MNA and Odor Perception

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Part 1

Malnutrition, General Health, Body Composition, Dental State, and Odor Perception

Many studies show that odor perception declines with age, while diminished odor perception is associated with poor general health and various diseases [1–3]. Though it has been suggested that many nutrients play a role in odor perception, and elderly people are prone to develop undetected malnutrition [4–8], results from previous published studies on the relation between odor perception and nutrition are conflicting [9–12]. It has been suggested that in elderly people living independently at home without obvious nutritional deficiencies, health problems are more important in explaining diminished odor perception than nutritional state, as measured by anthropometry. Muscle tissue diminishes with age owing to reduced mobility and a sedentary lifestyle; in combination with poor general health, this might cause diminished odor perception. Early detection of diminished odor perception might therefore be an indication of physical deterioration [13]. On the other hand, it has been suggested that declining odor perception can cause changes in food consumption and diminished food appreciation [14], as illustrated in Figure 1. The sensory properties of food (for example, flavor, texture) are important determinants of food consumption [15]. Ninety percent of food flavors consist of volatile odors [16], and changes in palatability or sensory quality of food can mainly be ascribed to a declining perception of odors [15].

Poor oral health is widespread among the elderly. Caries, periodontal disease, defective or ill-fitting dentures, and poor oral or denture hygiene are common [17, 18]. In addition, missing teeth can have detrimental effects on mastication, oral
health, and nutrition [19]. It has been suggested that the proportion of persons with an insufficient intake of nutrients is higher among edentulous individuals than in dentate persons [20]. Moreover, the oral cavity is an area where microorganisms may metabolize a variety of substances to produce malodors. Such malodors may cause a masking or adaptation of the olfactory receptors, hence leading to diminished food odor perception [21].

With increasing age, the combined influence of odor perception and oral health on nutritional state is to be expected, since both odor perception and dental health may affect food consumption [22].

It has been well established that nutritional and oral problems are widespread among elderly people living in retirement homes, where from a functional point of view both the degree of dependency and general health are expected to influence nutritional status. We therefore explored which age-associated factors – such as poor oral health, degree of dependency, body composition, diminished odor perception, and diminished functionality – are accompanied by an increased risk of malnutrition. In Figure 1, the different age-related phenomena under investigation are shown.

In the first experiment, using a validated screening tool for the detection of malnutrition – the Mini Nutritional Assessment (MNA) – elderly people living independently at home in the community were studied. In the second experiment, elderly people living in retirement homes with varying degrees of dependency were included.

**Subjects and Methods**

**Odor Perception**

To determine odor perception, the detection threshold for isoamylacetate (fruity banana/pear odor) was determined as the lowest detectable odor concentration. The described method has been widely used with many substances and
has been calibrated in previous studies [23–25]. The isoamylacetate solutions were prepared according to the procedure and substances described by Laska & Hudson [26]. Odors were presented in 250 ml polyethylene squeeze bottles containing 40 ml of solution and equipped with a flip-up spout with an interchangeable nose piece made of Teflon. Each person received a series of paired bottles (one blank containing the solvent only and one containing the odor). According to the so-called “forced choice” paradigm, the participants were asked to sniff and to indicate which one smelled stronger. An inter-trial interval of 30 s was chosen to allow recovery from adaptation. Detection thresholds were determined by using an ascending method of limits, starting at the lowest of the 14 prepared concentrations. Threshold was reached when five subsequent pairs were correctly indicated. All measurements were carried out in a well-ventilated and quiet room. Gas chromatography verification showed that headspace concentrations of freshly prepared solutions in the bottles remained constant over the whole testing period. During preliminary testing with this procedure, in which odor thresholds were obtained from 25 healthy young persons (aged 19–25 years, mean 22.3), it was shown that the mean threshold fell within the range found by others [27].

**Dental State**

Concomitant with the sensory tests, oral examinations were carried out in a standardized way by a dentist (K.C.). The number of natural teeth and dentures was counted and type of dentures was identified.

**Mini Nutritional Assessment**

The MNA is a rapid assessment tool and was used to evaluate the risk of malnutrition [28]. The protocol comprises 18 items involving anthropometry, general assessments, dietary assessments, and subjective assessment. MNA has recently been validated and can accurately assess nutritional status of elderly people as normal or well-nourished, borderline or at risk of malnutrition, and frankly malnourished. The scoring categorizes each person as well-nourished ($\geq 24$ points), at risk of malnutrition ($17–24$ points), and malnourished ($<17$ points).

**General Health and Body Composition**

The general health status was determined by the Medical Outcome Study (MOS) scores. The scale has been validated by Stewart et al. [29]. The MOS scale allows a quantitative measure of functional health of elderly people, based on the following concepts:

- **Physical functioning** – the extent to which health interferes with a number of daily activities such as sporting, walking, shopping.
- **Role functioning** – the extent to which health interferes with working or household activities.
- **Social functioning** – the extent to which health interferes with social activities such as visiting friends and family.
Mental functioning – general mood, well-being, depression, and fear.

Perceived health – general judgement concerning current state of health.

Perceived pain – amount of pain experienced.

The items were chosen to represent six health concepts, using the WHO definition of health [29].

Anthropometric measures were obtained to assess physical deterioration and the distribution of fat and muscle. The variables chosen were those used in similar studies of nutritional status [30] and odor perception [31]: mid-arm circumference (MAC), triceps skinfold thickness (TSF), mid-calf circumference (MCC), abdominal circumference (measured at the level of the umbilicus), and hip circumference (at the maximum protuberance of the buttocks). All persons were weighed in kilograms, and height was measured in meters. Circumferences were measured in millimeters using a flexible tape measure, and skinfold thicknesses in millimeters by a calibrated caliper. Muscle circumferences and areas were calculated as general indicators of protein status, muscle atrophy or protein-energy malnutrition. Arm muscle circumference (AMC) was derived as:

\[ AMC = MAC - (\pi \cdot TSF). \]

Arm muscle area (AMA), corrected for bone (AMAB), was derived as:

\[ AMAB = \left( \frac{(MAC - \pi \cdot TSF)^2}{4 \cdot \pi} \right) - (\text{men}), \]

or

\[ \left( \frac{(MAC - \pi \cdot TSF)^2}{4 \cdot \pi} \right) - 6.5 \quad (\text{women}). \]

For measuring the amount of body fat, different measures of subcutaneous fat were calculated. Body mass index (BMI) was derived from weight and height as a global measure of body fatness. As measures of subcutaneous fat, upper arm subcutaneous fat area was calculated as:

\[ \frac{MAC \cdot TSF}{2} - \frac{\pi \cdot (TSF)^2}{4}. \]

Drugs

Since odor perception was expected to be associated with both nutritional state and use of drugs, the following procedure was used to partition the persons into three groups: those taking no drugs; those taking drugs expected to influence odor perception; and those taking other types of drugs. Based on published studies by others, we identified active compounds in drugs which would be expected to have effects on odor perception [2, 32, 33]. By using the local database containing all drugs on the Belgian market with corresponding active substances, and a pharmacopoeia [34], a complete list of drugs known to influence odor perception was obtained. Where drugs interfering with odor perception did not occur on the list, the person taking them was classified as using “other drugs.” Where the person was taking one or more of the drug types on the list, they were classified as using “drugs expected to influence odor perception.”
**Study Population**

**Experiment 1**

In the first experiment, 67 elderly persons living at home (mean age 66.7 years, SD 6.8, range 55–82) took part. These people all participated in health and fitness programs. All were apparently healthy, without any nasal obstruction and without evidence of acute infection. Participants with alcohol abuse, mental deterioration, and dementia were excluded. Twenty-two used no drugs, 13 used drugs expecting to influence odor perception, and 32 used other drugs, mainly for prophylactic purposes. All participants were independent in the basic activities of daily living.

**Experiment 2**

Eighty-one persons in retirement homes took part in the second experiment (mean age 82.7 years, SD 7.2, range 61–98). The degree of dependency for basic activities of daily living (ADL) was evaluated with the Katz score [35]. Eleven used no drugs, nine took drugs for prophylactic purposes only, and 61 took drugs expected to influence odor perception. Thirty-five participants were independent, 22 had a minor degree of dependency (score B, C), and 24 participants were highly dependent (score D–G, O).

**Statistical Analysis**

The equation for the calculation of the sensory detection threshold used for statistical analysis is described by Stevens & Cain [36]. Normal distribution was tested with Kolmogorov-Smirnov test. To test the hypothesis as to whether two group means were equal or not, a Student’s t test was applied when data were normally distributed. When more than two groups were compared, one-way analysis of variance was used. When two categorical variables were compared, cross-tabulations were used and tested with the χ² test. When two continuous variables were compared, Pearson correlation coefficients (r) were calculated and tested for significance. To test the combined contribution of different independent variables on the dependent variable of interest, multiple regression was used. All statistical analysis were conducted using the SPSS package [37].

**Results**

**Experiment 1**

Table 1 shows the number of participants living in the community, including their mean age and MNA scores. As illustrated in Figure 2, the correlation between age and MNA score was not significant (r = 0.03, p = 0.39) and no significant difference was observed in MNA score between men and women (t test, p = 0.12). A significant correlation was found between age and odor perception (r = −0.21, p < 0.016), indicating that the proportion of elderly people with a poor
MNA and Odor Perception

Fig. 2. Age, gender and MNA score of elderly living independently at home (≥24 points = well-nourished, 17–24 points = at risk of malnutrition, <17 points = malnourished).

Table 1. Age and gender distribution of the population living independently at home, with mean Mini Nutritional Assessment (MNA), body mass index (BMI), and Medical Outcome Study (MOS) scores

<table>
<thead>
<tr>
<th></th>
<th>Number of persons</th>
<th>Mean BMI kg/m² (SD)</th>
<th>Mean age years (SD)</th>
<th>Mean MOS score, % (SD)</th>
<th>Mean MNA score (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>67</td>
<td>26.7 (3.9)</td>
<td>66.7 (6.8)</td>
<td>84.1 (12.2)</td>
<td>27.6 (1.7)</td>
</tr>
<tr>
<td>Men</td>
<td>15</td>
<td>27.5 (3.9)</td>
<td>66.0 (7.4)</td>
<td>83.9 (12.4)</td>
<td>27.4 (2.1)</td>
</tr>
<tr>
<td>Women</td>
<td>52</td>
<td>26.4 (3.9)</td>
<td>66.9 (6.7)</td>
<td>84.2 (12.2)</td>
<td>27.7 (1.6)</td>
</tr>
</tbody>
</table>

sense of smell increases with age. The correlations between age and MOS score \( r = 0.04, p = 0.36 \), odor perception and MNA score \( r = -0.02, p = 0.44 \), or odor perception and MOS score \( r = 0.00, p = 0.49 \) were not significant. However, the MOS score was significantly correlated with the MNA score, showing that a poor state of health status was associated with a high risk of malnutrition \( r = 0.31, p = 0.005 \) for social functioning; \( r = 0.33, p = 0.003 \) for perceived health). None of the other dimensions showed a significant correlation \( p > 0.05 \).

Neither MNA score nor odor perception differed significantly between persons taking drugs affecting odor perception and those taking other types of drugs.
Table 2. Age and sex distribution of the population living in retirement homes with mean Mini Nutritional Assessment (MNA), body mass index (BMI), and Medical Outcome Study (MOS) scores

<table>
<thead>
<tr>
<th>Number of persons</th>
<th>Mean BMI kg/m² (SD)</th>
<th>Mean age years (SD)</th>
<th>Mean MOS score, % (SD)</th>
<th>Mean MNA score (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>81</td>
<td>26.4 (4.3)</td>
<td>82.7 (7.2)</td>
<td>62.9 (17.5)</td>
</tr>
<tr>
<td>Men</td>
<td>16</td>
<td>26.8 (3.3)</td>
<td>82.8 (10.4)</td>
<td>71.3 (13.9)</td>
</tr>
<tr>
<td>Women</td>
<td>65</td>
<td>26.3 (4.5)</td>
<td>82.6 (6.3)</td>
<td>60.9 (17.7)</td>
</tr>
</tbody>
</table>

(t test, $p = 0.19$ and $p = 0.96$, respectively). Significant correlations were found between age ($r = -0.28, p = 0.001$), MOS score ($r = 0.18, p = 0.039$), and number of natural teeth. No significant correlation was observed between number of natural teeth and MNA score ($r = 0.01, p = 0.48$). None of the anthropometric variables except BMI ($r = 0.20, p = 0.05$) showed a significant correlation with MNA score ($p > 0.05$).

Among elderly people living independently at home, the effects of age, health status, use of drugs, dental state, body composition, and odor perception can be expected to increase the variability of the MNA score. To test the separate effects of these different independent variables on the risk of malnutrition and to determine their relative importance, multiple regression analysis was used.

The most important variable was AMC, for which there was a significant positive regression coefficient ($b = 3.28, p = 0.02$), indicating that persons who were not at risk of malnutrition had a higher muscle mass than those with malnutrition (total $R^2 = 0.53$).

Experiment 2

Table 2 shows the numbers of participants living in retirement homes, with their mean age and MNA scores. As shown in Figure 3, the correlation between age and MNA score was not significant ($r = 0.06, p = 0.25$). MNA scores for women were significantly lower than for men ($p = 0.048$). No significant correlation was found between age and odor perception ($r = -0.09, p = 0.19$). The correlations between age and MOS score ($r = -0.14, p = 0.11$), and odor perception and MNA score ($r = -0.02, p = 0.40$) were not significant. However, a high MOS score was associated with good odor perception ($r = 0.21, p = 0.03$); MOS subscales were also significant: social functioning ($r = 0.18, p = 0.04$), and mental functioning ($r = 0.29, p = 0.003$). Significant correlations were found between age and number of natural teeth ($r = -0.26, p = 0.001$) as well as MNA score and number of natural teeth ($r = 0.27, p = 0.001$).

MNA scores of people taking drugs affecting odor perception were significantly lower than in those taking other drugs ($t$ test, $p = 0.001$). Neither age nor odor
perception differed significantly between persons taking drugs affecting odor perception and those taking other drugs ($t$ test, $p = 0.99$ and $p = 0.42$, respectively).

As can be seen in Table 3, highly significant correlations were found between MNA score and BMI, AMC, AMA ($p < 0.0005$), as well as between MNA score and TST and AFA ($p < 0.05$), indicating that elderly people living in retirement homes who are at risk for malnutrition have lower muscle and fat mass than those not at risk.

To test the separate effects of the different independent variables on the risk of malnutrition and to determine their relative importance, multiple regression analysis was used. The most important variable was health status, showing a significant positive regression coefficient ($b = 0.045$, $p = 0.05$), implying that persons in a poor state of health are more often at risk of malnutrition than persons in a good health state (total $R^2 = 0.66$).
Table 3. Correlations (p value) between Mini Nutritional Assessment (MNA) and anthropometric measures

<table>
<thead>
<tr>
<th></th>
<th>Whole group (n = 148)</th>
<th>Retirement homes (n = 81)</th>
<th>Living at home (n = 67)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMI, kg/m²</td>
<td>0.29 (&lt;0.0005)</td>
<td>0.38 (&lt;0.0005)</td>
<td>0.20 (0.05)</td>
</tr>
<tr>
<td>Triceps skinfold thickness, mm</td>
<td>0.11 (0.05)</td>
<td>0.28 (&lt;0.0005)</td>
<td>NS</td>
</tr>
<tr>
<td>Arm fat area, cm²</td>
<td>0.14 (0.02)</td>
<td>0.30 (&lt;0.0005)</td>
<td>NS</td>
</tr>
<tr>
<td>Arm muscle circumference, cm</td>
<td>0.24 (&lt;0.0005)</td>
<td>0.19 (0.02)</td>
<td>0.18 (0.07)</td>
</tr>
<tr>
<td>Arm muscle area, cm²</td>
<td>0.23 (&lt;0.0005)</td>
<td>0.20 (0.01)</td>
<td>NS</td>
</tr>
<tr>
<td>Abdomen/hip ratio</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

Table 4. Correlations between Medical Outcome Study (MOS) general health scores and Mini Nutritional Assessment (MNA) for male and female elderly people living independently at home and in retirement homes

<table>
<thead>
<tr>
<th></th>
<th>Living at home (n = 67)</th>
<th>In retirement homes (n = 81)</th>
<th>Total group (n = 148)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical health</td>
<td>NS</td>
<td>NS</td>
<td>0.43 (&lt;0.0005)</td>
</tr>
<tr>
<td>Role functioning</td>
<td>NS</td>
<td>NS</td>
<td>0.43 (&lt;0.0005)</td>
</tr>
<tr>
<td>Social functioning</td>
<td>0.31 (0.005)</td>
<td>0.18 (0.04)</td>
<td>0.50 (&lt;0.0005)</td>
</tr>
<tr>
<td>Mental functioning</td>
<td>NS</td>
<td>0.29 (0.003)</td>
<td>0.42 (&lt;0.0005)</td>
</tr>
<tr>
<td>Perceived health</td>
<td>0.33 (0.003)</td>
<td>0.18 (0.18)</td>
<td>0.39 (&lt;0.0005)</td>
</tr>
<tr>
<td>Physical pain</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

Summary of Effects and Comparison between Elderly Living in the Community and Elderly Living in Retirement Homes

Participants living in retirement homes were older than those living in the community (p < 0.001). MNA scores for elderly people living in the community were higher than for those living in retirement homes (p < 0.001). Only 2% of the elderly people living at home were at risk of malnutrition, compared with 37% of those living in retirement homes (p < 0.001). In retirement homes, more people had complete dentures, used drugs affecting odor perception, or had a poor odor perception compared with elderly people living independently at home (p < 0.001).

A summary of statistical associations between MNA score and the different age-related phenomena under investigation is given in Tables 3–6 and in Fig-
MNA and Odor Perception

Table 5. Correlation ($r$) between Mini Nutritional Assessment (MNA) score and indices of sensory perception

<table>
<thead>
<tr>
<th></th>
<th>Living at home (n = 67)</th>
<th>In retirement homes (n = 81)</th>
<th>Total group (n = 148)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Odor perception</td>
<td>–0.02 ($p = 0.45$)</td>
<td>0.03 ($p = 0.41$)</td>
<td>0.38* ($p &lt; 0.005$)</td>
</tr>
<tr>
<td>Number of natural teeth</td>
<td>0.00 ($p = 0.47$)</td>
<td>0.27* ($p = 0.001$)</td>
<td>0.45* ($p &lt; 0.005$)</td>
</tr>
</tbody>
</table>

* Significant at $p = 0.005$.

Table 6. Mean Mini Nutritional Assessment (MNA) score (SD) and use of drugs affecting odor perception

<table>
<thead>
<tr>
<th></th>
<th>Using drugs affecting odor perception</th>
<th>Using other or no drugs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living at home</td>
<td>26.8 (2.92)</td>
<td>27.8 (1.42)</td>
</tr>
<tr>
<td>In retirement homes</td>
<td>23.4* (2.72)</td>
<td>25.5 (1.58)</td>
</tr>
<tr>
<td>Whole group</td>
<td>23.8* (2.99)</td>
<td>27.0 (1.83)</td>
</tr>
</tbody>
</table>

* Significant at $p < 0.0005$.

In the group as a whole, there was a significant correlation between risk of malnutrition and poor odor perception, as well as between use of drugs that affect odor perception and MNA score. For both elderly people living independently at home and for those living in retirement homes, general health and body composition were important factors, while in retirement homes, the number of natural teeth and the use of drugs are independent factors explaining the risk of malnutrition measured by the MNA score.

Discussion

Many elderly people have a monotonous or inadequate diet and are in a state of marginal nutritional deficiency. Energy intake is often found to be below recommended daily allowances, making it extremely difficult to meet requirements for vitamins and minerals [30, 38, 39]. Deficiencies have been reported for vitamin A, B1, B2, B6, B12, D, folic acid and iron. Malnutrition is associated with
increased mortality, frailty, increased risk of several diseases, susceptibility to infection, and reduced quality of life [40]. In our study, the risk of malnutrition was evaluated by MNA as a composite measure of 18 nutrition-related items. MNA is a validated quantitative evaluation tool, appropriate for assessing the risk of malnutrition in elderly people. In evaluating odor perception and dental state as a function of nutritional risk, it became clear that the relations between these variables are complex. Among elderly people living at home an association was found between poor general health and a tendency for lower MNA scores. Not surprisingly, persons without risk of malnutrition had a higher muscle mass than those with malnutrition.

Fig. 4. Odor perception and MNA score ($r = 0.34, p < 0.001$).
Among elderly people living in retirement homes, poor general health was associated with diminished odor perception, and a high risk of malnutrition was associated with a loss of natural teeth. In addition, MNA scores in those taking drugs affecting odor perception were lower than in those taking other drugs.

One would expect a relation between nutritional status and the sense of smell, but the relation between odor perception and nutrition in the elderly is controversial [41]. Poor nutrition with increased risk of several diseases, frailty, and decreased immunity is directly linked with poor general health, affecting sensory capacities. The controversy over the relation between odor perception and nutrition may be the result of the effect of general health and of use of drugs, both of which are linked with both poor nutrition and poor odor perception. The population under investigation was heterogeneous with regard to general health. Many other studies have shown that odor perception is related to medical condition and drug use [2, 13, 14, 25].

Murphy & Whithee [42] found an association between protein status and sensory measures of odor intensity and preference. Mattes et al. [12] found no differences in dietary factors (calcium, folic acid and protein), as measured by a food consumption study in patients with smell disorders. Ferris & Duffy [6] conducted a similar study and claimed that the severity of smell dysfunction had an effect on the adequacy of calcium intake. Published reports of the extent and nature of changes in body weight, BMI, and body fat and the relation with smell have also been controversial [41]. Recently, Hunter-Smith & Kessel [43] reported a reciprocal association between the ability to smell and BMI. On the other hand, Duffy et al. [10] and Mattes et al. [12] reported no differences in energy intake or BMI between those with and without a diminished sense of smell.

Fischer & Johnson [44] suggest that weight loss is multifactorial but can be attributed to diminished odor perception. Along these lines, Mattes et al. [12] and Mattes & Coward [45] found that the majority of persons with olfactory disorders show weight loss. Wysocki & Pelchat [14] observed that odor dysfunction can cause loss of enjoyment of eating. Duffy et al. [10] found an association between odor/flavor perception and altered preference or consumption of particular foods. A possible explanation could be that a loss of sensations during food consumption accompanies reduced food intake [9].

In general, previous studies where the relation between odor perception and nutritional state was explored did not use composite measures of nutritional risk but focused on single nutritional components, blood chemistries, or anthropometric sites. The MNA is an overall evaluation score of nutritional state and does not provide information about specific nutrients or biochemical indices. The results from previous studies are therefore difficult to compare with MNA scores. In general, focusing on the overall dietary pattern is more important for health, quality of life, and longevity than focusing on individual components [46]. Along these lines, it has been suggested by Mattes & Coward [45] that deficits or excesses of specific nutrients do not explain the age-related abnormalities
in taste and smell. Remedies focusing on single nutrients would therefore have limited value.

The MOS scale was used to distinguish the effect of general health from that of odor perception on the variability of nutritional state. In validation studies of the MOS scale carried out by others [29] on a total of 11,186 persons, objective medical data were related to independently obtained MOS scores. It became clear that patients in poor general health, assessed by medical criteria, show on average a 50% lower MOS score than healthy people. People with chronic medical conditions have lower MOS scores than those with acute illnesses or healthy people. These findings indicate that the MOS scale is a useful, reliable, and valid instrument for measuring general health in the elderly.

Our results show a significant relation between nutritional state and general health, while a significant relation was also observed between general health and odor perception. Along these lines, it has been suggested that physiological regression is in general more related to health than to age [47], and health status might also become more important than age for odor perception [9]. However, the results reported in published reports are cross-sectional in nature and do not provide definitive support for the hypothesis that diminished odor perception is caused by poor health or that improvement of general health might improve odor perception.

Volatile odors, originating from food, enter the nasal cavity retronasally during mastication. Decreased chewing ability in elderly people may prevent the release of the odors from the food. Decreased appetite and decreased ability to eat can restrict food selection [48], leading to poor nutrition. Papas et al. [20] showed a 20% drop in nutritional quality of food consumed by people who had upper or lower dentures, or both, compared with those who had their natural teeth. The chewing ability of denture wearers is particularly reduced, so they often choose only soft food, which frequently is nutritionally unbalanced [22, 49]. People wearing complete dentures have one sixth the masticatory ability of those with their natural dentition [50]. Tooth loss causes a significant loss of chewing ability, and complete dentures do not restore full oral function. Impaired mastication alters the sensory and psychological aspects of eating, causing restriction of food selection. Recent population-based studies suggest that edentulousness is correlated with reduced nutrient intakes and multiple dietary inadequacies, and edentulous individuals are more likely to have an atherogenic diet [19]. Our results with MNA show that the risk of malnutrition increases with tooth loss and with wearing complete dentures. Owing to the cross-sectional nature of our data, the results show no causal effect of dental state. Dental state may not be a direct cause of malnutrition but a contributing factor in those elderly people who have other risk factors [48].

In conclusion, our results show that elderly people at risk of malnutrition tend to have poorer health, poorer odor perception, and fewer natural teeth than elderly people not at risk of malnutrition.
Part 2

Malnutrition and Flavor Amplification

In part 1, it became clear that with age, poor nutritional status, and poor health status, odor perception declines to a considerable extent. On a group level, elderly people at risk of malnutrition tend to have worse odor perception than those not at risk of malnutrition. Since food flavors consist mainly of volatile odors, and flavor perception has been rated as the strongest determinant of food choice in the elderly [15], in this study we examined whether increasing the flavor level of food improved food preference and consumption of elderly people at risk of malnutrition.

Compensating for diminished sensory function with age might improve the quality of life for elderly people. Previous studies have shown that flavor amplification improves both preference and consumption of particular foods [31, 51, 52]. Since food habits of many elderly people are inadequate, leading to a poor nutritional state, nutrient-dense foods are the prime candidates for flavor amplification. Adding odors to nutrient-dense foods might act to make food more appealing and increase consumption in elderly people in a poor nutritional state. Compared with (saturated) fat, sugar and salt, exposure to additional amounts of flavors is generally harmless and self-limiting, with no detrimental health effects since only small quantities – well below the maximal tolerable doses – are needed to give foods a perceptibly stronger flavor [2].

For its nutritional benefit, it was decided in this study to test whether flavor amplification induced changes in preference and consumption of skimmed yogurt, and whether elderly people in a poor nutritional state could benefit from this.

Subjects and Methods

The study populations were the same as in experiments 1 and 2 of part 1 (Tables 1 and 2).

Food System for Flavor Amplification

Skimmed yoghurt was chosen as a major source of calcium and for its potential beneficial effects on cholesterol balance, cancer prevention, and immune function [53, 54].

The optimal sensory quality of the yoghurt was assessed during extended pilot studies with equal flavor intensities. The concentration ranges of flavors in the food samples were assessed by scientists of Perlarom S.A. (Belgium). All flavors used were mixtures of odoriferous molecules extracted from natural products or...
synthesized after chemical analysis of the natural product. Obvious differences between high and low concentrations of flavor in the samples were created for odoriferous compounds only, while preparation and logistical procedures were standardized. The other sensory characteristics such as taste, color, and texture were held constant.

For the preparation of the yoghurt samples, 25.0 g simplex sugar syrup (Pharmacopoeia) was mixed with 0.200 or 1.000 ml strawberry flavor (Perlarom S.A., Belgium) for low and high flavor levels, respectively; 375.0 g skimmed yoghurt (Delhaize, Belgium) was mixed with the syrup until the mixture was homogeneous.

**Preference and Consumption Measurements**

In random order, participants received two food samples (20 g) in small identical cups, pairwise at the same time, one containing the high food flavor level and the other the low flavor level. Participants were asked to indicate whether they could taste a difference between the food samples and if so, which of the two they preferred. The ratings were checked by the qualitative reactions of the participants.

During 2 days, independent of the preference measures, food dishes were supplied to the participants under controlled conditions between meals. In random order, participants received 400 g yoghurt with either a high or low flavor level. Sufficient food was available to allow respondents to eat as much as they wanted to, thus allowing consumption levels to be compared. On each testing day, all dishes were prepared individually under the same conditions. Participants were ignorant of the details of the study and it was verified that they added no sugar or other substances to the yoghurt. To measure the differences in consumed quantities, portions were weighed before and after the session. Testing took place in clean, ventilated, neutral dining rooms that were used for this experiment only and free of smoke or loud noise. Testing days were carefully selected by consulting the management of the centers to make sure that the meals supplied on both testing days were comparable in terms of energy contents and serving time. Before the sessions, the subjects were interviewed to verify that they did not consume either excessive or minimal amounts during their meals. If they did, they were excluded from further statistical analysis.

**Results**

Table 7 shows the mean MNA scores and ages of the elderly people preferring a high or a low flavor level. The proportion of men and women preferring either flavor level was equally distributed ($\chi^2$ test, $p > 0.11$). Among elderly people living
MNA and Odor Perception

<table>
<thead>
<tr>
<th>Preference for low flavor</th>
<th>Total group</th>
<th>At home</th>
<th>In retirement homes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean MNA score (SD)</td>
<td>25.8* (2.6)</td>
<td>27.5 (1.9)</td>
<td>24.4* (2.3)</td>
</tr>
<tr>
<td>Mean age, years (SD)</td>
<td>73.7 (10.9)</td>
<td>65.2* (6.2)</td>
<td>83.7 (5.3)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Preference for high flavor</th>
<th>Total group</th>
<th>At home</th>
<th>In retirement homes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean MNA score (SD)</td>
<td>24.6 (3.5)</td>
<td>27.7 (1.7)</td>
<td>22.9 (3.0)</td>
</tr>
<tr>
<td>Mean age, years (SD)</td>
<td>76.6 (10.2)</td>
<td>68.0 (6.6)</td>
<td>83.7 (6.4)</td>
</tr>
</tbody>
</table>

* Significant difference between persons preferring high and low odor level (p < 0.05).

Table 8. Nutritional risk in relation to flavor amplification, correlations between Mini Nutritional Assessment (MNA) score and consumed quantities of flavor-amplified yogurt (p value)

<table>
<thead>
<tr>
<th></th>
<th>High flavor level yogurt</th>
<th>Low flavor level yogurt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total group (n = 148)</td>
<td>0.13 (0.054)</td>
<td>0.26 (0.001)*</td>
</tr>
<tr>
<td>Elderly people in retirement homes (n = 81)</td>
<td>0.09 (0.18)</td>
<td>0.14 (0.08)</td>
</tr>
<tr>
<td>Elderly people at home (n = 67)</td>
<td>0.07 (0.32)</td>
<td>0.04 (0.41)</td>
</tr>
</tbody>
</table>

* Significant at p = 0.001.

...independently at home, no significant difference was observed in MNA score between those preferring a high and those preferring a low flavor level; however, those preferring a high flavor level were significantly older than those preferring a low flavor level (t test, p < 0.05).

Elderly people in retirement homes preferring the high strawberry flavor level had significantly lower MNA scores than those preferring the low flavor level (t test, p < 0.05). No significant difference in age was observed between those preferring high and low flavor levels.

A highly significant correlation was observed between the consumption of low flavor level yogurt and MNA score (r = 0.26, p = 0.001), indicating that elderly subjects at risk of malnutrition consume less of the low flavor level yogurt. No significant correlation was observed between consumption of the high flavor level yogurt and MNA score (r = 0.13, p = 0.054; Table 8).
A combined effect of age and MNA score on consumption levels is to be expected, so multiple regression analysis was used to determine their relative importance. Regression coefficients for both age and MNA score were significant ($p = 0.02$), showing that the effects of MNA and age on consumption levels are independent – for example, the effect of the MNA score cannot be ascribed to age (total $R^2 = 0.31$).

**Discussion and Conclusion**

Elderly people suffering from malnutrition might benefit from flavor-amplified food, and our results confirm that flavor amplification can influence food preference [31]. Compared to relatively young persons, most elderly people reacted positively to the flavor-amplified food and preferred high flavor levels. Elderly people who preferred a high strawberry flavor level tended to have lower MNA scores than those who preferred a low flavor level. In addition, a low MNA score was associated with a reduced consumption of low flavor level food, while the consumption of flavor-amplified food remained constant when the MNA score was low. Therefore, in order to assure that consumption levels of elderly people suffering from malnutrition remain the same as in well-nourished elderly people, flavor amplification is necessary and is generally harmless compared with adding fat, salt, and sugar.

However, caution is required, since the results are based only on 2 days of meal supply under controlled conditions and in selected elderly populations. Our results do not show whether improved preference would continue after 2 days, or whether they can be generalized to a larger range of candidate food products for flavor amplification. The aged population is heterogeneous in terms of health status, sensory capacities, nutritional state, living conditions, functional ability, attitudes, and perceived risk [55]. Therefore, the acceptability of flavor-amplified food for consumers under real-life conditions, including additional factors that determine food choice, deserves further study [52].

**References**

MNA and Odor Perception


Discussion

*Dr. Rubenstein:* All three papers made some important points. The question I have concerns all three of them. Dr. Griep, on your last slide with your conclusions, the information you presented was really a hypothesis rather than a set of conclusions, and it needs to be established that people who are at risk of malnutrition may benefit from enhanced flavor. Again, we have a lot of correlations between low scores on the MNA and, for example, low T cell function and mortality. These are important correlations, but they imply the need for interventional studies. We don’t know how much of the correlation is due to the malnutrition itself and how much to comorbidity. My feeling is that a significant amount of the correlation is due to the malnutrition, but not all of it. We need to be cautious about how we state these correlations; they set the stage for future interventional trials where we take the people who are clearly at risk for malnutrition or who have low MNA scores and do an intervention.

*Dr. Griep:* At the Faculty of Medicine and Pharmacy in Brussels, we have just started such an intervention, and we are now testing whether flavor amplification leads to a long-term effect.

*Dr. Guesry:* Did you measure zinc status in your patients? There are old papers that mention that flavor perception is related to zinc deficiency.

*Dr. Griep:* We measured plasma zinc and none of the subjects had a low zinc level. This is one of the points that I discussed in my PhD thesis: the relation between zinc status and...
sensory perception has indeed been described in the literature, but I could not confirm that any specific nutrient showed a clear relation with declining sensory perception. That was one of the reasons why I started working with MNA – I was expecting MNA to be a composite measure, a global score reflecting more than a single nutrient.

*Dr. Eastwood:* There appeared to be no correlation between MNA scores and the odor perception threshold in people living in the community – as I understood it – nor for people in institutions. But you did get a fit if you put them together. So essentially, you had two groups of people. If you look at the scattergram, it's not really very convincing. What do you think?

*Dr. Griep:* I agree. The relation is there, but becomes much weaker if you split the groups.