Zinc absorption in healthy elderly humans and the effect of diet \(^1\(^2\)

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**ABSTRACT** Absorption of a zinc stable isotope was measured on two consecutive occasions in nine young and eight elderly healthy men aged 24–40 and 70–83 y, respectively. A zinc stable-isotope label (0.8 mg \(^{70}\)Zn) was added to a test meal of either high or low zinc bioavailability, depending mainly on phytic acid content. Zinc absorption from the high-bioavailability test meal was not significantly different (\(P > 0.05\)) in the young (38.9 \(\pm\) 9.8%, \(\bar{x} \pm SD\)) and elderly (35.0 \(\pm\) 10.9%) subjects. Zinc absorption from the low-bioavailability test meal was 40% and 43% lower, at 23.4 \(\pm\) 10.2% and 19.8 \(\pm\) 6.1% in these young and elderly men, respectively. Again, no significant effect of age was found. These results show that aging does not lead to nutritionally relevant changes in zinc absorption and in the effect of dietary inhibitors on zinc absorption. Thus, zinc absorption ability seems to be preserved in healthy elderly people, at least until the age of 80 y. *Am J Clin Nutr* 1993;58:690–4.

**KEY WORDS** Zinc, aging, phytic acid, absorption, man, stable isotopes

**Introduction**

Aging results in structural and functional changes of the digestive system \(^1\). As a consequence, the ability of the digestive system to absorb micronutrients may be reduced. For example, absorption of carbohydrates, calcium, and of some vitamins may be impaired in elderly humans \(^2\–5\), particularly if aged \(> 70\) y. These changes may also be associated with an underlying pathology \(\text{eg, gastric atrophy may lead to a decrease in vitamin B}\text{-12 absorption}\). The effect of aging on zinc absorption remains unclear. Absorption of a single dose of a zinc radioisotope has been shown to decrease steadily with age \(^6\). Several studies have also confirmed that the absorption of zinc is lower in elderly subjects when either a zinc-tolerance test \(^7\) or a diet labeled with a stable isotope \(^8\–10\) is used. However, in all these studies zinc was administered either alone, as a salt, or with a diet nearly devoid of inhibitors of zinc absorption.

The potential impact of these findings for the requirements of the healthy elderly population is not known. Therefore, a study was undertaken using stable isotopes. Zinc absorption was measured in young and elderly healthy humans whose nutritional and health status were controlled. The effect of diet was also assessed by comparing the absorption of zinc from two test meals that differed in zinc bioavailability. These test meals were prepared with foods commonly consumed and differed mainly in the phytic acid content. Phytic acid is a major inhibitor of zinc absorption under normal dietary conditions, because it is present in a wide variety of foods of vegetal origin, eg, legumes, nuts, and cereal grains \(^1\). Phytic acid binds cations, notably zinc, making them less available for absorption. Our postulate is that any decrease in the global ability of the digestive system to absorb zinc will modify the effect of the composition of the diet.

**Subjects and methods**

**Subjects**

Eight elderly men aged 70–83 y were recruited from a senior citizens' association. All were Caucasian and physically fit. None had a disease or was taking medication that could knowingly interfere with zinc absorption or metabolism \(\text{eg, nephrotic, wasting, digestive, or liver disease, or a treatment with diuretics}\). Nine young healthy men aged 24–40 y served as control subjects. They were recruited among the staff of the Nestlé Research Centre. All subjects completed a medical questionnaire and underwent a medical examination by a physician. They were fully informed of the aims and purposes of the study, and signed an informed consent. The protocol was approved by the ethical committee of the Research Centre.

**Protocol**

A \(^{70}\)Zn stable-isotope label was prepared by dissolving zinc oxide \((88.61\% \(^{70}\)Zn, Oak Ridge National Laboratory, Oak Ridge, TN) in 0.01 mol HCl/L. Zinc concentration was measured by flame atomic absorption spectrometry. A precisely measured amount of label \((0.794 \text{ mg} \(^{70}\)Zn) was administered orally twice in each fasting subject, at 0800 3 wk apart, with a test meal of either high or low zinc bioavailability. These two test meals contained foods commonly consumed, but that differed widely in their phytic acid content, with as little difference as possible in other nutrients. The high-bioavailability test meal comprised two bread rolls made of white flour \((40 \text{ g each})\), 200 g cow milk (full

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fat), 10 g butter, and 20 g jam; the low-bioavailability test meal comprised two whole-wheat bread rolls (45 g each), 200 g unsweetened soya milk, 10 g butter, and 20 g jam. The energy and nutrient composition of both meals is shown in Table 1. The $^{65}$Zn label was added to the soya or cow milk just before administration. The glass was then rinsed with 50 mL distilled water, and this water was also drunk.

Special care was taken to normalize the subjects’ dietary regimens before and after each test meal containing the $^{65}$Zn. A standard evening meal was eaten ≥ 12 h before each test meal and another standardized meal was consumed ≥ 4 h after. Between times, subjects had access only to water with low mineral content. The standard evening meal was administered to prevent subjects from eating foods that might interfere with the test. The meal consisted of weighed portions of common foods (chicken, noodles, apple stew, bread). The second standard meal had a high fiber content (mixed salad), and was administered together with a fecal marker (100 mg Brilliant Blue, in two gelatin capsules; Morton Thiokol Ltd. Hounslow, UK). The high fiber content probably allowed a shorter transit time. Feces were collected in acid-washed polypropylene containers (Semadeni, Ostermundigen, Switzerland) until all of the fecal marker had been excreted. No equilibration period was included in the protocol because this would have changed the dietary intakes of the subjects.

Assessment of nutritional status

Height and weight (in light clothes, shoes off) were measured after fasting and immediately before the first test meal was administered. A 10-mL venous blood sample was drawn from fasted subjects before the first test meal. Serum zinc, total protein, albumin, and transthyretin were measured to assess zinc and global nutritional status. C-reactive protein (CRP) and α-1-acid glycoprotein (AAG) were also measured to detect possible infectious or inflammatory conditions. All material had been previously tested for contamination with trace metals.

Food analysis

Protein, fat, and fiber contents were measured by standard procedures. Total carbohydrate content was calculated by subtraction. Phytic acid was measured according to Makower (12), Fe (III) being replaced by Ce (IV) in the precipitation step. The detection limit for this method is 0.01 mg/g.

Sample preparation and analysis

Fecal samples were sterilized, frozen, and pooled to include all feces passed until no further fecal marker was detected. Feces were then freeze-dried and ground with a standard grinder (Compact Robot; Tefal, Selongey, France). Correction for sample loss (always < 5%) was applied. Total zinc and isotopic ratio were determined in duplicates on 0.5-g subsamples. Total zinc was measured by flame atomic absorption spectrophotometry (model AA 20; Varian, Mulgrave, Australia) after wet digestion with 14.4 mol nitric acid/L (Suprapur; Merck, Darmstadt, Germany) in a low-pressure digestion system (Seif, Unterschleissheim, Germany). A bovine liver standard reference material (National Institute of Standards and Technology, Washington, DC) was used as a control. A zinc concentration of 1.87 ± 0.03 nmol Zn/g (X ± SD, n = 6) was found, as compared with a certified value of 1.88 ± 0.12 nmol Zn/g.

The $^{65}$Zn-$^{65}$Zn isotopic ratio was measured on the same mineralized samples. Zinc was converted to the chloride form by repeated evaporation to dryness and subsequent redissolution in 10.1 mol hydrochloric acid/L, except that the last dissolution was in 2 mol HCl/L. Zinc was then purified by anion-exchange chromatography on AG1-X8 resin (Biorad, Fullerton, CA), according to the procedure described by Götz and Heumann (13), except that zinc was eluted with 1 mol HNO3/L. The $^{65}$Zn-$^{65}$Zn ratio was measured by thermal ionization mass spectrometry (THQ; Finnigan MAT, Bremen, Germany) using a silica gel ionization enhancement technique. All acids used were purified by subboiling in a quartz still (Kürner Analysetechnik, Rosenheim, Germany). Blood was allowed to clot for 60 min at room temperature and was centrifuged for 10 min at 1800 × g. Serum was transferred into acid-washed tubes and stored at −70 °C until analysis. Serum zinc was measured after protein precipitation by 0.4 mol trichloroacetic acid/L (14). Total serum protein content was measured with a COBAS analyzer (Hoffmann-La Roche, Basel, Switzerland) and serum-specific proteins (albumin, transthyretin, AAG, and CRP) with a nephelometer (Behring, Marburg, Germany) by using the reagents supplied by the respective manufacturers.

Zinc absorption calculation

Absorption was calculated from the dose of $^{65}$Zn administered, the total fecal zinc, and the $^{65}$Zn-$^{65}$Zn ratio in the fecal pool, as previously described (8). The fractional absorption calculated here represents the percentage of the stable isotope administered with the test meal that was not recovered in the fecal pool. Because fecal collection lasted 2–6 d, the calculated value slightly underestimates true absorption because ≈ 1% of the absorbed zinc is reexcreted each day (15).

Statistical analysis

Anthropometric and biochemical values as well as mean zinc absorption values were compared by Student’s t test. The effect

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**TABLE 1**

Composition of the test meals of high and low zinc bioavailability

<table>
<thead>
<tr>
<th>Energy (kJ)</th>
<th>Protein (g)</th>
<th>Zinc (mg)</th>
<th>Phytic acid (mg)</th>
<th>Calcium (mg)</th>
<th>Phytate/zinc (mol/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>zinc</td>
<td>1210</td>
<td>12.5</td>
<td>1.87†</td>
<td>0‡</td>
<td>238</td>
</tr>
<tr>
<td>Low</td>
<td>953</td>
<td>11.4</td>
<td>2.74†</td>
<td>538</td>
<td>87</td>
</tr>
</tbody>
</table>

* mol/mol.
† Stable-isotope label included.
‡ Below the limit of detection.
FIG 1. Relationship between the serum zinc-albumin ratio, taken as an indicator of zinc status, and $^{65}$Zn absorption from the high-bioavailability (low phytic acid) test meal. The broken line represents the best-fit curve describing that relationship (circled points were not used for the calculation).

of age and diet on zinc absorption was evaluated by analysis of variance (ANOVA) with repeated measurements (BMDF, University of California, Berkeley). Significance level was set at 0.05. The mathematical function described in Figure 1 was calculated with NCSS software (NCSS, East Kaysville, UT).

Results

Anthropometric measurements are reported in Table 2. Mean weights, heights, and body mass index values did not differ significantly. Zinc status, as assessed with serum zinc and the zinc-albumin ratio, did not differ between the young and elderly subjects (Table 2). Nutritional status, as assessed by serum transthyretin, was adequate and not significantly different in both groups. The low CRP (no value > 12 mg/L) and normal AAG values indicate that there was no infection or inflammation.

Zinc absorption from either the high-bioavailability or the low-bioavailability test meal tended to be lower in the elderly subjects (Table 3), but this was not statistically significant. The absorption of zinc from the low-bioavailability test meal was on average 40% and 43% lower than that from the high-bioavailability test meal in the young and elderly subjects, respectively. The mean difference between zinc absorption from the two test meals was 15% in both groups (Table 3). Statistical analysis by ANOVA with repeated measurements showed that the effect of diet composition was independent of age and that the effect of age was not significant. A relationship between the serum zinc-albumin ratio and the absorption of zinc from the high-bioavailability test meal may exist. This can be best fitted by an inverse exponential function, as shown on Figure 1. A similar but weaker relationship was also found between serum zinc and zinc absorption from the high-bioavailability test meal (not shown). In contrast, no relationship was found between either serum zinc or the zinc-albumin ratio, and zinc absorption from the low-bioavailability test meal (not shown).

Discussion

The present study shows that zinc absorption from a test meal of either high or low bioavailability is not significantly different in young and elderly healthy volunteers, although the biologically small differences observed here might have been statistically significant with a larger number of subjects. This finding is in contrast with previous studies (6–10), which found zinc absorption to be significantly lower in elderly subjects. Because nutritional status was carefully assessed here, some interpretation can be proposed.

On a group basis, global nutritional status does not differ between the young and elderly subjects. Serum transthyretin is a reliable indicator of protein status (16), and all subjects were in the normal range (200–360 mg/L). Serum zinc is not a reliable indicator of zinc status, particularly in elderly people, because albumin, which carries about two-thirds of serum zinc (17), decreases with age (18), as observed here. Thus, the lower serum zinc values generally observed in elderly people may be attributed to this decrease. Therefore, the serum zinc-albumin ratio was used as an indicator of zinc status because of its lower sensitivity to changes of serum protein concentrations. This ratio (or a similar one) has been previously used to assess zinc status in conditions in which serum proteins may vary (19, 20). When this ratio is used, the zinc status does not differ between the two groups in this study.

The elderly subjects absorbed slightly less $^{65}$Zn from both test meals than their younger counterparts. However, the difference ($\approx 10\%$) was not statistically significant and cannot be expected to lead to nutritionally relevant changes in the metabolism of zinc. These findings contrast with those of several other similar

<table>
<thead>
<tr>
<th>TABLE 2</th>
<th>Anthropometric measures and serum indexes relevant to zinc and global nutritional status*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Age</td>
</tr>
<tr>
<td>Young subjects</td>
<td>$y$</td>
</tr>
<tr>
<td>$n = 9$</td>
<td>32.5 ± 5.3</td>
</tr>
<tr>
<td>Elderly subjects</td>
<td>$n = 8$</td>
</tr>
</tbody>
</table>

* SD.
† In kg/m². Values are overevaluated by ≈ 3%.
‡ Alpha-1-acid glycoprotein.
§ Significantly different from group subjects, $P < 0.05$ (t test).
TABLE 3
Absorption of a $^{65}$Zn stable-isotope label added to a test meal of either low or high zinc bioavailability, in young and elderly healthy humans

<table>
<thead>
<tr>
<th></th>
<th>High bioavailability</th>
<th>Low bioavailability</th>
<th>Difference</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td><strong>Young subjects</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>36.0</td>
<td>20.3</td>
<td>15.7</td>
</tr>
<tr>
<td>2</td>
<td>49.3</td>
<td>44.1</td>
<td>5.2</td>
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<tr>
<td>3</td>
<td>39.7</td>
<td>35.1</td>
<td>4.6</td>
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</tr>
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<td>6</td>
<td>40.9</td>
<td>19.6</td>
<td>21.3</td>
</tr>
<tr>
<td>7</td>
<td>37.8</td>
<td>17.5</td>
<td>20.3</td>
</tr>
<tr>
<td>8</td>
<td>54.2</td>
<td>22.3</td>
<td>31.9</td>
</tr>
<tr>
<td>9</td>
<td>27.5</td>
<td>9.7</td>
<td>17.8</td>
</tr>
<tr>
<td>$\bar{x} \pm SD$</td>
<td>38.9 ± 9.8</td>
<td>23.4 ± 10.2</td>
<td>15.6 ± 9.8</td>
</tr>
<tr>
<td><strong>Elderly subjects</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>23.5</td>
<td>18.0</td>
<td>5.5</td>
</tr>
<tr>
<td>2</td>
<td>30.4</td>
<td>30.5</td>
<td>-0.1</td>
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<td>3</td>
<td>26.3</td>
<td>17.2</td>
<td>9.1</td>
</tr>
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<td>58.6</td>
<td>25.4</td>
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<tr>
<td>5</td>
<td>31.9</td>
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<tr>
<td>7</td>
<td>31.7</td>
<td>20.8</td>
<td>10.9</td>
</tr>
<tr>
<td>8</td>
<td>39.1</td>
<td>11.5</td>
<td>27.6</td>
</tr>
<tr>
<td>$\bar{x} \pm SD$</td>
<td>35.0 ± 10.9</td>
<td>19.8 ± 6.1</td>
<td>15.2 ± 11.2</td>
</tr>
</tbody>
</table>

* There were no significant differences between the young and elderly subjects; however, the effect of diet was significant ($P < 0.00001$).

Furthermore, the different amounts of zinc in the two test meals (2.74 vs 1.84 mg Zn) should not have had a significant influence on the results, because saturation of zinc absorption from a single test meal only occurs if the zinc content exceeds 4.5 mg (22). Therefore, the change in relative zinc absorption from the two test meals is largely attributed to the inhibitory effect of phytic acid. The results clearly show that this change in absorption is not modified by aging.

The decreased zinc absorption observed in other studies may be due to physiological changes. These changes may occur because of a slower whole-body turnover and/or because of a reduced excretion of endogenous zinc, and/or because of a better zinc status in elderly people. Whole-body protein breakdown, as measured with $[^{15}N]glycine$, is reduced in elderly people (23), largely because of the gradual decrease in muscle mass that occurs during aging. This could result in a lowered zinc turnover because zinc is bound to proteins in tissues and may explain the reduced excretion of endogenous zinc in elderly people (9). Thus, it is conceivable that the zinc requirement is also reduced.

It is well-known that zinc absorption is regulated by zinc status (24). Indeed, the results depicted in Figure 1 confirm this trend in nearly all subjects. These results also show that the elderly volunteers generally had better zinc status than the younger control subjects (their points are most often located on the right side of the plot). This may explain the slightly decreased absorption rate of these elderly subjects. Although no reliable index of zinc status is currently available, several studies seem to confirm that zinc status does not systematically decline with age, e.g., zinc concentrations of various human autopsy tissues from industrialized countries do not decrease with age (25–27). Erythrocyte zinc concentrations were also found to rise slightly during aging (28). One study only mentioned that zinc content of human cancellous bone decreases after the age of 50 y (29). Several other studies showed that serum and/or leukocyte zinc is generally adequate in healthy elderly people (30–32). Suboptimal zinc status in elderly humans has only been demonstrated in healthy elderly people of low socioeconomic status (33, 34), and in some institutionalized (35–37) or hospitalized individuals (36).

In conclusion, we found that the ability to absorb zinc shows little or no change in healthy elderly people, as compared with young adults of very similar zinc and global nutritional status. A slight decrease cannot be excluded however, but, in contrast with results of previous studies, it is too small to be of physiological significance. Whether zinc absorption can be modified by the combined effects of old age and disease remains largely unknown, and future research is needed in that direction also.

We are grateful to all subjects who whole-heartedly participated, and to the nurse at the metabolic unit, Isabelle Bartholdi.

References