantly over a 3-year follow-up. Inadequacy of the NRV for thiamine, dietary folate, Zn, Mg, Ca and I were significantly increased at a 3-year follow-up than baseline nutrition. The incidence of inadequate micronutrient intake was 21 % and remained inadequate micronutrient intake was 16·4 % at 3-year follow-up. Changes in micronutrient intakes were significantly associated with participants born in the UK and Italy, low levels of physical activity, having ≥2 medical conditions and used meal services.

Conclusions: Micronutrient intake decreases with age in older men. Our results suggest that strategies to improve some of the suboptimal micronutrient intakes might need to be developed and implemented for older men.

Keywords
Inadequate micronutrient intakes
Low physical activity
Medical condition
Meal service
Older men

Interest in the area of nutritional intake and its impact on the health of older people is increasing[1–6]. Epidemiological studies have indicated that older individuals are at higher risk of deficiencies in micronutrients, such as Ca, Fe, Zn, B vitamins and vitamin E[7–10]. The National Diet and Nutrition Survey in the UK reported an inadequate intake of vitamins D and K, Mg and selenium compared to the Reference Nutrient Intake for the adult population[11]. Likewise, the Australian Health Survey 2011–2012 documented an inadequate intake of vitamin B_6, Ca, Mg and Zn in older Australian men aged 71 years and above[12]. A previous longitudinal study showed that a large proportion of older Italian people were at higher risk of micronutrient deficiency or had exacerbating existing micronutrient

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deficiency after 10 years follow-up[13]. Also, a systematic review reported inadequate intakes of vitamins B_1, B_2 and D as well as thiamine, and riboflavin, Ca, Mg and selenium among individuals aged 65 years and above[14]. Inadequate intake of these essential micronutrients can increase the risk of infection, inflammation and chronic age-related degenerative diseases, including sarcopenia, cognitive dysfunction such as dementia, CVD, cognitive dysfunction, osteoporosis and cancer[15–17].

Although impaired absorption and utilisation of micronutrients, use of multiple medications, decrease in the perception of taste and smell, loss of appetite, chewing/swallowing difficulties, disability, depression and socio-economic barriers (such as loneliness, bereavement and economic instability) may contribute to inadequate intake of specific micronutrients in older individuals[18,19], predictors associated with the inadequacy of micronutrient intake remain less clear. A previous study indicated that many older individuals (particularly those who live alone and are frail) cannot prepare their meals or lack easy access to appropriate food, relying on ready-meals instead. This might have a negative impact on the ability to meet nutritional requirements[17]. Cross-sectional analyses conducted in the Concord Health and Ageing in Men Project (CHAMP) showed that inadequate intakes of micronutrients were only associated with the country of birth in community-dwelling men aged 75 years and over[16]. Particularly, older Australian men born in Italy or Greece were at risk of poor micronutrient intake[16]. Another cross-sectional study of older adults reported that micronutrient deficiency was associated with very old age, physical inactivity, frailty and irregular supplement use[18]. On the other hand, the Nutrition and Function Study observed that the prevalence of micronutrient inadequacy was significantly associated with older women who were black, reported a low income, less than 9 years of education and did not eat breakfast, but not in older men[20]. The majority of these aforementioned cross-sectional studies reported predictors of micronutrient deficiency in the older population; however, there is a lack of longitudinal studies on both changes in micronutrient intake and its predictors. Therefore, the objectives of this extension of the previous cross-sectional CHAMP study were to examine changes in micronutrient intake over 3 years among community-dwelling older men and to identify associations between socio-economic, health, lifestyle and meal-related factors as predictors and these changes in micronutrient intakes.

Methods

Study participants

The CHAMP is a large epidemiological study of ageing in men. Participants were recruited from three local government areas (Burwood, Canada Bay and Strathfield) surrounding Concord Hospital in Sydney, New South Wales, Australia. Potential participants were selected from the New South Wales electoral roll (electoral registration is compulsory in Australia)[21]. At baseline (CHAMP first wave), between January 2005 and June 2007, a total of 1705 study participants aged 70 years and over were recruited. Data were collected using self-report questionnaires, interviewer-administered questionnaires, and a wide range of clinical assessments. The study design has been reported in detail elsewhere[21].

Nutrition data were first collected at the third wave (between August 2010 and August 2013) of CHAMP follow-up (baseline nutrition in this study). A total of 958 men aged ≥75 years participated in this wave of CHAMP follow-up and 794 of these men participated in a diet history interview, providing baseline nutrition data for the study described in this paper. A total of 781 men participated in the fourth wave (between August 2014 and June 2016) of CHAMP (3-year follow-up in this paper).

Dietary intake

A detailed description of the dietary data collection method has been reported elsewhere[16]. Briefly, research dietitians administered a standardised diet history questionnaire at the participant's residence to measure dietary intake between August 2010 and August 2013 (baseline nutrition) and August 2014 to July 2016 (3-year follow-up). The Sydney South West Area Health Service's outpatient diet history form, which contains open-ended questions on food consumption at different mealtimes, was used to collect data at both time points. Diet history interviews took 45 min, during which participants were asked about their usual food consumption during the previous 3 months using standard household measures, food models and food photographs. If present during the interview, spouses/partners or other family members assisted participants to recall their dietary intake[22].

Dietary data handling

Dietary data (both at baseline nutrition and 3-year follow-up) were converted into nutrient intakes using FoodWorks 7 Professional for Windows (Xyris Software (Australia) Pty Ltd), and The Australian Food, Supplement and Nutrient Database 2007 (AUSNUT 2007). The median intake of thiamine, riboflavin, niacin, dietary folate equivalents, vitamins A, C, D, and E, Zn, Mg, P, Ca, K, Fe, Na and I was calculated for each participant. The dietary adequacy of each micronutrient was compared to the estimated average requirement of the Australian nutrient reference values (NRV) for males aged 70 years and over[23]. To evaluate the proportion of men meeting the estimated average requirement of micronutrients and to examine the associations between socio-economic, lifestyle and health factors and inadequate dietary intake of micronutrients, a composite 'micronutrient risk variable' was generated. Total of twelve micronutrients (riboflavin, dietary folate

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equivalents, vitamins A, C, D, and E, Zn, Mg, Ca, K, P and Fe) have been identified as essential micronutrients for the achievement and maintenance of physical and cognitive function and quality of life among older people[14,20,24–27]. Attainment of the NRV of twelve micronutrients was incorporated into a dichotomised variable (micronutrient risk variable) 'not meeting' (≤6 micronutrients) or 'meeting' (≥7 micronutrients) NRV using the cut-point method[28]. Of the twelve micronutrients, the median value was 7, that is, 50 % of participants met the NRV of seven micronutrients[28]. Hence, meeting the NRV for seven micronutrients was considered as 'meeting' and meeting the NRV for six or fewer micronutrients was considered as 'not meeting'. The data presented on dietary micronutrient intakes refer to food consumption only; intake through nutritional supplements was not assessed as detailed dosages or data on the consumption of dietary supplements were not available.

The following categories of change in micronutrient intakes from baseline to 3-year follow-up were assessed: maintained adequate micronutrient intake (meeting ≥ 7 micronutrients at baseline nutrition and 3-year follow-up); the transition from inadequate to adequate micronutrient intake from baseline to 3-year follow-up (i.e. meeting ≤ 6 micronutrients at baseline nutrition to meeting ≥ 7 micronutrients at 3-year follow-up); the transition from adequate to inadequate micronutrient intake (meeting ≥ 7 micronutrients at baseline nutrition to meeting ≤ 6 micronutrients at 3-year follow-up); and remained inadequate micronutrient intake (meeting ≤ 6 micronutrients at baseline nutrition and 3-year follow-up).

Socio-economic measures

Socio-economic variables included age, marital status, living arrangements (living alone *v.* living with others) and source of income. Sources of income were categorised as 'age pension only', 'age pension plus other sources of income' and 'other' sources of income (repatriation pension, veteran's pension, superannuation or other private income, own business/farm/partnership, wage or salary, other source or combination of sources of income). Source of income was used as a proxy of personal income, and we assumed that age pensioners had the lowest income.

Lifestyle factors

Smoking (categorised as non-smokers, ex-smokers or current smokers) and alcohol consumption were assessed. Participants were categorised into safe-drinkers (1–21 drinks per week), harmful drinkers (>21 drinks per week), lifelong abstainers, and ex-drinkers[29]. Physical activity was measured using the validated, self-administered Physical Activity Scale for the Elderly (PASE) questionnaire[30]. Participants were categorised into low, moderate and high activity based on the PASE score.

Anthropometric measurements

BMI (weight/height^2, with units kg/m^2) was determined by height measurements (using the Harpenden Portable Stadiometer, Holtain Limited) and by weight measurements (using Wedderburn digital scales) following standardised techniques. Participants were categorised as underweight (less than 22 kg/m^2), normal weight (between 22 and 30 kg/m^2) and overweight/ obese (over 30·0 kg/m^2) based on previous studies among older people aged 65 years and above[31–36].

Multimorbidity, self-rated health status and polypharmacy

Multimorbidity was defined as having two or more of the following medical conditions as identified in the questionnaire: diabetes, thyroid dysfunction, osteoporosis, Paget's disease, stroke, Parkinson's disease, epilepsy, hypertension, heart attack, angina, congestive heart failure, intermittent claudication, chronic obstructive lung disease, liver disease, cancer (excluding non-melanoma skin cancers), osteoarthritis and gout[37]. Self-rated health was obtained through response to the question, 'Compared to other people of your age, how would you rate your health?', and data were dichotomised into excellent/good *v.* fair/poor/very poor. Polypharmacy was categorised as the use of five or more regular prescription drugs[38].

Statistical analysis

The analysis was carried out using SPSS software version 24 (IBM Corp.). Descriptive characteristics of the study participants were expressed as means (SD) and percentages. Comparisons between groups were performed using the chi square test for categorical data. Statistical methods (e.g. Shapiro–Wilk for normality test) were used to examine data distribution.

The distributions of all micronutrients analysed were skewed; therefore, micronutrient intakes were reported as medians (IQR) for numerical variables and as percentages for categorical variables.

Wilcoxon Signed-Ranks Test was used to compare baseline and 3-year follow-up micronutrient intakes.

The multinominal logistic regression model was used to examine the associations between changes in micronutrient intake categories as the dependent variable (i.e. maintained adequate intake *v.* transition from inadequate to adequate *v.* transition from adequate to inadequate micronutrient intake *v.* continued inadequate intake) and baseline socio-economic factors (age, marital status, living arrangements and income), lifestyle factors (physical activity, smoking status and alcohol intake), health factors (BMI, self-rated health, multimorbidity and polypharmacy) and meal-related factors (meal preparation, meal service and able to go grocery shop) as the independent variables.

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Evidence against null hypotheses was considered statistically significant if P values were <0·05. The goodness of fit of the final adjusted logistic regression models was assessed using the Hosmer–Lemeshow statistic.

Results

Participants' characteristics

Socio-economic, lifestyle, health status and meal-related information according to micronutrient intakes are summarised in Table 1. Participants' mean (SD) age at baseline nutrition was 81·4 (SD 4·6) years. The majority of men who were married, born in Australia, physically active and received a pension had an adequate intake of micronutrients (i.e. met seven or more of the twelve micronutrients). Approximately one-third of participants (*n* 231) had inadequate intake of micronutrients (i.e. met six or fewer of the twelve micronutrients) assessed at baseline nutrition.

The transition from adequate to inadequate micronutrient intake was 21 % (*n* 115) at 3-year follow-up and 16·4 % (*n* 89) of men remained inadequate micronutrient intake at 3-year follow-up. Half of the participants (50·4 %, *n* 274) maintained adequate micronutrient intake, 12 % (*n* 66) participants were in the transition from inadequate to adequate micronutrient intake and 21 % (*n* 115) participants were in the transition from adequate to inadequate micronutrient intake category from baseline to 3-year follow-up.

Micronutrient intake and food sources

Median daily dietary micronutrient intakes at baseline and 3-year follow-up are shown in Table 2. The median daily intakes of thiamine, riboflavin, niacin, folate, vitamins A and D, K, Mg, Ca, P, Fe, Zn and I were significantly reduced at 3-year follow-up compared to baseline nutrition. There were no significant differences in vitamins C and E between baseline nutrition and 3-year follow-up among CHAMP men. Median daily intake of Na was significantly higher at a 3-year follow-up compared to baseline nutrition.

More than half of CHAMP participants had inadequate intake of the NRV for vitamins D and E, Na, K and Ca at both baseline nutrition and 3-year follow-up. Inadequate intakes of the NRV for thiamine, dietary folate, Zn, Mg, Ca and I were significantly increased at a 3-year follow-up compared to baseline nutrition (Table 2).

Factors associated with intake of micronutrients

The prospective associations between socio-economic, health status, lifestyle and meal-related factors at baseline and the changes in micronutrient intake at 3-year follow-up are shown in Tables 3 and 4. In the unadjusted and multivariate-adjusted analysis, older men who were born in the UK or Italy were more likely to transition from adequate to inadequate or remain in inadequate micronutrient intake at a 3-year follow-up. Similarly, older men with lower physical activity were more likely to transition from adequate to inadequate micronutrient intake or to have continued inadequate micronutrient intake. Those with two or more medical conditions were also more likely to transition from adequate to inadequate micronutrient intake or to have continued inadequate micronutrient intake category. Further, individuals who used meal services (e.g. meals on wheels) were more likely to transition from adequate to inadequate micronutrient intake or remain in the inadequate micronutrient intake category at a 3-year follow-up. No significant associations were observed for the transition of inadequate to adequate micronutrient intake category (Tables 3 and 4).

Discussion

In this prospective study, we examined changes in micronutrient intake over 3 years and assessed if socio-economic, health status, lifestyle and meal-related factors were associated with changes in micronutrient intake over this period among older Australian men. We found that intakes of vitamin A, thiamine, niacin, K, Mg, Ca, P, Fe and Zn significantly declined at a 3-year follow-up, whereas intakes of Na significantly increased compared to baseline nutrition.

The inadequacy of micronutrient intake is widespread among the older population. In line with our findings, inadequate intake of micronutrients such as vitamins A, C, D, and E, thiamine, riboflavin, pyridoxine, Ca, Mg, Zn, selenium, copper and Na have been found in American, Brazilian and Irish older population[20,27,39,40]. On the other hand, studies from Australia and New Zealand indicated an increased intake of micronutrients in the older population[41,42]. For example, an Australian longitudinal study involving individuals aged 62–99 years (mean age at baseline was 62·2 years) showed that the intakes of folate, vitamin B_{12}, Ca, Na and Fe significantly increased in older individuals over 10 years[41]. Similarly, Fernyhough and colleagues observed mean intake of folate and Ca density (mg/MJ) increased significantly over 6 years in community-dwelling older men from New Zealand[42]. Overall, the inadequacy of dietary micronutrient intake varies between different countries. However, the findings from these and our studies suggest that inadequate dietary intake of vitamin D, Ca and Mg is common in the older population.

Insufficient micronutrient intakes may be a result of the limited variety of foods in the usual diet of older men in Australia. The main food sources of vitamin A, thiamine, niacin, K, Mg, Ca, P, Fe and Zn were breakfast cereals, wholegrain bread, milk, cheese, chicken, beef, banana, potato, sweet potato and carrot. Hence, it is prominent that compared to the Australian Dietary Guideline for men aged 70 years and over (which recommended five serves of

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Table 1 Baseline characteristics of the study population according to micronutrient intake (*n* 794)*

	Baseline nutrition	Meeting ≥7 micronutrients		Meeting ≤6 micronutrients		
Variables	*n*	*n*	%	*n*	%	*P*
Socio-demographic and economic factors						
Age (years)	752					0·56
75–79 (reference)	316	226	71·5	90	28·5	
80–85	271	183	67·5	88	32·5	
85+	165	112	67·9	53	32·1	
Mean	81·37	80·95		81·56		
SD	4·61	4·39		4·71		
Marital status	749	520	69·4	229	30·6	0·57
Married/de facto (reference)	566	396	70·0	170	30·0	
Divorced/separated/widowed/never married/other	183	124	67·8	59	32·2	
Living arrangements	752	522	69·4	230	30·6	0·16
Living alone	156	101	64·7	175	29·4	
Living with others (Reference)	596	421	70·6	55	35·3	
Country of birth	754	523	69·4	231	30·6	<0·0001
Australia (reference)	402	301	74·9	101	25·1	
UK	34	23	67·6	11	32·4	
Italy	150	80	53·3	70	46·7	
Greece	25	20	80·0	5	20·0	
Others	143	99	69·2	44	30·8	
Post-school qualification	742	518	69·8	224	30·2	0·002
Bachelor's degree or higher	98	55	56·1	43	43·9	
Other†	644	463	71·9	181	28·1	
Income	752	522	69·4	230	30·6	0·01
Age pension only	299	191	63·9	108	36·1	
Age pension + another source	163	125	76·7	38	23·3	
Other source‡	290	206	71·0	84	29·0	
Health and lifestyle factors						
BMI (kg/m^2)	726	504	69·4	222	30·6	0·51
Underweight (<22)	40	31	77·5	9	22·5	
Normal (22–30)	496	343	69·2	153	30·8	
Overweight/obese (>30)	190	130	68·40	60	31·6	
Mean	27·66	27·51		28·01		
SD	3·91	3·89		3·93		
PASE	747	519	69·5	228	30·5	0·02
Low activity	183	112	61·2	71	38·8	
Median activity	375	272	72·5	103	27·5	
High activity	189	135	71·4	54	28·6	
Self-rated health	753	523	69·5	230	30·5	0·11
Fair/poor/very poor	194	126	64·9	68	35·1	
Excellent/good	559	397	71·0	162	29·0	
Cigarette smoking	748	518	69·3	230	30·7	0·74
Non-smoker	309	213	68·9	96	31·1	
Ex-smoker	415	290	69·9	125	30·1	
Current smoker	24	15	62·5	9	37·5	
Alcohol consumption	747	519	69·5	228	30·5	0·66
Safe-drinker	535	373	69·7	162	30·3	
Harmful drinker	37	23	62·2	14	37·8	
Ex-drinker	110	75	68·2	35	31·8	
Lifelong non-drinker	65	48	73·8	17	26·2	
Multimorbidity	753	523	69·5	8230	30·5	0·42
<2	419	286	68·3	133	31·7	
2+	334	237	71·0	97	29·0	
Polypharmacy	748	519	69·4	229	30·6	0·63
<5	415	291	70·1	124	29·9	
5	333	228	68·5	105	31·5	
Meal-related factors						
Able to prepare own meal	753	523	69·5	230	30·5	0·54
No	31	20	64·5	11	35·5	
Yes	722	503	69·7	219	30·3	
Meal service (e.g. MOW)	753	523	69·5	230	30·5	0·65
Yes	23	15	65·2	8	34·8	
No	730	508	69·6	222	30·4	
Able to go grocery shop	753	523	69·5	230	30·5	0·81
No	15	10	66·7	5	33·3	
Yes	738	513	69·5	225	30·5	

PASE, Physical Activity Scale for the Elderly; MOW, Meals on Wheels.
*Missing data for age (*n* 42), marital status (*n* 45), living arrangement (*n* 42), country of birth (*n* 40), post-school qualification (*n* 52), income (*n* 42), BMI (*n* 68), PASE (*n* 47), self-rated health (*n* 41), multimorbidity (*n* 41), polypharmacy (*n* 46), smoking (*n* 46), alcohol consumption (*n* 47), meal related factors (*n* 41).
†Other post-school qualification, trade/apprenticeship/certificate/diploma/no qualifications.
‡Other income, manager/professional/paraprofessional/tradesperson/clerk/salesperson/ personal service worker/inadequately stated/unknown.

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Table 2 Median micronutrient intakes and proportion of participants meeting/not meeting the NRV at baseline nutrition and at 3-year follow-up among men aged 75 years and older (*n* 607)

Nutrients	EAR/AI of the NRV (male ≥70 years old)	Baseline nutrient intake (*n* 607) Median	IQR	Meeting the NRV %	Not meeting the NRV %	Three-year nutrient intake (*n* 607) Median	IQR	Meeting the NRV %	Not meeting the NRV %
Micronutrients									
Thiamine (mg/d)-EAR	1	1·66	1·3, 2·2	91·7	8·3	1·49**	1·1, 2·7	88	12*
Riboflavin (mg/d)-EAR	1·3	2·15	1·7, 2·8	91·4	8·6	2·06***	1·6, 2·7	90·4	9·6
Niacin (mg/d)-EAR	12	50·42	42·4, 61·1	100	0	47·24***	38·9, 57·2	100	0
Dietary folate (μg/d)-EAR	320	388·53	294·9, 495·6	69·5	30·5	368·79*	284·1, 475·9	64	36*
Vitamin D (μg/d)-AI†	15	4·47	3·3, 6·1	1·2	98·8	3·84***	2·7, 5·4	0·8	99·2
Vitamin A (μg/d)-EAR‡	625	1001·55	734·1, 1363·7	85	15	957·48*	688·2, 1295·8	80·9	19·1
Vitamin E (mg/d)-AI§	10	9·89	7·1, 13·5	50	50	9·88	7·3, 13·2	49·8	50·2
Vitamin C (mg/d)-EAR	30	110·43	74·4, 156·1	98·5	1·5	111·54	71·6, 159·7	97·9	2·1
Na (mg/d)-UL‖	2300	1986·49	1525·0, 2494·7	32·3	67·7	2109·97***	1646·8, 2520·8	37·6	62·4
K (mg/d)-AI	3800	3357·77	2783·5, 3998·5	32·5	67·5	3276·20*	2702·6, 3897·3	29·7	70·3
Mg (mg/d)-EAR	350	359·41	282·7, 435·7	52·6	47·4	339·47**	277·4, 410·0	46	54*
Ca (mg/d)-EAR	1100	798·16	619·6, 1047·1	20·6	79·4	768·57**	609·3, 959·4	14·2	85·8**
P (mg/d)-EAR	580	1590·18	1308·0, 1912·4	100	0	1471·62***	1242·1, 1747·8	99·8	0·2
Fe (mg/d)-EAR	5	13·04	10·5, 16·0	99·2	0·8	12·14**	10·0, 14·9	98·2	1·8
Zn (mg/d)-EAR	12	13·33	11·0, 16·7	67·8	32·2	12·15***	10·0, 14·9	54	46***
I (μg/d)-AI	100	107·47	85·2, 146·8	59·1	40·9	108·15	83·0, 139·4	47·5	52·5***

NRV, nutrient reference values; EAR, estimated average requirement; AI, adequate intake; UL, upper level.
†Vitamin D data should be interpreted with caution.
‡Retinol equivalent.
§α-Tocopherol equivalent.
‖Na naturally present in foods as well as Na added during processing but excludes the ‘discretionary salt’ added by participants in home-prepared foods or ‘at the table’; inadequate intake refers to the proportion of participants who consumed amounts above the UL.
For comparison between baseline and 3-year follow-up: *$P < 0·05$, **$P < 0·01$ and ***$P < 0·001$.

Table 3 Univariate analyses for the prospective association between changes in micronutrient intake and socio-economic, health and lifestyle and meal-related activities of daily living (*n* 607)*

	Changes in micronutrient intake between baseline nutrition and 3-year follow-up								
	Transition from inadequate to adequate micronutrient intake from baseline nutrition to 3-year follow-up†			Transition from adequate to inadequate micronutrient from baseline nutrition to 3-year follow-up OR†			Remained inadequate micronutrient intake at baseline nutrition and 3-year follow-up†		
Variables	OR	95 % CI	*P*	OR	95 % CI	*P*	OR	95 % CI	*P*
Age (years) (continuous)	1·02	0·94, 1·09	0·69	1·03	0·98, 1·09	0·28	1·00	0·93, 1·08	0·94
Marital status									
Married/de facto (reference)	1			1			1		
Divorced/separated/widowed/never married/other	0·95	0·28, 3·26	0·93	1·35	0·49, 3·71	0·56	1·18	0·45, 3·05	0·74
Living arrangements									
Living with others (reference)	1			1			1		
Living alone	1·55	0·42, 5·74	0·51	1·68	0·58, 4·86	0·34	1·38	0·51, 3·77	0·53
Country of birth									
Australia (reference)	1			1			1		
UK	1·92	0·78, 4·74	0·16	2·28	1·26, 4·13	0·007	1·99	1·24, 3·21	0·004
Italy	1·55	0·88, 2·75	0·13	2·05	1·27, 3·33	0·003	2·26	1·27, 4·06	0·006
Greece	2·31	0·79, 6·80	0·13	1·91	0·61, 5·95	0·26	1·74	0·57, 5·31	0·33
Others	1·27	0·79, 2·03	0·31	1·30	0·82, 2·07	0·27	1·37	0·84, 2·21	0·24
Post-school qualification									
Bachelor's degree or higher (reference)	1			1			1		
Other	1·25	0·45, 3·50	0·67	1·23	0·50, 3·03	0·66	1·59	0·83, 305	0·16
Income									
Age pension only (reference)	1			1			1		
Age pension + another source	0·97	0·62, 1·51	0·89	1·24	0·65, 2·34	0·51	1·09	0·63, 1·86	0·76
Other source	1·21	0·71, 1·04	0·49	1·06	0·60, 1·87	0·84	1·60	0·85, 3·01	0·15
BMI (continuous)	1·01	00·96, 1·07	0·59	1·05	0·98, 1·12	0·15	1·00	0·61, 1·65	0·98
Physical Activity Scale for the Elderly									
High activity (reference)	1			1			1		
Median activity	0·75	0·75, 1·51	0·42	1·42	0·79, 2·55	0·24	1·59	0·83, 3·06	0·16
Low activity	1·65	0·68, 4·05	0·27	2·12	1·00, 4·52	0·05	2·78	1·19, 6·50	0·02
Self-rated health									
Excellent/good (reference)	1			1			1		
Fair/poor/very poor	1·77	0·88, 3·59	0·11	1·46	0·80, 2·67	0·22	1·26	0·63, 2·52	0·52
Cigarette smoking									
Non-smoker (reference)	1			1			1		
Ex-smoker	0·60	0·32, 1·13	0·12	1·13	0·68, 1·87	0·63	1·41	0·82, 2·41	0·21
Current smoker	1·27	0·21, 7·57	0·79	1·04	0·22, 4·81	0·96	1·81	0·49, 6·71	0·38
Alcohol consumption									
Safe-drinker (reference)	1			1			1		
Harmful drinker	1·25	0·55, 2·82	0·60	1·84	0·78, 4·34	0·16	1·77	0·89, 3·52	0·10
Ex-drinker	1·75	0·92, 3·33	0·09	1·32	0·66, 2·65	0·43	1·08	0·27, 4·32	0·92
Lifelong non-drinker	1·00	0·28, 3·53	0·99	0·61	0·21, 1·81	0·37	0·64	0·23, 1·74	0·38
Multimorbidity									
<2 (reference)	1			1			1		
2+	1·39	0·89, 2·14	0·14	2·24	1·30, 3·86	0·004	2·24	1·32, 3·80	0·003
Polypharmacy									
<5 (reference)	1			1			1		

Table 3 *Continued*

	Changes in micronutrient intake between baseline nutrition and 3-year follow-up								
	Transition from inadequate to adequate micronutrient intake from baseline nutrition to 3-year follow-up†			Transition from adequate to inadequate micronutrient from baseline nutrition to 3-year follow-up OR†			Remained inadequate micronutrient intake at baseline nutrition and 3-year follow-up†		
Variables	OR	95 % CI	*P*	OR	95 % CI	*P*	OR	95 % CI	*P*
5	0·94	0·49, 1·83	0·86	1·04	0·62, 1·75	0·88	1·22	0·68, 1·09	0·50
Able to prepare own meal									
Yes (reference)	1			1			1		
No	1·34	0·45, 4·01	0·60	1·66	0·89, 3·09	0·11	1·74	0·83, 3·62	0·14
Meal service									
No (reference)	1			1			1		
Yes	1·79	0·88, 3·69	0·11	1·96	1·11, 3·38	0·02	1·91	1·11, 3·29	0·02
Able to go grocery shop									
Yes (reference)	1			1			1		
No	1·06	0·23, 4·89	0·94	1·72	0·29, 10·30	0·56	1·32	0·71, 2·43	0·38

*Reference category: maintained adequate micronutrient intake at baseline and 3-year follow-up

†Adjusted by age, BMI, marital status, country of birth, living arrangement, post-school education, income, smoking habit, alcohol intake, self-rated health, multimorbidity, polypharmacy, Physical Activity Scale for the Elderly, meal-related factors.

vegetables and two serves of fruits daily)(43), CHAMP men had insufficient fruit and vegetable intake.

Besides, the outcomes of inadequate micronutrient intakes in this current study reflect the current socio-demographic and epidemiological profile of Australian older men, which is attributed to the increasing number of medical conditions associated with ageing. We found that around 29 % of older men who had two or more medical conditions were meeting six or fewer micronutrients. It has been shown that an increased number of chronic diseases are not the outcomes of ageing rather it may be due to lifestyle choices, such as diet(44,45). Further, epidemiological studies and clinical trials stated that age-related chronic diseases can be reversed or prevented with the help of healthy lifestyle intervention(44).

In addition to the changes in micronutrient intake, we also found that half of the participants did not meet the NRV for vitamins D and E, K and Ca at both baseline nutrition and 3-year follow-up. While, the proportion with inadequate intakes of the NRV for thiamine, dietary folate, Mg, Ca, Zn and I increased at a 3-year follow-up compared to baseline nutrition. Similarly, a longitudinal study of ninety-six community-dwelling older French individuals showed that at both baseline and 4-year follow-up, the intakes of Fe, vitamins C and B_{12} were higher while intakes of Ca, Zn, vitamins A, B_1, B_6 and B_9 were significantly lower than the French dietary guideline(46). Likewise, the SENECA study reported that inadequacy of the European Recommended Dietary Intake for thiamine, riboflavin, vitamin A and C increased over 10 years in Italian older men (mean aged 81·9 years)(13). These studies including our study indicate that inadequate intake of certain essential micronutrients may be a risk of subclinical malnutrition in a healthy older population(13).

In this study, we found that factors such as country of birth, physical activity, multimorbidity and meal service use were associated with the changes in micronutrient intake over 3 years. Associations between socio-economic, lifestyle and health factors (e.g. increased age, living alone, physical impairment, low income, unemployment, cognitive impairment, depression, taking multiple medications and not usually eating breakfast) and poor nutrient intake among the community-dwelling older population have previously been reported(15,17,18). In our study, older men who were born in the UK or Italy were more likely to change from having adequate to inadequate micronutrient intakes or to continue to have inadequate micronutrient intakes compared to participants who were born in Australia. Our findings are consistent with previous studies that observed Italian older men are at risk of micronutrient deficiencies(13,14,47,48). Although, Italian adults tend to have an adequate intake of vegetables and fruits(49), however, previous CHAMP study observed that the consumption of vegetables and fruits among Italian-born older Australian men seems to be lower compared to Australian Dietary Guidelines(50). This may explain the observed inadequate micronutrient intake in Italian-born

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Table 4 Multivariate-adjusted analysis for the prospective association between changes in micronutrient intake and socio-economic, health and lifestyle and meal-related activities of daily living (*n* 607)*

	Changes in micronutrient intake between baseline nutrition and 3-year follow-up								
	Transition from inadequate to adequate micronutrient intake from baseline nutrition to 3-year follow-up†			Transition from adequate to inadequate micronutrient from baseline nutrition to 3-year follow-up†			Remained inadequate micronutrient intake at baseline nutrition and 3-year follow-up†		
Variables	OR	95 % CI	*P*	OR	95 % CI	*P*	OR	95 % CI	*P*
Country of birth									
Australia (reference)	1·00			1·00			1·00		
UK	1·02	0·42, 2·49	0·96	3·25	1·28, 8·26	0·01	3·15	1·26, 7·90	0·01
Italy	1·01	0·55, 1·85	0·98	2·23	1·25, 3·99	0·007	1·87	1·16, 3·02	0·01
Greece	1·44	0·52, 3·95	0·48	2·07	0·70, 6·08	0·19	1·36	0·52, 3·55	0·54
Others	1·41	0·88, 2·24	0·14	1·41	0·87, 2·28	0·16	1·32	0·83, 2·09	0·25
Physical Activity Scale for the Elderly									
High activity (reference)	1·00			1·00			1·00		
Median activity	0·78	0·39, 1·54	0·47	1·53	0·86, 2·72	0·15	1·58	0·83, 2·98	0·16
Low activity	1·66	0·70, 3·93	0·25	2·23	1·07, 4·65	0·03	2·70	1·19, 6·12	0·02
Multimorbidity									
<2 (reference)	1·00			1·00			1·00		
2+	1·03	0·62, 1·69	0·91	1·86	1·15, 2·99	0·01	2·24	1·32, 3·80	0·003
Meal service (e.g. MOW)									
No (reference)	1·00			1·00			1·00		
Yes	1·23	0·82, 1·83	0·32	2·18	1·28, 3·71	0·004	2·18	1·35, 3·51	0·001

MOW, Meals on Wheels.
*Reference category: maintained adequate micronutrient intake at baseline and 3-year follow-up.
†Adjusted by age, BMI, alcohol intake, meal service, meal preparation, multimorbidity, and Physical Activity Scale for the Elderly.

CHAMP men. It has also been noted that food preference and dietary habits in Italian-born older Australian may be influenced by socio-economic characteristics. As noted by Giuli *et al.*[51], nutritional and dietary habits in older Italian population are correlated with age, level of education and economic status. Hence, socio-economic and behavioural factors should be taken into account when exploring factors associated with a micronutrient intake

In this present study, we observed that older men who reported low levels of physical activity were more likely to transition from having adequate to inadequate intakes of micronutrients or remaining at inadequate for intakes of micronutrients over 3 years. The association between poor mobility and lower nutrient intake in the older population has been reported previously[52]. Low physical activity in the older population may increase the risk of inadequate micronutrient intake through limited access to nutritious foods, a decline in appetite and sensory impairment. Functional impairments may cause mobility limitations that impact on the ability to access food and prepare meals[53] and is associated with poor appetite among older people[54,55]. It has also been shown that functional and sensory (hearing and vision) impairments that affect daily living are linked with reduced dietary intake and appetite[56].

The changes in micronutrient intake (i.e. transition from adequate to inadequate or remain inadequate) were associated with multimorbidity (in men who had two or more medical conditions). A significant inverse association between multimorbidity and nutrient inadequacy has also been shown in other studies[40]. Besides, multimorbidity is associated with polypharmacy[57]. Polypharmacy, in turn, is associated with malnutrition[58,59]. A number of cross-sectional studies showed the association between polypharmacy and inadequate intake of vitamin A, D, E, K, and B_{12}, thiamine, niacin and folate in community-dwelling older people[60]. However, in this present study, we found no association between polypharmacy and changes in micronutrient intake. In addition, multimorbidity is also associated with functional impairment and disability[61]. It has been shown that functional impairment and disability may increase the risk of poor nutrient intake[61]. Further, some medical conditions cause malabsorption or increased metabolism that may, in turn, result in anorexia and micronutrient deficiency among the older population[62].

Interestingly, in the current study, we found that participants using a meal service (e.g. meals on wheels) were more likely to have inadequate micronutrient intake. It has been shown that home-delivered meal programmes meet recommended guidelines and increase nutrient intakes in terms of protein and energy only if all three meals (i.e. breakfast, lunch and dinner) are ordered and consumed[63]. Evidence from a previous case-control study showed that daily intake of micronutrients was below the recommended dietary guidelines in both the case and control groups; most participants in the experimental group, however, received 2–3 meals per week and rarely or never consumed an entire meal at the time of delivery[64]. In contrast, a review of eight studies reported that only two found that home-delivered meal programmes significantly improved diet quality, increased nutrient intake, and

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reduced food insecurity and nutritional risk among older participants[65]. It is important to ensure that programmes such as meals on wheels provide meals that contain adequate micronutrients. The meals on wheels programme can potentially improve micronutrient intake using the skills of food industry chefs to produce tasty meals from traditional cuisines or healthy dietary pattern[17], which has been shown to be effective in meeting micronutrient requirements[66]. Traditional cuisine often includes stewed rather than boiled vegetables, which preserves levels of micronutrients[17]. It becomes important to involve dietitians and nutritionists in the meal planning and preparation process to minimise micronutrient loss of meals on wheels diets and allow adherence to standard dietary guidelines[17].

A major strength of our study is that we have longitudinal data that enabled us to examine the association between changes in nutrient intake and socio-economic, health status, lifestyle and other factors likely to affect dietary intake among older men over time. A further strength of our study is that the study includes a large representative group of older Australian men, as demonstrated by the fact that their socio-demographic and health characteristics are similar to those of older men in the nationally representative Men in Australia Telephone Survey[67]. In addition, we have used the cut-point method to evaluate the proportion of men with intakes of micronutrients above or below the NRV. The use of this method results in a better estimate of the true distribution of micronutrient intakes[28]. Furthermore, we used a validated diet history method to assess the nutritional intake of our study population[68]. Diet history method has less systematic errors than FFQ since it does not limit the variability of response[69], which makes them more suited to estimate the usual nutrient intake. We also used AUSNUT 2007 that contains 37 nutrient values for 4425 foods[70]. We used the IQR, that allows us to ignore extreme data values and present the difference between the first and third quartiles.

The study also had some limitations. We lacked data on nutrient values for vitamins B_6 and B_{12} as these two nutrients are not included in the AUSNUT 2007, which was used in this study. AUSNUT 2007 also contains limited vitamin D data so these results need to be interpreted with caution[71]. We could not incorporate the intake of nutrients from supplements, as we did not have detailed data on dosage or levels of dietary supplements. Also, we did not have any data on serum micronutrients. We acknowledge that the estimation of food intake may be under- or over-reported. The effect of social desirability bias may persist across diet data. Self-reported diet data may have been influenced by the participant's desire to gain approval from dietitian/researchers, which may consequently overestimate food and nutrient intake[72]. However, if participants reported energy intake above or below two SD from the median, they were excluded to avoid probable misreporting. Also, we removed outliers for extreme micronutrient intakes. In addition, we had a relatively short follow-up of 3 years; thus, the results may not be maintained over longer follow-up periods. Like all observational studies, the non-interventional design precludes any interpretation of causality. Finally, our study was limited to community-dwelling men, so our results may not apply to older women or institutionalised individuals.

Conclusion

This study is an extension of the previous cross-sectional CHAMP study providing a better understanding of the relationship between changes in micronutrient intake and a range of socio-economic, health and meal-related factors among older Australian men. Our findings support the need to improve awareness of the consumption of more micronutrient-dense food among older men in order to ensure their micronutrient intakes to meet the NRV for long-term health benefits. Multivitamin or specific micronutrient supplementation may be essential for this population to ensure adequate intake of micronutrients. Our results also suggest that new policies are required for meal service programmes to ensure that micronutrients and phytochemicals are retained during meal preparation. Additionally, the involvement of a dietitian or nutritionist as a part of meals on wheels programme may help to achieve micronutrient requirements. It would also be beneficial to provide educational advice to older Australians and their caregivers to improve consciousness of reducing sedentary behaviour as well as encouraging increased physical activity to maintain health and mobility. It might also be beneficial to develop targeted health promotion and clinical interventions to improve micronutrient intake among this group.

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the Concord Hospital Human Research Ethics Committee, Sydney, Australia. Written informed consent was provided by all study participants.

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