Short communication

The absorption of vitamin E is influenced by the amount of fat in a meal and the food matrix

Yvonne M. Jeanes, Wendy L. Hall, Susan Ellard, Elizabeth Lee and John K. Lodge*
Centre for Nutrition and Food Safety, School of Biomedical and Molecular Sciences, University of Surrey, Guildford, Surrey GU2 7XH, UK

(Received 1 April 2004 – Revised 24 June 2004 – Accepted 29 June 2004)

Vitamin E absorption requires the presence of fat; however, limited information exists on the influence of fat quantity on optimal absorption. In the present study we compared the absorption of stable-isotope-labelled vitamin E following meals of varying fat content and source. In a randomised four-way cross-over study, eight healthy individuals consumed a capsule containing 150 mg 2H-labelled RRR-α-tocopheryl acetate with a test meal of toast with butter (17.5 g fat), cereal with full-fat milk (17.5 g fat), cereal with semi-skimmed milk (2.7 g fat) and water (0 g fat). Blood was taken at 0, 0.5, 1, 1.5, 2, 3, 6 and 9 h following ingestion, chylomicrons were isolated, and 2H-labelled α-tocopherol was analysed in the chylomicron and plasma samples. There was a significant time (P<0.001) and treatment effect (P<0.001) in 2H-labelled α-tocopherol concentration in both chylomicrons and plasma between the test meals. 2H-labelled α-tocopherol concentration was significantly greater with the higher-fat toast and butter meal compared with the low-fat cereal meal or water (P<0.001), and a trend towards greater concentration compared with the high-fat cereal meal (P=0.065). There was significantly greater 2H-labelled α-tocopherol concentration with the high-fat cereal meal compared with the low-fat cereal meal (P<0.05). The 2H-labelled α-tocopherol concentration following either the low-fat cereal meal or water was low. These results demonstrate that both the amount of fat and the food matrix influence vitamin E absorption. These factors should be considered by consumers and for future vitamin E intervention studies.

Tocopherol: Fat: Plasma: Chylomicrons

Vitamin E has been the subject of a number of clinical trials investigating its potential cardioprotective effects, even though there is limited information on factors that influence its bioavailability. It is widely accepted that dietary fat is required for the absorption of vitamin E; however, the amount of fat required for maximal absorption is unknown. The process is similar for all the fat-soluble vitamins and other dietary fats in that there is a prerequisite for the formation of mixed micelles containing dietary lipids and products of lipid hydrolysis, emulsified in the presence of bile salts (Cohn et al. 1992; Cohn, 1997). The importance of bile salts and pancreatic secretions is demonstrated in subjects with either cholestatic liver disease or cystic fibrosis who malabsorb vitamin E and become vitamin E deficient (Sokol et al. 1989). The amount of fat necessary for maximal vitamin E absorption in man in currently undetermined (Cohn, 1997; Leonard et al. 2004). There are only a few human studies that have investigated the influence of dietary fat on vitamin E absorption. Dimitrov et al. (1991) reported significantly greater plasma α-tocopherol (the major form of vitamin E in tissues) levels in human subjects after 5 d when given 800 mg synthetic vitamin E with a high-fat diet compared with a low-fat diet. However, no difference in plasma vitamin E levels was found following a 50 mg supplement taken with either 3 or 36 g fat for 7 d (Roodenburg et al. 2000). Supplementation vitamin E is usually encapsulated in the esterified form, which requires de-esterification before absorption. This, however, does not appear to be rate limiting, as the biokinetics of α-tocopherol, α-tocopheryl acetate and α-tocopheryl succinate have been found to be all similar (Cheeseman et al. 1995). A recent study compared vitamin E bioavailability from a fortified breakfast cereal to that from a capsule (Leonard et al. 2004) and found increased bioavailability from the fortified meal; both forms were taken with ‘fat-free’ milk.

Vitamin E capsules represent an important source of vitamin E in terms of consumer use and in clinical studies. Such studies rarely include any indication of relative bioavailability. As there are limited controlled human data on the

Abbreviation: TAG, triacylglycerol.

* Corresponding author: Dr John K. Lodge, fax +44 1483 876 416, email j.lodge@surrey.ac.uk
influence of dietary fat on vitamin E absorption we investigated the influence of both the amount of fat and the food matrix on plasma α-tocopherol uptake as assessed by stable-isotope (2H)-labelled α-tocopherol kinetics. We chose to study this using common breakfast meals as sources of fat for our test meals, as it is common in clinical studies for subjects to take vitamin capsules in the morning at breakfast.

Materials and methods

Materials

RRR-α-5, 7-(C2H5)-tocopheryl acetate and all rac-α-5-(C2H5)-tocopheryl acetate were kind gifts from Cognis Nutrition and Health (Düsseldorf, Germany and LaGrange, IL, USA). The purity of the acetates was 98.8% for both species. Isotopic purity was determined to be >99.9% by LC-MS. The 2H-labelled RRR-α-tocopheryl acetate was encapsulated (150 mg) into hard gelatine capsules, with no other ingredients, for human consumption. The 2H-labelled all rac-α-tocopheryl acetate was used as an internal standard. All reagents for vitamin E extraction and analysis were obtained from Sigma-Aldrich Chemical Co. (Poole, Dorset, UK).

Subjects

To estimate the sample size required to demonstrate a significant difference between treatments with 0.05 probability and 80% power, we used a within-group variation of 20%, based on previous observations (Roxborough et al. 2000), and a difference to detect between treatments of 25%. This was based on the relatively large difference between amounts of fat in our test meals. A sample size of ten was calculated. In total eight healthy volunteers were recruited from within the University of Surrey. Selection criteria stated that subjects must be non-smoking, not taking dietary supplements and with no gastrointestinal disorders as determined from a written questionnaire. Subjects with blood lipid abnormalities were also excluded (criteria of total cholesterol < 6 mmol/l and triacylglycerol (TAG) < 1.5 mmol/l).

Study design

A within-subject, repeated-measures design was used, with each subject serving as their own control. Each subject consumed a capsule containing 150 mg 2H-labelled RRR-α-tocopheryl acetate with a different test meal on four separate occasions in a randomised order, each study day separated by 7 d. On study days each subject consumed the capsule with one of four test meals. These were: (1) two slices of white toast with 20 g butter (containing 17.5 g fat, 6.8 g protein, 41.2 g carbohydrate, 1356 kJ); (2) 40 g cornflakes with 75 g full-fat milk plus 75 g single cream (containing 17.5 g fat, 7.5 g protein, 41.0 g carbohydrate, 1436 kJ); (3) 40 g cornflakes with 75 g semi-skimmed milk (containing 2.7 g fat, 8.1 g protein, 41.9 g carbohydrate, 894 kJ); (4) a glass of water (containing 0 g fat, protein, carbohydrate and 0 kJ). Subjects (fasted for 12 h) were cannulated at 07.30 hours and immediately a blood sample was taken (10 ml). Subjects then consumed the capsule with the test meal at 08.00 hours, and further blood samples were taken at 08.30, 09.00, 09.30, 10.00, 11.00 and 14.00 hours. Subjects then consumed a standard lunch comprising a sandwich and low-fat yoghurt (containing 2.5 g fat, 23 g protein, 59 g carbohydrate, 1428 kJ). A further blood sample was taken at 17.00 hours. Blood sampling therefore corresponded to times 0, 0.5, 1, 1.5, 2, 3, 6 and 9 h following ingestion of the vitamin E capsule with the test meal. This time period was chosen, as we were primarily interested in chylomicron vitamin E transport. Subjects were only allowed water during the study period.

The study was approved by the University of Surrey Advisory Committee on Ethics.

Isolation of blood components

At each time point, plasma was harvested from whole blood following centrifugation at 3500 rpm for 10 min at 10°C. A sample of plasma (4 ml) was used for chylomicron isolation, while the remainder was snap-frozen in liquid N2 and stored at −80°C ready for analysis. To isolate chylomicrons, plasma (4 ml) was overlaid with an equal volume of saline solution (density 1.006 g/ml) in a Beckman ultracentrifuge tube. The samples were spun at 110 000 g for 15 min at 16°C using a 70.1 Ti Beckman Coulter rotor and a Beckman Optima XL-100 ultracentrifuge (Weintraub et al. 1987). The top 1 ml fraction, which comprises the chylomicrons, was harvested using a syringe and needle and subsequently snap-frozen in liquid N2 and stored at −80°C ready for analysis.

Vitamin E extraction and analysis

Total vitamin E was extracted from plasma and chylomicron samples by a combination of sodium dodecyl sulfate, ethanol and hexane as described previously (Burton et al. 1985). Tocopherols were analysed by LC–MS using a method we have recently developed (Hall et al. 2003). The system used was a Micromass LCT™ Column (2.1 × 50 mm, C18, 3.5 μm) with a mobile phase consisting of 100% methanol (LC–MS Chromasolv; Sigma-Aldrich).

Occasionally the presence of a small amount (<0.2 μmol/l) of 2H-labelled α-tocopherol was found in baseline plasma samples as a result of carry-over from the previous intervention (only when the meal followed the toast with butter meal; six occasions in total). In these circumstances, the labelled α-tocopherol concentrations were corrected for baseline by subtracting this baseline value from all time points over that study period.

Biochemical analysis

Total plasma cholesterol and TAG were determined using enzymic kits supplied by Randox (Crumlin, County
Antrim, UK), and analysed automatically using a SPACE biochemical analyser (Alfa-Wasserman, Woerden, Holland).

Statistical analysis

Data were analysed using two-way repeated-measures ANOVA (Statistica version 5.1; StatSoft Inc., Tulsa, OK, USA), with meal and time as within-subject factors. Post hoc analysis of effects was carried out using Tukey’s honestly significant difference test. Statistical significance was assigned at \( P < 0.05 \), and a trend towards significance if \( P < 0.1 \) and \( > 0.05 \). Values shown are means and standard deviations.

Results

Subject characteristics

Eight healthy normolipidaemic volunteers (five female, three male) participated in the study. Their mean age was 28 (SD 6) years and mean BMI was 23 (SD 4) kg/m². Fasting plasma cholesterol and TAG levels were 4·2 (SD 0·7) and 0·95 (SD 0·2) mmol/l respectively. Fasting plasma \( \alpha \)-tocopherol was 23·6 (SD 2·2) \( \mu \)mol/l, and their labelled \( \alpha \)-tocopherol/kg body weight following dosing was 2·3 (SD 0·1) mg/kg.

Influence of the test meals on plasma and chylomicron lipids

The concentration of plasma cholesterol did not differ significantly during the study period (data not shown). Baseline (pre-meal) plasma TAG concentrations were 0·9 mmol/l. Following the cereal with full-fat milk meal, plasma TAG increased to a maximum of 1·19 mmol/l after 1 h then gradually returned to baseline between 3 and 6 h. Plasma TAG did not increase above baseline following the other meals (data not shown). Chylomicron TAG concentration showed a significant difference over time (\( P = 0·025 \)), and a trend towards a difference between test meals (\( P = 0·051 \)). Increases in chylomicron TAG concentration only occurred following the higher-fat meals. Following the cereal with full-fat milk meal, chylomicron TAG increased from 0·4 mmol/l to a maximum of 0·58 mmol/l following 1 h, then decreased back to baseline by 3 h. Following the toast with butter meal, chylomicron TAG increased from 0·28 mmol/l to a maximum of 0·37 mmol/l after 1 h, then decreased back to baseline also by 3 h.

Influence of the test meals on \( ^2 \)H-labelled \( \alpha \)-tocopherol uptake into plasma and chylomicrons

Fig. 1 shows \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration in chylomicrons and plasma following the ingestion of a capsule containing 150 mg \( ^2 \)H-labelled \( \alpha \)-tocopheryl acetate with the test meals. There was a significant difference in \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration in both chylomicrons and plasma over time (\( P < 0.001 \)), and a significant difference in \( ^2 \)H-labelled \( \alpha \)-tocopherol concentrations between the test meals (\( P < 0.001 \)). The test meal of toast and butter (17·5 g fat) resulted in the earliest response, and the largest \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration, in both plasma and chylomicrons over the study period. There was a significantly greater \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration when the capsule was ingested with the high-fat cereal meal (17·5 g) compared with the low-fat cereal meal (2·7 g fat) (\( P < 0.05 \)). There was a trend towards a greater \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration when the capsule was ingested with the toast and butter meal compared with the cereal with full-fat milk meal, both containing 17·5 g fat (\( P = 0·065 \)). There was no difference in either chylomicron or plasma \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration following either the low-fat cereal meal or water, which remained negligible over the study period.

There was considerable inter-individual variation in labelled \( \alpha \)-tocopherol responses in plasma and chylomicrons (data not shown). Subjects varied not only in the labelled \( \alpha \)-tocopherol concentration (for example, toast meal of toast and butter (17·5 g fat) resulted in the earliest response, and the largest \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration, in both plasma and chylomicrons over the study period. There was a significantly greater \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration when the capsule was ingested with the high-fat cereal meal (17·5 g) compared with the low-fat cereal meal (2·7 g fat) (\( P < 0.05 \)). There was a trend towards a greater \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration when the capsule was ingested with the toast and butter meal compared with the cereal with full-fat milk meal, both containing 17·5 g fat (\( P = 0·065 \)). There was no difference in either chylomicron or plasma \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration following either the low-fat cereal meal or water, which remained negligible over the study period.

There was considerable inter-individual variation in labelled \( \alpha \)-tocopherol responses in plasma and chylomicrons (data not shown). Subjects varied not only in the labelled \( \alpha \)-tocopherol concentration (for example, toast meal of toast and butter (17·5 g fat) resulted in the earliest response, and the largest \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration, in both plasma and chylomicrons over the study period. There was a significantly greater \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration when the capsule was ingested with the high-fat cereal meal (17·5 g) compared with the low-fat cereal meal (2·7 g fat) (\( P < 0.05 \)). There was a trend towards a greater \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration when the capsule was ingested with the toast and butter meal compared with the cereal with full-fat milk meal, both containing 17·5 g fat (\( P = 0·065 \)). There was no difference in either chylomicron or plasma \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration following either the low-fat cereal meal or water, which remained negligible over the study period.

There was considerable inter-individual variation in labelled \( \alpha \)-tocopherol responses in plasma and chylomicrons (data not shown). Subjects varied not only in the labelled \( \alpha \)-tocopherol concentration (for example, toast meal of toast and butter (17·5 g fat) resulted in the earliest response, and the largest \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration, in both plasma and chylomicrons over the study period. There was a significantly greater \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration when the capsule was ingested with the high-fat cereal meal (17·5 g) compared with the low-fat cereal meal (2·7 g fat) (\( P < 0.05 \)). There was a trend towards a greater \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration when the capsule was ingested with the toast and butter meal compared with the cereal with full-fat milk meal, both containing 17·5 g fat (\( P = 0·065 \)). There was no difference in either chylomicron or plasma \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration following either the low-fat cereal meal or water, which remained negligible over the study period.

There was considerable inter-individual variation in labelled \( \alpha \)-tocopherol responses in plasma and chylomicrons (data not shown). Subjects varied not only in the labelled \( \alpha \)-tocopherol concentration (for example, toast meal of toast and butter (17·5 g fat) resulted in the earliest response, and the largest \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration, in both plasma and chylomicrons over the study period. There was a significantly greater \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration when the capsule was ingested with the high-fat cereal meal (17·5 g) compared with the low-fat cereal meal (2·7 g fat) (\( P < 0.05 \)). There was a trend towards a greater \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration when the capsule was ingested with the toast and butter meal compared with the cereal with full-fat milk meal, both containing 17·5 g fat (\( P = 0·065 \)). There was no difference in either chylomicron or plasma \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration following either the low-fat cereal meal or water, which remained negligible over the study period.

There was considerable inter-individual variation in labelled \( \alpha \)-tocopherol responses in plasma and chylomicrons (data not shown). Subjects varied not only in the labelled \( \alpha \)-tocopherol concentration (for example, toast meal of toast and butter (17·5 g fat) resulted in the earliest response, and the largest \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration, in both plasma and chylomicrons over the study period. There was a significantly greater \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration when the capsule was ingested with the high-fat cereal meal (17·5 g) compared with the low-fat cereal meal (2·7 g fat) (\( P < 0.05 \)). There was a trend towards a greater \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration when the capsule was ingested with the toast and butter meal compared with the cereal with full-fat milk meal, both containing 17·5 g fat (\( P = 0·065 \)). There was no difference in either chylomicron or plasma \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration following either the low-fat cereal meal or water, which remained negligible over the study period.

There was considerable inter-individual variation in labelled \( \alpha \)-tocopherol responses in plasma and chylomicrons (data not shown). Subjects varied not only in the labelled \( \alpha \)-tocopherol concentration (for example, toast meal of toast and butter (17·5 g fat) resulted in the earliest response, and the largest \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration, in both plasma and chylomicrons over the study period. There was a significantly greater \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration when the capsule was ingested with the high-fat cereal meal (17·5 g) compared with the low-fat cereal meal (2·7 g fat) (\( P < 0.05 \)). There was a trend towards a greater \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration when the capsule was ingested with the toast and butter meal compared with the cereal with full-fat milk meal, both containing 17·5 g fat (\( P = 0·065 \)). There was no difference in either chylomicron or plasma \( ^2 \)H-labelled \( \alpha \)-tocopherol concentration following either the low-fat cereal meal or water, which remained negligible over the study period.
with butter meal, plasma range 0·7 to 26·1 µmol/l at 9 h)
but also in the time that labelled α-tocopherol began to
increase in concentration (toast with butter meal, plasma
range 2 to 6 h). However, the variation was consistent
intra-individually, subjects showing the same responsive-
ness between meals. For example, the least responsive
subject following the toast and butter meal was also the
least responsive in the other meals. Variation was also
consistent between the chylomicron and plasma data for
each individual subject.

Discussion

One of the major determinants of bioavailability is the
extent of absorption (Jackson, 1997). Thus it is expected
that factors that increase absorption will increase bioavail-
ability. In the present study we have shown that both the
amount of dietary fat in a meal and the food matrix of
the meal influence the absorption, and hence bioavailabil-
ity, of vitamin E. There was little or no increase in
plasma and chylomicron labelled α-tocopherol when a cap-
sule containing labelled vitamin E was consumed with a
low-fat cereal meal (2·5 g fat) or with water (0 g fat).
Indeed the presence of 2·5 g fat did not appear to influence
vitamin E absorption over the study period (9 h). However,
the meals comprising 17·5 g fat resulted in significantly
higher 3H-labelled α-tocopherol concentrations in plasma
and chylomicrons. The plasma and chylomicron concentra-
tion of 3H-labelled α-tocopherol was also greater when
the vitamin E capsule was consumed with a toast and
butter meal compared with a cereal with full-fat milk
meal, even though both meals contained 17·5 g fat. Thus,
both the amount of fat in a meal and also the physical prop-
erties of a meal influence vitamin E absorption and
bioavailability.

These data increase the current understanding of the role
of fat in vitamin E absorption. Although a few studies have
looked at vitamin E levels following diets of differing fat
content, this is the first controlled study directly comparing
the influence of varying dietary fat amounts on vitamin E
absorption and bioavailability. Previously, a 3-week diet
rich in unsaturated fat was found to increase serum concen-
trations of α-tocopherol by 7 %, whereas a diet rich in satu-
rated fat decreased α-tocopherol concentration by a similar
amount (Ohrvall et al. 2001). Plasma α-tocopherol levels
were found to be similar following 7 d of supplementation
with 50 mg vitamin E consumed with either a low-fat
(<6·5 g fat/d) or a high-fat (about 45 g fat/d) meal (Rooden-
burg et al. 2000). However, significantly greater plasma
uptake of α-tocopherol was found in human subjects fed
a high-fat diet (about 115 g fat/d) compared with a low-
fat diet (about 51 g fat/d) over 5 d of supplementation
with 800 mg synthetic vitamin E (Dimitrov et al. 1991).
These studies have attempted to assess relative bioavailabil-
ity by measuring steady-state plasma levels; however, this
is impractical due to the regulation of plasma concentra-
tions and the unknown relationship between intake and
plasma concentrations (Cohn, 1997). We have used stable
isotopes so that the ingested and newly absorbed vitamin
E can be directly monitored, which eliminates compli-
cations due to endogenous vitamin E.

We have also shown in the present study that the matrix
of the meal is important for vitamin E absorption, as differ-
ences were observed between test meals of different com-
position but the same fat content. A few studies have
investigated the influence of the physical properties of the
meal on vitamin E bioavailability. Hayes et al. (2001) reported that milk enhanced vitamin E uptake, irre-
spective of fat content. Their conclusions were based on a
similar percentage increase in plasma α-tocopherol after a
4-week supplementation with a fat-soluble version of vita-
min E dispersed in 1 % fat milk, and a water-soluble vita-
min E in skimmed milk (0·1 % fat). Greater vitamin E
bioavailability was found when a capsule was consumed
with cereal and fat-free milk, rather than with fat-free
milk alone (Leonard et al. 2004). Even though the micro-
dispersion of vitamin E in milk appears to increase vitamin
E bioavailability in previous studies (Hayes et al. 2001),
in the present study the high-fat meal containing milk pro-
duced a lesser response to that of the isoenergetic toast
with butter meal. Thus the physical properties of toast
and butter appear to provide a better medium for vitamin
E absorption. The physical properties of food are known
to affect gastric emptying; foods that are high in fibre,
viscosity and protein slow gastric emptying (Low, 1990),
thus providing a potential explanation for the differences
between meals.

The present study was aimed at vitamin E uptake during
the absorptive period, measurements were taken up to 9 h,
which approximates to the peak in chylomicron vitamin E
transport (Traber et al. 1998). In the circulation, chylomi-
crons undergo extensive hydrolysis by endothelial bound
lipoprotein lipase, during which time vitamin E can be
transferred to peripheral tissues and circulating lipoproteins
(Traber et al. 1985). Excess chylomicron surface area is
produced and along with vitamin E is transferred to
HDL. HDL can donate its vitamin E, therefore there is a
constant flux of vitamin E among circulating lipoproteins
(Traber et al. 1992). Also, we have previously shown
that vitamin E metabolism is rapid, as the specific vitamin
E metabolites, the carboxyethyl-hydroxychromans, are
found in the urine 6 h following vitamin E ingestion and
peak at 9 h (Lodge et al. 2001). Therefore in the present
study we can assume that in this 9 h study period there is
multi-compartmentalisation of labelled α-tocopherol with
α-tocopherol pools in lipoproteins (plasma), the liver and
peripheral tissues.

The large inter-individual variation in response to
labelled vitamin E observed in the present study is consist-
ent with previous observations (Roxborough et al. 2000).
The fact that this intra-individual variation was consistent
between meals does suggest that individuals do differ in
their response to vitamin E supplementation. As the vari-
ation was large within the chylomicrons, it is probable
that the mucosal handling of vitamin E is an important
source of variability. This could reflect either the transport
of α-tocopherol into the enterocyte, or in the packaging
of chylomicrons themselves. Further work is required in
this area.

In summary, the present study demonstrates that both the
amount of fat and the physical properties of a meal influ-
ence the absorption of supplemental vitamin E. As vitamin
E supplements are frequently used by consumers and in clinical studies, these findings are of relevance and need to be considered.

Acknowledgements

We are grateful to the British Heart Foundation and The Royal Society for funding, and to the Medical Research Council for supporting Y. M. J. We are also grateful to Dr Christine Gärtner and Dr James Clark of Cognis Nutrition and Health (Düsseldorf, Germany and LaGrange, IL, USA respectively) for the gift of the 2H-labelled tocopherols. We thank our subjects who participated in the study.

References


