



Tinnitus and mobile phone use

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ABSTRACT

Objectives The mechanisms that produce tinnitus are not fully understood. While tinnitus can be associated with diseases and disorders of the ear, retrocochlear diseases and vascular pathologies, there are few known risk factors for tinnitus apart from these conditions. There is anecdotal evidence of an link between mobile phone use and tinnitus, but so far there have been no systematic investigations into this possible association.

Methods 100 consecutive patients presenting with tinnitus were enrolled in an individually matched case–control study. For each case a control subject was randomly selected from visiting outpatients matched for sex and age. The patient's history was obtained and clinical examinations were conducted to exclude patients with known underlying causes of tinnitus. Mobile phone use was assessed based on the Interphone Study protocol. ORs were computed by conditional logistic regression with years of education and living in an urban area as covariates.

Results Mobile phone use up to the index date (onset of tinnitus) on the same side as the tinnitus did not have significantly elevated ORs for regular use and intensity or for cumulative hours of use. The risk estimate was significantly elevated for prolonged use (≥ 4 years) of a mobile phone (OR 1.95; CI 1.00 to 3.80).

Conclusions Mobile phone use should be included in future investigations as a potential risk factor for developing tinnitus.

INTRODUCTION

Subjective tinnitus (tinnitus aurium) is defined as a sound sensation that cannot be attributed to an external sound source. It may be a symptom of various diseases. The mechanisms that produce tinnitus are not fully known and are associated with nearly all diseases and disorders of the middle and inner ear and retrocochlear diseases, as well as head trauma and environmental and occupational hearing loss.¹ There are different hypotheses for the various pathophysiological aspects of tinnitus.² Tinnitus seems to be generated predominantly in the primary afferent synapses of the cochlea^{3 4} but leads to cortical reorganisation.⁴ Tinnitus is experienced by patients either uni- or bilaterally as a sound in the ear/head of varying quality (eg, roaring, hissing, ringing) and it may have a pulsatile or non-pulsatile character, the former possibly being due to vascular pathology.

Tinnitus is usually intermittent and sometimes associated with specific conditions such as listening to loud music, fever, the use of certain drugs like aspirin or quinine, or transient perturbations of the middle ear, and subsides in a few seconds to a few days. Studies indicate that 10–15% of adults have

What this paper adds

- ▶ The prevalence of chronic tinnitus is increasing.
- ▶ Noise-induced hearing loss, head trauma and ototoxic drugs are known to increase the risk of tinnitus, but the aetiology in a significant proportion of patients remains unknown.
- ▶ High intensity and long duration of mobile phone use are possibly associated with the development of tinnitus.
- ▶ Because tinnitus affects quality of life and current therapeutic interventions have limited effectiveness, assessment of potential risk factors and their prevention should be a public health priority.

chronic tinnitus.^{5–7} Prevalence increases with advancing age.¹

Tinnitus severely affects the quality of life of 1–3% of the general population, causing sleep disturbance, work impairment and psychological distress.⁸

Tinnitus is more common in the elderly but occurs in all age groups. It may become more prevalent in the future as a direct consequence of increased recreational noise-induced hearing loss (eg, from loud music) combined with longer life spans.

Tinnitus treatment is problematic, and evidence-based therapeutic interventions are rare. As only a few interventions that effectively reduce tinnitus loudness and annoyance are available,^{9 10} it is important to focus research on possible risk factors and prevention.

The last few years have seen the development of extensive mobile phone use, such that the most people in developed countries regularly use these phones. There are concerns that exposure to electromagnetic fields from mobile telecommunication devices could be a risk factor for tinnitus.¹¹ However, up to now there have been no systematic investigations of this problem. Due to the high microwave energy that is absorbed in the cochlea and along the auditory pathway during mobile phone use^{12 13} there is, theoretically, a possibility that prolonged exposure alters the dynamics of the system, thereby increasing the risk of tinnitus.

Our study was designed to examine whether mobile phone use increases the risk of tinnitus.

MATERIALS AND METHODS

Study design and participants

The study was carried out as a hospital-based case–control study at the Ear-Nose-Throat (ENT) Department of the Medical University of Vienna,

Austria. Patients with acute and chronic tinnitus (aged between 16 and 80 years) were enrolled consecutively over 1 year as they presented at the outpatient unit. About half of the patients (47 of those finally included) were enrolled at their first visit to the ENT outpatient unit. The remaining patients were enrolled during the course of their diagnostic visits. For each case a matched control was selected from the same department, of the same age group (± 2.5 years for those <55 years; ± 5 years for those >55 years), the same gender and ethnic group and within 3 weeks after enrolment of the respective patient. Cases were defined as patients suffering from sound sensations not attributable to external sources and presenting at the ENT outpatient unit after November 2003 (until the projected number of cases was reached in November 2004). Chronic tinnitus was defined as tinnitus lasting for longer than 3 months. Tinnitus onset was the date of the first occurrence of this sound sensation. Exclusion criteria were diseases of the middle ear, post middle ear surgery status, retrocochlear disease, severe psychiatric and systemic diseases and medication with drugs that can influence tinnitus (ototoxic or psychopharmacological drugs). Furthermore, patients were excluded for whom an underlying disease (eg, hypertension, noise-induced hearing loss) could be established after completion of the diagnostic tests. Controls were patients without any concomitant condition related to tinnitus and were selected randomly from the daily lists of outpatients attending the ENT department for various reasons (phoniatic patients without speech disorders and without myognathic problems ($n=44$), acute laryngitis ($n=29$), diagnostic clarification prior to tonsillectomy ($n=22$), acute pharyngitis ($n=5$)). Participants gave written informed consent. Overall, 11 patients refused to participate (four cases and seven controls).

Diagnostics/investigation procedure

The diagnostic test battery for the selection of patients consisted of the following:

- ▶ the taking of a patient history with special regard to tinnitus and its risk factors
- ▶ clinical ENT examination with otomicroscopy
- ▶ pure-tone (125 Hz to 8 kHz) and speech audiogram
- ▶ tympanogram and testing of the stapedius reflex
- ▶ subjective rating of the tinnitus
- ▶ tinnitus matching
- ▶ MRI (if indicated, to exclude retrocochlear pathology).

Each enrolled case received a standardised questionnaire (Structured Tinnitus Interview, STI).¹⁴ Items refer to the central characteristics of tinnitus history, aetiological factors and tinnitus-related psychological complaints. In addition, a medical interview was conducted. The patient's history and a clinical examination for possible underlying causes of tinnitus were obtained by usual clinical procedures. For each patient a case report form was compiled and maintained according to good clinical practice guidelines.

Pure-tone and speech audiometry (Clinical Audiometer AC 40, Interacoustics, Assens, Denmark) were performed and a thorough inquiry into hearing history conducted to exclude tinnitus related to sensorineural hearing loss (deviation from age specific levels of more than -10 dB in any frequency), sudden deafness and Ménière's disease. Tympanometry and stapedius reflex measurements (Impedance Audiometer AZ 26, Interacoustics) were carried out to exclude tinnitus related to conductive hearing loss. If retrocochlear hearing loss was suspected, cranial MRI was applied.

For the evaluation of tinnitus, tinnitus matching as a psychoacoustic measurement of tinnitus was carried out. The

audiometric tinnitus simulation test determined the character (pure-tone, narrow and wide band), frequency and intensity of the tinnitus. Tinnitus matching was performed contralaterally.

With the help of this procedure, tinnitus subtypes (especially temporo-mandibular joint dysfunction-related tinnitus, cervical tinnitus, acute tinnitus/sudden deafness/noise trauma, suspected cochlear-synaptic tinnitus) could be identified. This information was used to exclude patients with known underlying pathologies (11 of the 58 eligible patients enrolled at their first visit were excluded).

For exploration of mobile phone habits, we used a standardised questionnaire (based on the protocol of the WHO Interphone Study¹⁵). The original Interphone Study protocol consists of a computer assisted personal interview. However, preliminary assessment revealed that following this procedure is associated with a number of shortcomings, in particular, problems keeping track of the use of different mobile phones that are assessed one after another. Therefore, we decided to present the questionnaire on paper to allow participants examine questions before answering them and also review their answers.

In short, for each mobile phone the participant used or had used in the past, the type of phone, duration and intensity of use, side of the head the phone was predominantly held, use of hands-free devices, and use in urban/rural areas and in cars were assessed.

Except for the STI and clinical tinnitus investigations, the same procedure was followed for controls including audiometric examination.

Statistical methods

Data on mobile phone use were censored at the date of first occurrence of tinnitus. The index date for controls was that of the first occurrence of tinnitus in the matched case. Intensity of use, cumulative number and duration of calls were categorised based on the distribution of these variables in controls; the median (excluding never users) was chosen as cut-off. Reference category was never use of a mobile phone (prior to the index date) for intensity of use and never use or use for less than 1 year for duration of use. The latter categorisation was chosen for comparison with data on duration of use obtained in studies on tumours of the head. In all cases data on mobile phone use were adjusted for the use of hands-free devices (ie, only a fraction of exposure duration or intensity while not using hands-free devices was counted). Further adjustments were applied for the side of the head of predominant use. For laterality analysis, mobile phone use was categorised according to whether it occurred on the same side (ipsilateral use) of the head as the tinnitus (controls were assigned the side of the matched case) or the opposite side (contralateral use). This was accomplished by weighting exposure on the side of the tinnitus or the opposite side by the fraction of use on this side ranging from 0% to 100% (for never to always using the phone on the side of the tinnitus or the opposite side, respectively). For years of mobile phone use the predominant side of use was chosen for laterality analysis except for those using the mobile phone equally on both sides who were assigned to both ipsilateral and contralateral user categories. In addition, the same analyses were carried out (using the same categories) without considering laterality but only adjusting for the use of hands-free devices. Each indicator of mobile phone use was entered independently into the regression model. Conditional logistic regression analyses for individually matched data were used to estimate ORs and 95% CIs. All analyses were adjusted for years of education (less than and 12 years or more) and living in an urban area. These adjustments

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were introduced because mobile phone use has been shown to correlate with socio-economic status and area of living is associated with intensity of exposure because, on average, the output power of mobile phones is higher in rural areas. Further analyses were conducted stratified according to severity of tinnitus and whether tinnitus onset was sudden or gradual.

RESULTS

Participant characteristics were comparable in cases and controls (table 1). Gender and age were in agreement because they were used for matching, but also other personal characteristics did not differ significantly between cases and controls. There was a slight tendency for a somewhat higher socio-economic status in controls, implied by higher education and a higher rate of white collar workers and urban residents.

The characteristics of tinnitus are shown in table 2. Tinnitus was more often unilateral on the left side (38%). Tinnitus was described as being distressful most of the time in 38% of patients and not distressful in only 26%. Vertigo was reported by 29% of patients.

Almost all participants at the time of inquiry used a mobile phone (92% and 93% for cases and controls, respectively); however, at the time of the first occurrence of tinnitus (and the respective index date in controls) only 84% of cases and 78% of controls were using a mobile phone. Another 17% of cases and 12% of controls had used a mobile phone at that time for less than 1 year. Considering mobile phone use at the same side as the tinnitus, ever users prior to the occurrence of tinnitus had a moderately but not significantly increased OR of 1.37 (95% CI 0.73 to 2.57). Moderate increases in ORs were noted for all indicators of intensity of use: average daily duration of use for 10 min or more was associated with an OR of 1.71 (95% CI 0.85 to 3.45), cumulative hours of use of 160 or more gave an OR of 1.57 (95% CI 0.78 to 3.19), and cumulative number of calls in excess of 4000 an OR of 1.28, which was less than the OR for a lower number of calls (OR 1.46), possibly indicating a greater importance of duration as compared to number of calls but maybe also differences in amount of misclassification. A significant result was obtained for duration of use of 4 or more years: OR 1.95 (95% CI 1.00 to 3.80). Test for trend of duration of use was also significant

Table 1 Demographic characteristics of cases and controls*

	Cases	Controls	p Value
Gender			
Male	54	54	
Female	46	46	
Age (mean SD)	42.5±14.4	42.5±14.5	
Partner			
With	66	69	0.742
Without	28	28	
Education			
<12 years	36	29	0.371
≥12 years	63	69	
Occupation			
Unemployed	6	6	0.624
Retired	16	16	
In education	15	10	
Blue collar	9	10	
White collar	48	53	
City resident			
Yes	70	76	0.361
No	23	18	

*Some percentages do not add up to 100 because of missing values.
p Values are for comparison of non-matching variables.

Table 2 Tinnitus characteristics (n=100 patients)

	Cases
Location of tinnitus	
Right side	27
Left side	38
Both sides	35
Time since onset of tinnitus	
< 1 month	45
1–6 months	22
7–12 months	9
>1 year	24
Onset of tinnitus	
Suddenly	48
Gradually	52
Tinnitus distressing	
Most of the time	38
Sometimes	36
Not distressing	26
Vertigo	29
Stress score (>half of maximum)	27
Social effects score (>half of maximum)	7
Hearing problems score (>half of maximum)	11

($p=0.046$). Changing reference to never users increased the OR to 2.58 (95% CI 1.08 to 6.19). Stratification according to subjective severity of tinnitus and whether the onset of tinnitus was sudden or gradual did not affect these results.

For contralateral use, ORs were generally smaller except for the higher categories of average and cumulative duration of use.

Without considering laterality (ie, the side of mobile phone use in relation to the side of the occurrence of tinnitus), intensity and duration of use showed estimates of relative risks above one but none reached significance (table 3).

DISCUSSION

The prevalence of tinnitus has increased over the past decade and is currently 10–15% in industrialised countries.⁶ The rise in incidence may be due to better diagnostic tools and increased awareness of the disease; however, a number of environmental factors may increase the risk of tinnitus, with noise being the most important. Electromagnetic fields emitted by hand-held cellular phones are suspected of increasing the risk of tinnitus.

As most people use mobile phones more or less intensively, there is concern about possible effects on health.^{16–18} Practitioners are confronted with reports of tinnitus related to mobile phone use by their patients.¹⁹

We focused on ipsilateral mobile phone use because microwave energy is predominantly (97–99%) absorbed at the side of the head to which the phone is held during calls.²⁰ However, only a small fraction of participants used the phone exclusively on one side of their head. Hence, for most users indicators of intensity of use were divided into ipsi- and contralateral fractions. Therefore, slightly higher ORs for average and cumulative duration of contralateral use could be because high values of contralateral use may be a mixture of high contralateral and very high ipsilateral use.

In our study increases in risk for ipsilateral use were noted for all variables of intensity of use, but only duration of use of 4 or more years prior to tinnitus onset was statistically significant. As the study was designed to detect a 2.5-fold increase in risk with 80% power,²¹ sensitivity was lower for less pronounced risks.

Assessing mobile phone use retrospectively is associated with potential bias. Recent validation studies in volunteers comparing

Table 3 Mobile phone use and risk of tinnitus estimated by conditional logistic regression

	Ipsilateral*				Contralateral†				Overall‡		
	No. of cases/controls	OR	95% CI		No. of cases/controls	OR	95% CI		No. of cases/controls	OR	95% CI
Mobile phone use											
Never	27/33	1.00		26/31	1.00			16/22	1.00		
Ever	73/67	1.37	0.73 to 2.57	74/69	1.31	0.65 to 2.44		84/78	1.86	0.74 to 4.65	
Average duration											
Never	27/33	1.00		26/31	1.00			16/22	1.00		
<10 min/day	30/34	1.02	0.48 to 2.16	33/42	0.93	0.43 to 2.00		42/46	1.57	0.59 to 4.22	
≥10 min/day	43/33	1.71	0.85 to 3.45	41/27	2.03	0.91 to 4.51		42/32	2.65	0.95 to 7.35	
Cumulative hours of use											
Never	27/33	1.00		26/31	1.00			16/22	1.00		
<160 h	31/34	1.17	0.56 to 2.42	34/36	1.16	0.55 to 2.47		29/31	1.60	0.61 to 4.22	
≥160 h	42/33	1.57	0.78 to 3.19	40/33	1.61	0.72 to 3.62		55/47	2.25	0.82 to 6.16	
Cumulative number of calls											
Never	27/33	1.00		26/31	1.00			16/22	1.00		
<4000 calls	37/33	1.46	0.71 to 3.00	41/37	1.37	0.66 to 2.84		32/28	1.93	0.72 to 5.20	
≥4000 calls	36/34	1.28	0.62 to 2.63	33/32	1.27	0.58 to 2.83		52/50	1.80	0.69 to 4.72	
Years of mobile phone use											
Never, <1	34/41	1.00		36/37	1.00			33/34	1.00		
1–3	33/36	1.23	0.61 to 2.47	39/35	1.17	0.56 to 2.47		18/25	0.76	0.35 to 1.68	
≥4	33/23	1.95	1.00 to 3.80	25/28	0.91	0.39 to 2.09		49/41	1.26	0.63 to 2.50	

Age and gender are matching variables; years of education and living in an urban area are included as covariates in analyses.

*Mobile phone use only counted if it occurred on the same side of the head where tinnitus later developed.

†Mobile phone use on the opposite side of the head from where tinnitus later developed.

‡Every use of a mobile phone prior to onset of tinnitus (or reference date in controls) is counted.

self-reported use with records from network operators show moderate agreement, but it is likely that agreement is worse for mobile phone use further in the past.²² People tended to underestimate the number of calls per month, whereas duration of calls was overestimated. Furthermore, underestimation was more likely in light users and overestimation in heavy users. Substantial random error in measurement of the number and duration of calls leads to underestimation of the risk. It has been shown that this is even the case in the presence of moderate amounts of differential recall bias.²³ Further analysis of recall bias²⁴ confirmed a tendency for increasing bias for earlier periods of mobile phone use, but no indication of differential bias was found. Greater overestimation of duration of use for periods more distant in the past in cases compared to controls was not only limited to one country (Italy) but may specifically be attributed to memory problems in brain tumour patients after surgery.

We observed a strong correlation between the different indicators of intensity of use (Spearman correlation coefficients between 0.83 and 0.96), while the correlation with duration of use was noticeably smaller (between 0.52 and 0.71). Differences in correlation coefficients between cases and controls were negligible, with a maximum difference of 0.04, indicating similar patterns of recall.

Among the data collected on mobile phone use, date of first use seems to be less affected by recall error, and so results for duration of mobile phone use should not cause underestimation of true risk.

Another possible bias is introduced due to the different types of mobile phones used in the past and differences in usage patterns that influence output power (eg, using a phone in cars or other vehicles could be associated with higher exposure). Although it has been assumed that area of use and using a phone in a car has a strong impact on exposure, it has been shown by software modified phones recording output power that this is not necessarily the case.²⁵ On the other hand, studies in the USA and Sweden found distinct differences in output power between

regions, but this only accounted for a small proportion of the variance.^{26–27} Morrissey²⁸ demonstrated high variability (up to two to three orders of magnitude) of output power within individuals and within the same area. Comparison of power output between different countries reveals that mobile phones operate for a much longer time at maximum power than previously assumed, except for Sweden, where output power distribution more closely follows textbook behaviour.

The number of confounders that could be assessed was limited in this study. Living in an urban area and years of education as a proxy for socio-economic status were included in the model but did not affect risk estimates. Another possible confounder could be hearing impairment induced by loud music (eg, by using portable players). Usage of such devices could be correlated to mobile phone use and also to risk of tinnitus. However, hearing was assessed by pure tone and speech audiometry, and patients with impairments were excluded.

Selection bias does not explain the obtained results because refusal was negligible (only four cases and seven controls refused).

Considering all potential biases and confounders, it is unlikely that the increased risk of tinnitus from prolonged mobile phone use obtained in this study is spurious. Because of the high prevalence of tinnitus and the widespread use of mobile phones, even a slightly increased risk would be of public health importance.

From a theoretical point of view this possible association of mobile phone use and tinnitus is plausible, because the cochlea and the auditory pathway are located in an anatomical region where a considerable amount of the power emitted by mobile phones is absorbed.^{12–13} Calcium imbalance in the neural acoustic pathway and also activation of nitric oxide synthase could be factors in tinnitus aetiology.²⁹ It is well known that exposure to modulated high-frequency electromagnetic fields has the potential to affect calcium homeostasis, especially in neural tissue.³⁰ Effects on nitric oxide levels in tissues exposed to mobile phone radiation have been observed that could be due to activation of nitric oxide synthase.³¹

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Although there is a plausible mechanism of action to explain mobile phone radiation-induced tinnitus, other aetiological pathways are possible. For example, it may be that prolonged constrained posture while using a mobile phone during walking, affects blood flow at the side of mobile phone use causing adaptive local vascular responses that could lead to tinnitus in mobile phone users. Furthermore, there are indications that crossmodal interactions (eg, due to oral facial manoeuvres) and cranio-cervical manipulations of the head, neck or extremities could affect tinnitus either as aetiological factors or conditions that are related to maintaining the phantom sound sensation.³²

Earlier studies on non-mobile phone radio operators revealed an increased incidence of tinnitus that was, however, related to hazardous noise levels.³³ Recently, an increased risk of tinnitus was reported in call centre operators who experience high job strain.³⁴ Although headsets have typically a limiter ensuring sound above a set level is not transmitted, in a noisy environment operators tend to tune the headphones to the limit thereby increasing the risk of noise-induced hearing impairment and, consequently, of tinnitus. We have excluded patients with a history of sudden or intermittent deafness or a deviation from age-specific hearing thresholds of more than 10 dB in any audiogram frequency. Therefore, the reported association of tinnitus with mobile phone use is unlikely a noise-induced phenomenon as in studies of radio and call centre operators.

Tinnitus strongly interferes with the daily lives of people. There are very few interventions available that effectively reduce tinnitus loudness and annoyance. Therefore, all measures should be taken to avoid any further increase in tinnitus prevalence.

Our results indicate that high intensity and long duration of mobile phone use might be associated with tinnitus. This possibility should be explored further by assessing mobile phone usage history in studies of tinnitus aetiology in the future.

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