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Review Article

Role of nutrition in the development and prevention of age-related hearing loss: A scoping review

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Age-related hearing loss (ARHL) is a major and increasingly prevalent health problem worldwide, causing disability and social isolation in the people who present it. This impairment is caused by genetic and environmental factors. Nutritional status has been identified as a related risk associated with hearing loss (HL). This scoping review aimed to characterize the links between HL and nutritional status. PubMed, Embase, Cochrane and Scopus databases were searched up to December 2019. Studies examining the relation between nutrition and dietary habits and HL were included. After screening 3510 citations, 22 publications were selected for inclusion in the current review, all of which were published between 2010 and 2019. Diets rich in saturated fats and cholesterol have deleterious effects on hearing that could be prevented by lower consumption. Conversely, greater consumption of fruit and vegetables, and of polyunsaturated fatty acids (omega-3) and anti-oxidants in the form of vitamins A, C, and E, prevent the development of ARHL. The current literature suggests a possible association between nutritional status and hearing loss. More studies are needed to better characterize the clinical consequences of this association.

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Introduction

Age-related hearing loss (ARHL) or acquired hearing loss is one of the most frequent chronic diseases in elderly individuals, with a prevalence of 35%. According to data collected by the WHO, about 466 million people suffer from a disabling degree of hearing loss (HL), with men being more affected than women.[1] Its appearance and development are influenced by genetic[2] and environmental factors,[3–7] including eating habits. In the context of the latter, HL has been analyzed from three different perspectives: a) the consequences of prolonged nutritional deficiencies[8]; b) the positive influence of various components of the diet on preventing HL[9]; c) the effect of supplementation with anti-oxidant components to prevent HL.[10–12] The relationship between food intake and hearing changes is of practical interest, since dietary changes can be made that can at least delay, or even prevent the development of HL.[13]

Adoption of a diet whose main components are vegetables, fruits, whole grains, and an adequate quantity of fish[14] is usually associated with a decrease in systemic inflammation, which could help maintain proper hearing.[15]

The aim of this study was to use scoping review methods to analyze how a healthy diet may mediate the risk of, or protection against, HL. We limited our search to studies that have evaluated the composition of the diet in humans and in which the diagnosis of HL was made through objective audiometry tests.

Methods

This scoping review was performed according to the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR).[16]

Data sources and search strategy

MEDLINE [PubMed], Embase [via Embase.com] and CENTRAL (Cochrane Central Register of Controlled Trials [via Wiley]) were searched from their inception until Dec 16th, 2019. We imposed no language or temporal restrictions on any of the searches, although they were limited to studies on humans. The reproducible search strategy for PubMed can be found in Appendix 1. The search strategies were developed by an experienced medical librarian [CC] and peer-reviewed by another librarian [JM] according to best practice recommendations.[17] Keywords for the main search were identified with the Yale MeSH Analyzer text analysis tool,[18] Medical Subject Headings (MESH, via the US National Library for Medicine MESH browser), and Embase subject headings (EMTREE, via Embase.com). An exhaustive electronic search strategy was devised, based on the selected keywords, and a library of the retrieved articles was created with Rayyan software,[19] which enables blinded screening of abstracts and titles.

Study selection

To select articles obtained in this search, the following inclusion criteria were applied: (1) study carried out on humans; (2) study involves adult participants; (3) auditory function assessed by a trained audiologist by measuring pure tone air conduction; (4) study that evaluated the composition of the diet and (5) published in English. The following exclusion criteria were applied: (1) article is a review; (2) self-reported hearing-loss; (3) sudden deafness; (4) alcohol intake; (5) study analyzed dietary supplementation instead of whole food intake. All the articles identified were independently screened by two reviewers. After abstract screening, full-text versions of the articles deemed potentially suitable for inclusion were retrieved and independently evaluated against the eligibility criteria by the same reviewers. Disagreements between the reviewers about study eligibility were resolved by discussion.

Data extraction and risk assessment of bias

Data charting focused on relevant study characteristics and was conducted independently, in duplicate, by two reviewers, using a customized data-extraction form. Perceived discrepancies in the extracted data were resolved by the reviewers through discussion after rereading the full-text articles. The studies included in this scoping review were appraised for methodological quality according to appropriate research designs for observational studies: the Newcastle–Ottawa Scale (NOS)[20] for cohort studies, and the modified NOS for cross-sectional studies.[21]

Data synthesis

The results of this scoping review were synthesized to indicate the significance and direction of the observed associations, and summarized as tables. Information about study characteristics was extracted to describe the studies and populations.

Results

Search findings

A total of 3263 citations were retrieved by database searching. An additional 525 records were identified by reviewing the references cited in selected retrieved articles and by citation tracking of articles in Scopus (see Fig. 1).

After duplicates were removed, we screened 3510 article titles and abstracts. 3430 were excluded, leaving the full text of 80 articles to be retrieved and assessed for

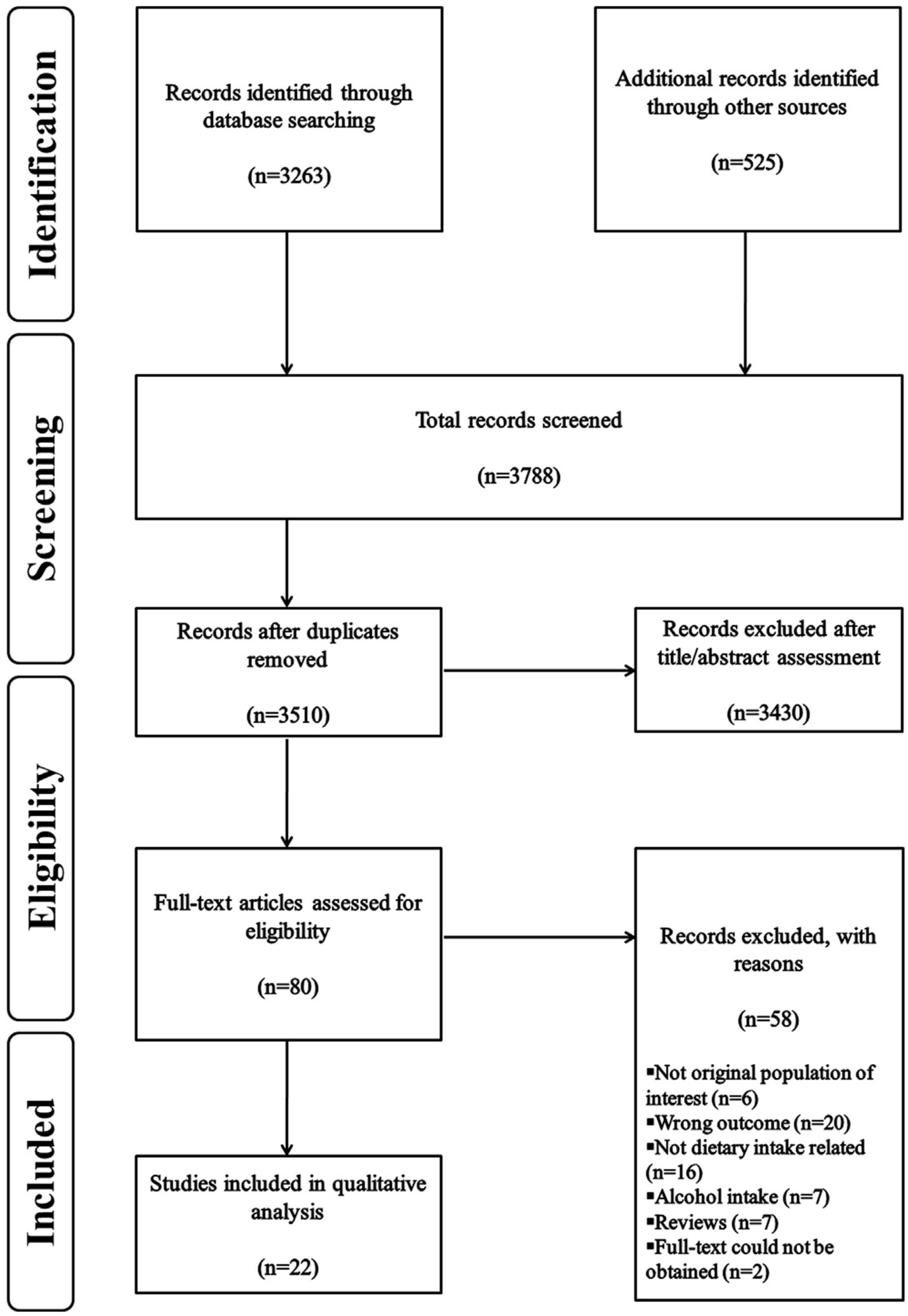

Figure 1 Flow diagram of the study selection process.

eligibility. This resulted in the exclusion of 58 further articles, for the following reasons: not a population of interest (n = 6); wrong outcome (n = 20); not dietary intake (n = 17); reviews (n = 7); alcohol intake (n = 6); unable to retrieve full article (n = 2). Finally, therefore, 22 studies were considered eligible for this review.

Study characteristics

The general data of the investigations included in this systematic review are presented in Table 2. All the articles were published between 2010 and 2019 and studied the influence of nutritional factors on hearing function. Eleven studies analyzed macronutrients,[15,22–31] eight studies evaluated micronutrients[13,29,31–36] and five studies focused on other dietary factors.[29,37–40] This scoping review covers twelve cross-sectional[15,27,29–32,34–36,38–40] and ten cohort studies.[13,22,24–27,29,33,37,41] Six studies included participants from the Blue Mountains Hearing Loss Study (Australia),[24–27,31,33] while nine used data from the National Health and Nutrition Examination Survey (NHANES) of the USA[15,23,32] and Korea.[28,34–36,38,39] All the investigations used mixed-gender samples, except one[41] that comprised only males. The average age of participants varied between 40[40] and 75.[35] The period of the original interventions ran from 1971 (the first to start)[30] to 2016[22] (the last to finish), the last intervention beginning in 2012.[39] One study was carried out over two periods (1992–1994 and 1997–1999),[27] and another analyzed three age cohorts of 70-year-olds on three occasions (1971–1972, 1992–1993 and 2000–2001).[30] The duration of the cohort studies ranged from 2[37] to 18 years,[13] with an overall mean of 8.1 years.

The main results of the studies are summarized in Tables 1 and 2. Nutrient intake was evaluated principally using the Food Frequency Questionnaire (FFQ)[22–26,30,31,33,37–39,41] and 24-h dietary recall,[15,28,29,32,34–36] although the semi-quantitative FFQ,[13] a dietary history,[30] and a food preference questionnaire[40] were also used for this purpose.

Audiological examination in all studies consisted of pure-tone audiometry (PTA), except for that of Shargorodsky et al.,[13] which analyzed self-reports of HL. Audiometric questionnaires were included in three studies,[15,23,31] otoscopic examinations were carried out in three,[23,26,35] and tympanometry was performed in two studies.[15,23] Apart from these, Spankovich et al.[31] examined cochlear function by recording transient evoked otoacoustic emissions (TEOAEs), and Hwang et al.[37] assessed temporal ordering (central auditory system) using the pitch pattern sequence (PPS).

Table 3 summarizes the quality assessment of the 22 studies according to research designs for observational studies.[21,22]

Discussion

We performed a scoping review of 22 studies, summarizing the current knowledge about the factors associated with diet composition and hearing status. The principal findings were that some individual nutrients and diet types are associated with hearing level. Diets rich in cholesterol and unsaturated fatty acids are harmful to hearing. Conversely, diets rich in polyunsaturated fatty acids, such as omega-3 and those from certain fish, the regular consumption of vegetables and fruits, and the intake of anti-oxidants in the form of various vitamins have a protective effect against HL.

Moreover, a previous study has shown that if prolonged nutritional deficiencies in children are corrected in time through provision of proper nutrition, the onset of HL in adulthood can be prevented.[8] However, further research is needed to establish definitively the connection between nutrition and HL.

The study of dietary patterns has been based on two methodologies: the analysis of retrospective studies and the execution of prospective studies based on nutritional recommendations and established guidelines.[42] Adherence to a healthy diet is associated with a lower prevalence of the development of HL.[41] Poor dietary habits are related to overweight and obesity.[41,43] Lalwani et al.[43] identified that a high body mass index (BMI) are related to the presence of ARHL in children of both sexes. Likely, Croll et al.[22] identified similar results in older adults for the BMI and fat mass in a cross-sectional analyze, but this association disappeared after 4 years follow-up. These results suggest that maintaining a normal weight may help prevent HL in the elderly. However, we have not found any published research that confirms this hypothesis.

Nowadays, it is difficult to predict the importance that the intake of carbohydrates has in the development of HL.[44] However, the preferentially consumed types of food that contain carbohydrates are not associated with a healthy diet (whole grain, vegetables and fruit), but rather with simple sugars, that include monosaccharides and disaccharides, which regularly involved foods with added sugar and high levels of triglycerides.[45] Additionally, the regular intake of low molecular weight carbohydrates also increases blood triglyceride levels,[46] which is associated with HL in men and women.[30] Regarding this point, in the Blue Mountains Hearing Study, a significant correlation was noted between high glycemic levels and the presence of HL in a group of adults.[24] Conversely, higher carbohydrate intakes were associated with better auditory function.[31] This observed discrepancy, despite the measurements being made in the same cohort, albeit over different durations, could be a consequence of the different methods employed. On the one hand, Gopinath et al.[23] studied the glycemic index and used the PTA measurement to evaluate HL, while on the other, Spankovich et al.[31] analyzed carbohydrate intake through the FFQ and evaluated HL by determining the TEOAEs. However, it should be pointed out that PTA is the most commonly used technique for evaluating hearing levels, and the most frequently employed in all the studies.[47]

Diets rich in cholesterol are usually associated with harmful effects on hearing. Not all fatty acids have a clearly deleterious effect, since an inverse relationship between the consumption of polyunsaturated fatty acids (PUFAs) and/or the consumption of fish has been described with respect to the incidence and prevalence of HL. In relation to the frequency of consumption of fish that are rich in omega-3 fatty acids, eating them at least twice a week was found to reduce the frequency with which presbycusis developed by 42% by the end of a 5-year follow-up.[25] The mechanisms that could explain this beneficial effect are based on modifying vascular disorders at the cochlear level and on inflammatory changes related to arteriosclerosis.[48] However, other researchers found no significant association between regular fish intake and auditory levels.[29] The discrepancy can be explained by the different study period (5 *vs.* 13 years). In another study, elevated serum lipid levels were observed in patients presenting with sudden sensory HL,[49] but this association has not been confirmed in cases of slow progressive onset of HL, as occurs in patients with ARHL. Conversely, subjects with diets poor in both fat and protein are more likely to experience "hearing discomfort".[28]

Only one study reviewed here evaluated the role of protein intake and its influence on HL. Kim et al.[28] reported a negative correlation between low-protein intake and hearing discomfort based on mean hearing thresholds, but not on the degree of HL. However, this interpretation

Table 1 Characteristics of the studies reviewed.

Authors and reference	Sample	Dietary factor evaluated	Intervention and comparison	Main results
Choi et al. (2014)[32]	■ United States ■ 2592 participants - 47.8% ♂, 52.2% ♀ - Age: 20–69 years	■ Vitamin (beta-carotenes and vitamins C and E) and Mg intake	■ Participants classified by total nutrient intake quartiles	■ Subjects with high intake of both beta-carotene and Mg had lower (better) high-PTA compared with their low-intake counterparts (−14.82%; 95% CI: −20.50%, −8.74%), multiplying the effects of high beta-carotene only or high Mg only ($p = 0.082$) ■ Subjects with high vitamin C and Mg intake had lower high-PTA (−10.72%; 95% CI: −16.57%, −4.45%)
Croll et al. (2019)[22]	■ Netherlands ■ 2906 participants (663 follow-up) - 43.3% ♂, 56.7% ♀ - Age: 66.1 (7.3) years	■ Diet quality	■ Participants divided into LF (0.25, 0.5 and 1 kHz) or HF (2, 4 and 8 kHz) ■ Multivariate linear regression models	■ Higher intakes of unsaturated fats were associated with a 0.16 dB (95% CI: 0.03, 0.29) increase in hearing thresholds ■ Higher intakes of sugar containing beverages were associated with a 0.04 dB (95% CI: −0.07, −0.01) dB decrease in hearing thresholds ■ Higher consumption of nuts was associated with a 0.95 dB (95% CI: −1.52, −0.37) decrease in hearing thresholds
Gallagher et al. (2019)[41]	■ United Kingdom ■ 2512 participants ■ HL: 996 - 100% ♂ - Age: 53.0 (4.4) years ■ No HL: 890 - 100% ♂ - Age: 50.8 (4.2) years	■ Dietary patterns	■ Participants classified by quintiles ■ Subjects divided into HL (PTA > 25 dB) and no HL	■ Inverse association between healthy dietary pattern and HL as a dichotomous variable (OR: 0.87; 95% CI: 0.77, 0.90; $p < 0.001$) and as an ordinal variable (OR: 0.87; 95% CI: 0.81, 0.94; $p < 0.001$) ■ Direct association between traditional dietary pattern and HL as a dichotomous variable (OR = 1.18; 95% CI: 1.02, 1.35; $p < 0.02$) and as an ordinal variable (OR = 1.17; 95% CI: 1.03, 1.33; $p < 0.02$)
Gopinath et al. (2010)[25]	■ Australia ■ 2442 participants ■ HL: 397 - 50.8% ♂, 49.2%♀ - Age: 72.7 (8.3) years ■ No HL: 656 - 39.5% ♂, 60.5%♀ - Age: 63.5 (7.8) years	■ Omega-3 fatty acids and fish intake	■ Participants classified by PUFA intake quartiles ■ Subjects divided into any HL (PTA > 25 dB) and no HL	■ Inverse association between total omega-3 PUFA intake and the prevalence of HL (OR = 0.89; 95% CI: 0.81, 0.99) ■ Inverse association between total omega-3 PUFA intake and the incidence of HL (OR = 0.76; 95% CI: 0.60, 0.97)

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Table 1 (*continued*)

Authors and reference	Sample	Dietary factor evaluated	Intervention and comparison	Main results
				■ Consumption of ≥2 servings of fish/week were associated with a 42% lower risk of HL vs. <1 serving/week (OR = 0.58; 95% CI: 0.35, 0.95) ■ Association between fish intake of ≥1 to <2 servings/week and progression of HL (OR = 0.53; 95% CI: 0.32, 0.88)
Gopinath et al. (2010)[24]	■ Australia ■ 2442 participants ■ HL: 397 - 50.8% ♂, 49.2%♀ - Age: 72.7 (8.3) years ■ No HL: 656 - 39.5% ♂, 60.5%♀ - Age: 63.5 (7.8) years	■ Carbohydrates intake (dietary GI, cereal fiber and sugar)	■ Participants classified by GI quintiles ■ Subjects divided into any HL (PTA > 25 dB), mild HL (PTA = 26 −40 dB) and moderate-severe HL (PTA > 40 dB)	■ Higher mean dietary GI was related to a higher prevalence of any HL comparing 1st and 5th quintiles (OR = 1.41; 95% CI: 1.01, 1.97) ■ Subjects in the 5th quintile had a 76% greater risk of HL than those in the 1st quintile (p = 0.04) ■ Both higher carbohydrate (p = 0.03) and sugar intakes (p = 0.05) increased the incidence of HL
Gopinath et al. (2011)[26]	■ Australia ■ 2442 participants ■ HL: 397 - 50.8% ♂, 49.2%♀ - Age: 72.7 (8.3) years ■ No HL: 656 - 39.5% ♂, 60.5%♀ - Age: 63.5 (7.8) years	■ Dietary cholesterol intake	■ Participants classified by total dietary fat quartiles	■ Subjects in the 4th quartile showed a higher prevalence of HL than those in the 1st quartile (p = 0.04) ■ Both subjects in the 2nd (OR = 0.39; 95% CI: 0.21, 0.71) and the 3rd (OR = 0.51; 95% CI: 0.29, 0.91) quartiles of dietary monounsaturated fat intake had lower risk of HL progression after 5-years follow-up compared with those of the 1st quartile
Gopinath et al. (2011)[33]	■ Australia ■ 2956 participants (1309 follow-up)	■ Anti-oxidant intake	■ Participants classified by total anti-oxidant intake quintiles ■ Subjects divided into any HL (PTA > 25 dB), mild HL (PTA = 26 −40 dB) and moderate-severe HL (PTA > 40 dB)	■ Subjects in the 5th quintile of vitamin A intake had a 47% lower risk of having moderate-severe HL in comparison with the 1st quintile (OR = 0.53; 95% CI: 0.30, 0.92) ■ Higher intakes of vitamin E were associated with a 14% lower risk of HL (OR = 0.86; 95% CI: 0.78, 0.98) ■ No association between dietary anti-oxidant intake and 5-year incidence of HL
Gopinath et al. (2014)[27]	■ Australia ■ 2443 participants - 50.8% ♂, 49.2%♀	■ Diet quality	■ Participants classified by total diet score quintiles	■ Participants in the 1st quintile had a two-fold greater likelihood of HL prevalence

Table 1 (*continued*)

Authors and reference	Sample	Dietary factor evaluated	Intervention and comparison	Main results
	- Age: 67.2 (8.9) years			(OR = 2.62; 95% CI: 1.08, 6.36)
Hwang et al. (2012)[37]	■ Taiwan ■ 265 participants - 44.5% ♂, 55.5%♀ - Age: 63.2 (5.7) years	■ Tea drinking	■ Non-tea drinkers *vs.* Oolong tea drinkers	■ Oolong tea drinking was positively associated ($\beta \pm SE = 4.75 \pm 0.95$; $p < 0.001$) with PPS, but not with PTA
Jung et al. (2019)[36]	■ Korea ■ 5925 participants - 42.9% ♂, 57.1%♀ - Age: 57.6 (11.2) years	■ High-potassium diet	■ Participants classified by potassium intake tertile ■ Multivariate logistic regression analysis	■ High potassium intake was associated with lower hearing thresholds for all frequencies ($p < 0.001$) ■ For the univariate logistic regression, participants in the low and middle tertiles had 2120-fold and 1472-fold higher odds of HL, respectively, compared with subjects in the highest tertile ($p < 0.001$) ■ For the multivariate logistic regression, participants in the low and middle tertiles had 1642-fold ($p < 0.006$) and 1469-fold ($p < 0.014$) higher odds of HL, respectively, compared with subjects in the highest tertile
Kang et al. (2014)[34]	■ Korea ■ 1910 participants - 42.4% ♂, 57.6%♀ - Age: 62.5 (8.3) years	■ Vitamin intake	■ Participants classified by vitamin intake quartiles	■ Subjects in the highest quartile for intake of carotenoids, retinol, riboflavin, niacin and vitamin C had lower PTA than those in the lowest quartile for all the ranges of frequency ($p < 0.001$) ■ Subjects with the highest intake of vitamin D had higher PTA than those with the lowest intake in the mid- and high-frequency ranges ($p < 0.001$) ■ Individuals who used dietary supplementation had lower PTA than those with no dietary supplementation ($p < 0.001$) ■ Vitamin C intake was related to better hearing of mid-frequencies (2000–3000 Hz) (OR = −0.012; 95% CI: −0.022, −0.002)
Kim et al. (2015)[28]	■ Korea ■ 4615 participants - 44.4% ♂, 55.6%♀	■ Low-fat and low-protein diets	■ Simple and multiple logistic regression analysis	■ Fat intake was negatively associated with hearing thresholds (OR = 0.74; 95% CI: 0.64, 0.85; $p < 0.001$) and

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Table 1 (*continued*)

Authors and reference	Sample	Dietary factor evaluated	Intervention and comparison	Main results
	- Age: 68.3 (0.1) years			the correlation was maintained after adjusting for age and sex ($p < 0.002$) and all of the retrieved variables ($p < 0.011$) ■ Carbohydrate intake was positively associated with hearing thresholds only when adjusting for age and sex (OR = 1.18; 95% CI: 1.00, 1.39; $p < 0.047$) ■ Protein intake was significantly correlated with hearing thresholds (OR = 0.85; 95% CI: 0.61, 0.85; $p < 0.001$) and the correlation was maintained after adjusting for all variables (OR = 0.81; 95% CI: 0.67, 0.96; $p < 0.017$) ■ Total energy intake was significantly correlated with hearing thresholds only in the unadjusted model (OR = 0.85; 95% CI: 0.74, 0.97; $p < 0.034$)
Kim et al. (2019)[35]	■ Korea ■ 3720 participants ■ HL: 665 - 50.8% ♂, 49.2%♀ - Age: 75.4 (6.0) years ■ No HL: 3055 - 39.5% ♂, 60.5%♀ - Age: 71.8 (4.8) years	■ Vitamin intake	■ Participants classified by nutrient intake quartiles ■ Multivariate logistic regression analysis	■ Subjects with higher intakes of riboflavin (OR = 0.71; 95% CI: 0.54, 0.94; $p < 0.016$), niacin (OR = 0.72; 95% CI: 0.54, 0.96; $p < 0.025$) and retinol (OR = 0.66; 95% CI: 0.51, 0.86; $p < 0.002$) presented a lower prevalence of age-related HL
Lee et al. (2018)[38]	■ Korea ■ 13,448 participants (♂ and ♀) - Age: >19 years	■ Coffee consumption	■ Multivariate logistic regression analysis	■ Subjects aged 40–64 years who consumed coffee daily presented lower risk of HL in comparison with the rare consumption group (OR = 0.50; 95% CI: 0.33, 0.78; $p < 0.0021$) ■ Consumption of brewed coffee seemed to be inversely associated with HL (OR = 0.61; 95% CI: 0.44, 0.84; $p < 0.0028$)
Lee et al. (2019)[39]	■ Korea ■ 3575 participants - 39.6% ♂, 60.4%♀ - Age: 52 (45, 58) years	■ Chocolate consumption	■ Multivariate logistic regression analysis	■ Individuals who consumed chocolate (26.78%) had lower rate of unilateral or bilateral HL ($p < 0.001$) ■ Chocolate intake decreases the risk of bilateral HL and high-tone HL ($p < 0.001$) ■ Lower odds of any HL (OR = 0.83; 95% CI: 0.70, 0.98, $p < 0.03$), bilateral HL

Table 1 (*continued*)

Authors and reference	Sample	Dietary factor evaluated	Intervention and comparison	Main results
				(OR = 0.79; 95% CI: 0.64, 0.98, $p < 0.03$) and high-tone HL (OR = 0.78; 95% CI: 0.66, 0.91, $p < 0.02$) were concluded in subjects who consumed chocolate compared with non-consumers ■ Severity of HL was inversely correlated with the frequency of chocolate intake per week ($p < 0.001$)
Péneau et al. (2013)[29]	■ France ■ 1823 participants - 55% ♂, 45%♀ - Age: 64.5 (3.8) years	■ Nutrient and food intake	■ Participants classified by meat, seafood and fruit/vegetable intake quartiles ■ Multivariate linear regression analysis	■ Vitamin B_{12} intake was associated with lower HL in women ($p = 0.03$) ■ Intakes of retinol were related to a non-significantly better HL in women ■ Higher intake of meat as a whole ($p = 0.03$), red meat ($p = 0.014$) and organ meat ($p = 0.017$) was related with a better HL compared with lower intakes ■ Higher intake of seafood as a whole and of shellfish was associated with a non-significantly better HL in men
Rosenhall et al. (2015)[30]	■ Sweden ■ 524 participants - 47.5% ♂, 52.5%♀ - Age: 70–75 years	■ Dietary habits	■ Multiple logistic regression model	■ High intake of fish was associated with better hearing in the low and mid-range frequencies (0.5–2 kHz) in men ($p = 0.008$) ■ High intake of foods rich in molecular carbohydrates was related to poorer HF hearing (4–8 kHz) in women ($p = 0.0003$)
Shargorodsky et al. (2010)[13]	■ United States ■ 3559 participants (♂ and ♀) - Age: 40–74 (at baseline) years	■ Vitamin intake	■ Participants classified by vitamin intake quintiles ■ Cox proportional hazards multivariate regression	■ No significant association between vitamin intake (vitamin E, vitamin C, beta-carotene, folate, vitamin B_{12}) and risk of HL ■ Men aged ≥60 years presented an inverse correlation between folate intake and HL (OR = 0.79; 95% CI: 0.65, 0.96)
Spankovich et al. (2011)[31]	■ United States ■ 2111 participants - 43.9% ♂, 56.1%♀ - Age: 67.2 (8.9) years	■ Diet quality	■ Participants classified by dietary intake quintiles ■ Multivariate linear regression analysis	■ Increased BMI was associated with better HPTA ($r = -0.76$; $p = 0.001$) ■ Higher energy intakes were associated with poorer TEOAE ($r = -0.068$;

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Table 1 (*continued*)

Authors and reference	Sample	Dietary factor evaluated	Intervention and comparison	Main results
				p = 0.006) and HPTA (r = 0.054; p = 0.012) ▪ Higher carbohydrate, vitamin C, vitamin E, riboflavin, magnesium and lycopene intakes were significantly associated with larger TEOAE amplitude and better pure tone thresholds, while higher consumption of cholesterol and retinol showed the inverse associations
Spankovich & Le Prell (2013)[23]	▪ United States ▪ 2366 participants - 42.8% ♂, 57.2%♀ - Age: 40.18 (0.3) years	▪ Healthy diet	▪ Participants classified by HEI quintiles	▪ Negative association between diet quality and thresholds at higher frequencies (Wald F = 6.54; df = 4.29; p < 0.05) ▪ Higher dietary quality was associated with lower hearing thresholds
Spankovich & Le Prell (2014)[15]	▪ United States ▪ 2176 participants - 40.9% ♂, 59.1%♀ - Age: 40.7 (0.3) years	▪ Diet quality	▪ Participants classified by HEI quintiles	▪ Pure-tone thresholds were different for participants in the two HEI groups (top 60% *vs.*bottom 40%) at 3 kHz (Wald F = 22.453; df = 1.29; p < 0.001), 4 kHz (Wald F = 42.712; df = 1.29; p < 0.001) and 6 kHz (Wald F = 13.306; df = 1.29; p = 0.001)
Vuckovic et al. (2013)[40]	▪ Europe, Caucasus and Central Asia ▪ 4401 participants - 42.4% ♂, 57.6%♀ - Age: 40 (17.7) years	▪ Coffee intake	▪ Non-coffee drinkers *vs.* Coffee drinkers	▪ The intake of two (p = 0.01) or three cups of coffee per day (p = 0.003) was associated only with an improvement in medium frequency PTA

CI: confidence interval; dB: decibels; df: degrees of freedom; GI: glycemic index; HEI: hearing index eating; HL: hearing loss; HPTA: HF pure tone average; Hz: hertz; kHz: kilohertz; OR: odds ratio; PPTS: pitch pattern sequence; PTA: pure tone average; PUFA: polyunsaturated fatty acid; SE: standard error; TEOAE: transitory evoked otoacoustic emissions; vs.: versus.

should be regarded with caution, since only at low frequencies did the hearing threshold exhibit a statistically significant association with protein intake. Consistent with these findings, insufficient protein intake by pigs produced ototoxic side effects.[50] Therefore, low protein intake might have detrimental effects on the auditory system through its consequences for neural function.

The antioxidant effects of vitamins A, C, and E are known to be of potential benefit to the prevention and treatment of HL, having been studied as components of the regular diet and as dietary supplements.

Vitamin A, in the form of its active metabolite, retinoic acid, is essential for the normal development of the inner ear, in addition to its effects protecting against continued exposure to ambient noise,[51] and preventing infections, especially in malnourished children.[52] High levels of consumption of vitamin C are associated with better levels of hearing in the medium-frequency range; the consumption of beta-carotene, vitamins C and E, as well as magnesium, improves the average PTA response at high frequencies, its protective role being significantly stronger when administered in combination compared with as an isolated intake.[32] Likewise, Gopinath et al. reported that the high level of intake of vitamins A and E was inversely associated with the prevalence of HL,[33] but 5-years longitudinal analysis did not show any association with the incidence of HL. Findings about the effects of vitamin D on hearing presented in previous reports are not consistent.

High serum vitamin D concentration was associated with worse hearing at high frequencies.[34] These results

Table 2 Summary of main results and conclusions.

Nutrient type	Dietary factor evaluated	Association with hearing loss
Macronutrients	Carbohydrates	↓ Gopinath et al. (2010)[24]
		↔ Kim et al. (2015)[28]
		↔ Rosenhall et al. (2015)[30]
		↑ Spankovich et al. (2011)[31]
	Cereal fiber	↑ Gopinath et al. (2010)[24]
	Cholesterol	↓ Gopinath et al. (2011)[26]
		↓ Spankovich et al. (2011)[31]
	Fats	↔ Croll et al. (2019)[22]
		↓ Gopinath et al. (2011)[26]
		↓ Kim et al. (2015)[28]
	Fish	↑ Gopinath et al. (2010)[25]
		↔ Rosenhall et al. (2015)[30]
	Healthy dietary pattern	↑ Gallagher et al. (2019)[41]
		↑ Spankovich & Le Prell (2013)[23]
	Higher mean glycemic index diet	↓ Gopinath et al. (2011)[26]
	Meat	↔ Péneau et al. (2013)[29]
	Omega-3 PUFA	↑ Gopinath et al. (2010)[24]
	Protein	↔ Kim et al. (2015)[27]
	Sugar	↔ Croll et al. (2019)[22]
		↓ Gopinath et al. (2010)[24]
Micronutrients	Total diet score	↓ Gopinath et al. (2014)[27]
	Traditional dietary pattern	↓ Gallagher et al. (2019)[41]
	Beta-carotenes	↑ Choi et al. (2014)[32]
	Carotenoids	↑ Kang et al.(2014)[34]
	Lycopene	↑ Spankovich et al. (2011)[31]
	Folate	↑ Shargorodsky et al. (2010)[13]
	Magnesium	↑ Choi et al. (2014)[32]
		↑ Spankovich et al. (2011)[31]
	Niacin	↑ Kang et al. (2014)[34]
		↑ Kim et al. (2019)[35]
	Potassium	↑ Jung et al. (2019)[36]
	Riboflavin	↑ Kang et al. (2014)[34]
		↑ Kim et al. (2019)[35]
		↑ Spankovich et al. (2011)[31]
	Vitamin A/retinol	↔ Gopinath et al. (2014)[33]
		↑ Kang et al. (2014)[34]
		↔ Kim et al. (2019)[35]
		↓ Spankovich et al. (2011)[31]
	Vitamin B_{12}	↔ Péneau et al. (2013)[29]
	Vitamin C	↑ Choi et al. (2014)[32]
		↑ Kang et al. (2014)[34]
		↑ Spankovich et al. (2011)[31]
	Vitamin D	↓ Kang et al. (2014)[34]
	Vitamin E	↔ Gopinath et al. (2014)[33]
		↑ Spankovich et al. (2011)[31]
Other	Chocolate	↑ Lee et al. (2019)[39]
	Coffee	↑ Lee et al. (2018)[38]
		↑ Vuckovic et al. (2013)[40]
	Tea	↔ Hwang et al. (2012)[37]

↑ Negative association (protective factor); ↓ positive association (risk factor); ↔ equivocal association (pros and cons).

have been reported in an animal model in which a vitamin D-deficient diet was able to prevent hearing loss in mice with hypervitaminosis D.[53] Ahigh prevalence of vitamin D deficiency or insufficiency has been reported in patients with hearing problems.[54] On the other hand, the deficit of vitamin B_{12} and folic acid (B_9), especially in older age, is associated with an increase in serum homocysteine (Hcy) concentrations, which have a detrimental effect on blood flow at the cochlear level.[55] Serum vitamin $B_{12}$is not significantly associated with hearing loss, but people with moderate levels of B_9 have 32% lower odds of experiencing HL at lower frequencies

Table 3 Levels of evidence and Newcastle–Ottawa Scale scores for observational studies.

Study	Design	Level of evidence	Newcastle–Ottawa scale								
			Selection				Comparability	Exposure/outcome			Total Score
			1	2	3	4	1	1	2	3	
Choi et al. (2014)[32]	Cross-sectional[a]	III	★	★	★	★★	★★	★★	★		10
Croll et al. (2019)[22]	Cohort[b]	III	★	★	★	★	★★	★	★	★	9
Gallagher et al. (2019)[41]	Cohort	III	★	★	★	★	★★	★	★	★	9
Gopinath et al. (2010)[25]	Cohort	III	★	★	★	★	★★	★	★	★	9
Gopinath et al. (2010)[24]	Cohort	III	★	★	★	★	★★	★	★	★	9
Gopinath et al. (2011)[26]	Cohort	III	★	★	★	★	★★	★	★	★	9
Gopinath et al. (2011)[33]	Cohort	III	★	★	★	★	★★	★	★	★	9
Gopinath et al. (2014)[27]	Cohort	III	★	★	★	★	★★	★	★	★	9
Hwang et al. (2012)[37]	Cohort	III			★	★	★★	★	★	★	7
Jung et al. (2019)[36]	Cross-sectional	III	★	★	★	★★	★★	★★	★		10
Kang et al. (2014)[34]	Cross-sectional	III	★	★	★	★	★★	★★	★		9
Kim et al. (2015)[28]	Cross-sectional	III	★	★	★	★	★★	★★	★		9
Kim et al. (2019)[35]	Cross-sectional	III	★	★	★	★	★★	★★	★		9
Lee et al. (2018)[38]	Cross-sectional	III	★	★	★	★★	★★	★★	★		10
Lee et al. (2019)[39]	Cross-sectional	III	★	★	★	★★	★★	★★	★		10
Péneau et al. (2013)[29]	Cohort	III	★	★	★	★	★★	★	★	★	10
Rosenhall et al. (2015)[30]	Cross-sectional	III	★	★	★	★★	★	★★	★		10
Shargorodsky et al. (2010)[13]	Cohort	III	★	★	★	★	★★		★	★	8
Spankovich et al. (2011)[31]	Cross-sectional	III	★	★	★	★★	★★	★★	★		10
Spankovich & Le Prell (2013)[23]	Cross-sectional	III	★	★	★	★★	★★	★★	★		10
Spankovich & Le Prell (2014)[15]	Cross-sectional	III	★	★	★	★★	★★	★★	★		10
Vuckovic et al. (2013)[40]	Cross-sectional	III	★	★	★	★	★★	★★	★		9

[a] Cross-sectional studies (modified Newcastle–Ottawa Scale[21]): Selection (maximum ★★★★★): 1) representativeness of the sample, 2) sample size, 3) non-respondents, 4) ascertainment of the exposure (risk factor). Comparability (maximum ★★): 1) the subjects in different outcome groups are comparable, based on the study design or analysis. Confounding factors are controlled. Outcome (maximum ★★★): 1) assessment of outcome; 2) statistical test.

[b] Cohort studies: Selection (maximum ★★★★): 1) representativeness of the exposed cohort, 2) selection of the non-exposed cohort, 3) ascertainment of exposure, 4) demonstration that outcome of interest was not present at start of study. Comparability (maximum ★★): 1) comparability of cohorts on the basis of the design or analysis. Outcome (maximum ★★★): 1) assessment of outcome, 2) follow-up was long enough for outcomes to occur, 3) adequacy of cohort follow-up.

(0.5–4.0 kHz).[56] Finally, vitamin C supplementation significantly decreases the permanent hearing threshold, while its deficiency has no effect on HL.[57]

Limitations

The most important limitation of the data is their heterogeneity across studies with respect to dietary factors, study design, and outcomes of interest. This makes it impossible to determine the true relationship between nutrition and HL. In addition, most studies have examined the role of each nutrient in isolation, without taking into account the overall intake. Thus, the limited and sometimes contradictory results make it important to carry out further research into this matter.

Conclusions

This scoping review leads us to conclude that diets rich in saturated fats and cholesterol have clearly detrimental effects in relation to the development of HL. This damage can be prevented by restricting their consumption, and by increasing that of vegetables and fruits, polyunsaturated fatty acids (omega-3), and of anti-oxidants in the form of vitamins A, C, and E, which have a protective effect against HL, especially in older people.

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Conception and design of study: L. Rodrigo, H. Olmedillas; Acquisition of data: L. Rodrigo, M.A. Rodríguez, H. Olmedillas; Analysis and/or interpretation of data: L. Rodrigo, H. Olmedillas, C. Campos-Asensio, I. Crespo; Drafting the manuscript: L. Rodrigo, H. Olmedillas, M.A. Rodríguez; Revising the manuscript critically for important intellectual content: C. Campos-Asensio, I. Crespo.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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Appendix A. Supplementary data

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