Bioelectromagnetics

WILEY | BioEM

RESEARCH ARTICLE

Brain Tumor and Mobile Phone Risk Among Young People: Analysis of Japanese People Using the MOBI-Kids International Case-Control Study

Noriko Kojimahara[1] | Kosuke Kiyohara[2,3] | Yasuto Sato[1,3] | Kanako Wake[4] | Masao Taki[4,5] | Gemma Castano-Vinyals[6,7,8] | Naohito Yamaguchi[9] | The Study Group of MOBI-Kids Japan

[1]Graduate School of Public Health, Shizuoka Graduate University of Public Health, Shizuoka, Japan | [2]Department of Food Science, Faculty of Home Economics, Otsuma Women's University, Tokyo, Japan | [3]Department of Public Health, Tokyo Women's Medical University, Tokyo, Japan | [4]National Institute of Information and Communications Technology (NICT), Tokyo, Japan | [5]Department of Computer Science, Tokyo Metropolitan University, Tokyo, Japan | [6]Barcelona Institute for Global Health (IsGlobal), Barcelona, Spain | [7]Universitat Pompeu Fabra (UPF), Barcelona, Spain | [8]CIBER Epidemiología y Salud Pública (CIBERESP), Madrid, Spain | [9]Saiseikai Research Institute of Health Care and Welfare, Tokyo, Japan

Correspondence: Noriko Kojimahara (nkojimahara@s-sph.ac.jp)

Received: 7 March 2025 | **Revised:** 3 September 2025 | **Accepted:** 22 October 2025

Funding: This study was supported by the Japanese Ministry of Internal Affairs and Communications Grant for Research on the Biological Electromagnetic Environment (No. JPMI10001). Funding for the coordination of the MOBI-Kids international study was obtained from the European Community's Seventh Framework Programme under grant agreement numbers 226873 and 603794 and from the Spanish Ministry of Science and Innovation (MINECO). Funding sources had no role in the study design; collection, analysis, and interpretation of data; writing of the report; or decision to submit the article for publication.

Keywords: adolescence | brain tumor | mobile phone | radiofrequency

ABSTRACT

This study investigated the association between mobile phone use and brain tumors in young people aged 10–29 years, specifically within the Japanese population. Building upon the international MOBI-Kids study, this Japanese case-control study included 120 brain tumor patients and 360 controls treated in the Kanto area, broadening the age range and including all primary brain tumors, unlike the international study. The data were evaluated using unconditional logistic regression, both unadjusted and adjusted for age and sex, with respect to the duration and intensity of mobile phone use. The analysis accounted for differences in the output power of various mobile phone generations prevalent in Japan, particularly the high-output 2G PDC system. Despite this rigorous exposure modeling, the study found no increased risk of brain tumors associated with mobile phone use, even when factoring in the weighted power output. The findings align with other recent international studies that also report no causal association. While acknowledging limitations such as potential recall bias and a relatively small sample size for sub-analyses, the study's strengths include its expanded age range and a realistic assessment of Japanese mobile phone usage patterns. Due to the ever-changing exposure conditions from wireless technology, further studies are needed to address their relation to young people's health.

1 | Introduction

In 2011, the International Agency for Research on Cancer of the World Health Organization (WHO) classified radiofrequency electromagnetic fields (RF-EMFs) as "possibly carcinogenic to humans (Group 2B)" owing to the potential carcinogenic risk of developing glioma and acoustic neuroma in adults (Baan et al. 2011; WHO 2024). WHO recommended further examination of the potential effects of RF-EMF on the onset of brain tumors in children. According to the WHO research agenda

Summary

- Our study, focusing on young people in Japan, found no association between brain tumors and mobile phone use, based on a rigorous case-control design expanding the MOBI-Kids international case control study.
- Analysis accounted for mobile phone generation differences, including Japan's high-output 2G PDC system with different phone types and power outputs.

(WHO 2010), an international case-control study involving 14 countries (Australia, Austria, Canada, France, Germany, Greece, India, Israel, Italy, New Zealand, Spain, the Netherlands, Korea, and Japan) was initiated to investigate brain tumor risk as a health effect for children and young people associated with mobile phones (Sadetzki et al. 2014). In the International MOBI-Kids study (Castaño-Vinyals et al. 2022), mobile phone use did not increase the risk of brain tumors among adolescents aged 10–24 years (899 brain tumor patients and 1910 controls). This study considered both RF and extremely low frequency as EMF exposures, and included several validation studies (van Wel et al. 2024; Goedhart et al. 2018; Turner et al. 2019)as well as the patterns (Langer et al. 2017) and trends in mobile phone use (Sato et al. 2016). We previously reported that mobile phone use was not associated with increased odds ratios (OR) in Korean and Japanese case-control study (Kojimahara et al. 2024), involving 118 patients with brain tumors and 236 matched controls. Out of 66 Japanese brain tumor cases aged ≤ 24 years, 36 midline brain tumors were not included in the original MOBI-Kids international study.

Figure 1 shows the number of mobile phone contracts and generations in Japan before and during the study period. In the late 1980s, automobile shoulder phones were introduced in Japan, followed by first-generation mobile phones (1G, analog) in 1988. In 1993, personal digital cellular (PDC), a Japanese digital second-generation (2G) mobile communication system similar to the Global System for Mobile Communications (GSM), became widely used in Japan. In 1998, cdmaOne (2.5G), Faster Code Division Multiple Access (cdma) than PDC, was introduced and used for approximately 5 years as a bridge to the next generation. In 2001, W-CDMA, a third-generation mobile communication system (3G) was launched, and in 2012, the 2G service ended in Japan, and a long-term evolution system (LTE, 3.9–4G) was launched. Of the 218 million mobile phone contracts in 2023, LTE had 120.88 million and 5G mobile phones had 86.51 million (Ministry for Internal Affairs and Communication of Japan 2024). However, few studies have focused on the health effects of mobile phone use in the Japanese population.

This study aimed to adopt a modified exposure assessment using weights that account for the average output power of the mobile phone generations devices in the actual environment while utilizing the differences in output among various generations used in Japan. The incidence rate of total brain tumors per population in 2023 was 4.5 cases (5.0 cases in men and 4.1 cases in women) (per 100,000 population), and the incidence rate among young people is approximately half of that (Foundation for Promotion of Cancer Research 2025). No change has been noted since the introduction of mobile phones in Japan. In contrast, in Northern Europe, where mobile phones have been widely used for the longest time, it has been reported that the age-adjusted death rate for brain tumors has increased since 2007 (Hardell and Carlberg 2017). However, Deltour et al. (2022) reported no changes in glioma incidence rates from mobile phone use published incidence rates in Nordic countries.

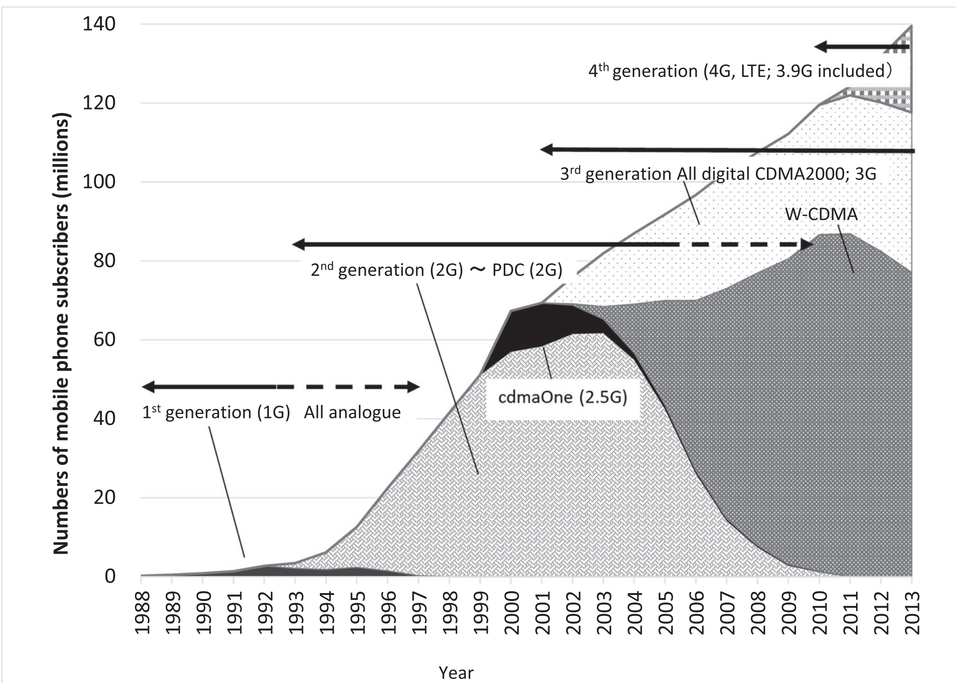

FIGURE 1 | Trends in the number of mobile phone contracts in Japan before and during research period. 2G: second-generation; 3G: third-generation; CDMA: code division multiple access; LTE: long-term evolution; PDC: personal digital cellular; W-CDMA: wideband code division multiple access.

2 | Materials and Methods

2.1 | Study Design and Population

The MOBI-Kids international study assessed the association between mobile phone use and brain tumors in young people between 2011 and 2015 in 14 countries, as previously described (Castaño-Vinyals et al. 2022). MOBI-Kids Japan is an unmatched case-control study of 120 patients with brain tumors and 360 controls, conducted as a sub-analysis of the MOBI-Kids International matched case-control study (Table 1). Compared to the MOBI-Kids international study, the present MOBI-Kids Japan study used more relaxed inclusion criteria focusing a period when most Japanese used 2G PDC mobile phones. The inclusion criteria for the study were as follows: first, patients were aged 10– 29 years, in contrast to the MOBI-Kids international study (10–24 years). Second, all primary brain tumors were allowed, in contrast to the MOBI-Kids international study, which excluded midline brain tumors such as craniopharyngiomas, or gliomas spread to midlines. Third, participants of MOBI-Kids JAPAN widely included those in residential areas throughout Japan, in contrast to only the Kanto area in the MOBI-Kids international study.

Participants were recruited from pre-registered medical institutions in the Kanto region. The case group included patients with brain tumors from 19 medical institutions, whereas the control group included patients with appendicitis from 14 medical centers. Inpatients and guardians who consented to participate in the study after receiving an explanation from the attending physicians were included. Parental approval was required for the participation of patients aged < 18 years. The Tokyo Women's Medical University Ethics Committee approved this study (No. 2394-R, 2011, revised in 2018). Informed consent was obtained from all the participants and/or their legal guardians. All procedures were performed in accordance with the principles of the Declaration of Helsinki.

2.2 | Questionnaires and Study Instruments

Trained interviewers administered a computer-assisted questionnaire developed by a team that made use of experience from the INTERPHONE study (INTERPHONE Study Group 2010; Takebayashi et al. 2006, 2008). The main questionnaire included demographic variables and histories of mobile phone use, including 2G, 3G, and 4G, as well as Wi-Fi and cordless phone use. Parents reported maternal smoking history and other exposures before conception, during pregnancy, and during delivery. The parental occupational history was recorded. Details of the data collection are provided in Table S1. Clinical questionnaires regarding disease status, surgery, pathology, and imaging, were described in outcome measures section in more details.

2.3 | Exposure Assessment

In accordance with the International MOBI-Kids protocol (Sadetzki et al. 2014), a trained interviewer conducted an approximately 60-min standardized interview with admitted patients. Information such as mobile phone use (2G, 3G, and 4G, other than personal handheld-phone system [PHS]), number of calls and call duration, primary laterality when using mobile phones, use of hands-free devices, and Wi-Fi use were

TABLE 1 | MOBI-Kids Japan protocol compared to the MOBI-Kids international study.

	MOBI-Kids international study	MOBI-Kids Japan
Study design	Case-control study	Unmatched case-control study
	1:2 matched for age, gender, and resident area	Adjusted for age and gender
Cases	$n = 30$ (Japanese)	$n = 120$
-Age	10–24 years	10–29 years
-Pathology	Primary brain tumors, except for midline tumors	All primary brain tumors
-Area	Kanto area	Residence in Japan of people who received treatment in the Kanto area
Controls	$n = 224$ (Japanese)	$n = 360$
-Age	10–24 years	10–29 years
-Conditions	Appendicitis inpatients	Appendicitis inpatients
-Area	Kanto area	Individuals residing in Japan who received treatment in the Kanto area
Exposure	CSE from mobile phones* from RF and EMF classified by phone model CSE from Cordless phone (DECT)	Mobile phone use (duration and number of calls) weighted by communication system (2G, 3G, and 4G) VoIP use
Analysis	Conditional logistic regression	Unconditional logistic regression

*Electromagnetic field (EMF) and radiofrequency (RF) algorithm that estimates the cumulative specific energy (CSE) in center of gravity (COG) of the brain tumors.
Abbreviation: VoIP, voice over Internet protocol.

collected from the patients and/or guardians. Simultaneously, data on socioeconomic status (SES), mobile phone use, history of exposure during pregnancy, and occupation were collected from the parents using self-administered questionnaires.

In the INTERPHONE study (INTERPHONE Study Group 2010), the output power of GSM phones with software-modified phones was highly variable (Vrijheid et al. 2009). However, Iyare et al. (2021), and van Wel et al. (2021) reported that mobile phones with newer technology (3G–4G) have substantially lower average output power. The significant difference in output power between PDC and other communication systems cannot be ignored in the exposure assessments. Therefore, a weighting factor that considers the output power was introduced for mobile phone use. The output power in a real environment is highly variable owing to the adaptive power control (APC) of each communication system. The weights were obtained by multiplying the maximum peak power by the estimated ratio of average to maximum power (Kojimahara et al. 2024). Table 2 shows the lists the weights of the different communication systems, LTE was weighted at 2, and PDC was weighted at 135, CMDA and WCDMA were weighted at 1. It should be noted that the weight of the PDC is much higher than that of other communication systems.

PDC has been widely used in Japan as 2G instead of the globally adopted GSM. As shown in Figure 1, cdmaOne was adopted for a very short period of 2.5G by a Japanese telecommunications company. Therefore, cdmaOne phones were classified as 2G phones in this study, considering the small number of users and difficulty in distinguishing from PDC based on the responses to the questionnaire.

Exposures from both digitally enhanced cordless telecommunications (DECT), one of the communication types of cordless phones and headset use were not assessed in this study because they were rarely used: only one participant acknowledged DECT use, and only three used headsets for more than half of their mobile phone use. Furthermore, phone model classification was not considered in this study, even though the MOBI-Kids international study considered phone model classification based on the location and shape of the antenna (Lee et al. 2016). The MOBI-Kids validation study (Goedhart et al. 2018) reported that laterality was poorly recalled; thus, the risk analysis of the study did not take into account self-reported laterality, similar to how the MOBI-Kids international study handled it.

2.4 | Outcome Measures

Classification based on the International Classification of Diseases for Oncology (Louis et al. 2021), as well as clinical information, such as tumor location, occasion for tumor discovery, and subjective symptoms, were collected from neurosurgeons at the contracted medical institutions to accurately determine the onset time of brain tumors and to establish a 1-year lead time. MOBI-Kids Japan included midline glioma and other pathological tumors that met the exclusion criteria in addition to the inclusion criteria of the MOBI-Kids international study, as shown in Table S2 (Zumel-Marne et al. 2020). In the International MOBI-Kids study, histopathological and imaging diagnoses were randomly evaluated by neuroradiologists and pathologists, respectively.

2.5 | Statistical Analysis

"Regular use" of mobile phones and Wi-Fi was defined as "at least once a week for three consecutive months or longer." Mobile phone use, cumulative years of use, cumulative number of calls, and cumulative call duration until 1 year before the diagnosis date were calculated and weighted by mobile phone generation and Voice over Internet Protocol (VoIP). The association between each factor and the risk of brain tumor morbidity was determined using unconditional logistic regression analysis. Mobile phone users in the appendicitis group were divided into tertiles based on their exposure. Subsequently, the mobile phone users in the brain tumor group were assigned to the corresponding exposure index groups, which, along with the mobile phone non-user group, were utilized as categories in the analysis to calculate the p for trends. Adjustment variables were age (continuous), sex (male and female), residential area (Kanto area and all over Japan except Kanto area), and mother's education as SES. All analyses were performed using IBM SPSS Statistics for Windows, Version 23.0. (Armonk, NY). The t-test and χ^2 test were used to determine the differences in the means of the continuous and categorical variables, respectively.

TABLE 2 | Estimation of weights applied to intensity of use data for mobile phones types in MOBI-Kids Japan study (Kojimahara et al. 2024).

Network	Generation or communication system	Service period	Peak output power (mW)	APC–Tx power ratio (avg./max.)	Weights applied to intensity of use data
CDMA2000	3G	2000–2012	200	0.005	1
WCDMA	3G	2004	250	0.005	1
LTE	4G	2014	200	0.01	2
PDC	2G	1993–2012	800	0.5	135*
CdmaOne	2.5G	1998–2005	200	0.005	1
VoIP	NA	2000	NA	NA	1

*PDC is a 3-slot TDMA system that transmits radio wave 1/3 of time. The weight is then $800 \times 0.5/3$.
Abbreviations: CDMA, code division multiple access; LTE, long term evolution; PDC, personal digital cellular; UMTS, Universal Mobile Telephone System; VoIP, voice over Internet protocol.

3 | Results

3.1 | Histology of Brain Tumor Cases

As shown in Table S3 online, MOBI-Kids Japan included 120 cases of brain tumors, 30 of which met the inclusion criteria of the international MOBI-Kids study. It also included cases that could not be matched to controls in the international study, tumors with midline spread, and cases with histologies that were excluded from the international study. The MOBI-Kids Japan study included 47 gliomas, five meningiomas, and two embryonal tumors, as well as 52 cases (43%) of other histories that were not included in the international MOBI-Kids criteria. Fifteen germinomas, 11 craniopharyngiomas, and 26 others were included in these other morphologies.

3.2 | Patient Characteristics

Table 3 shows the characteristics of the 120 patients and 360 appendicitis controls who underwent appendectomy in MOBI-Kids Japan. The participation rate was slightly lower in the appendicitis group (65.9%) than in the brain tumor group (71.9%). Although no significant differences were observed in the proportion of patients by sex or age, the number of patients whose mothers had only a high school education or less, representing SES, was significantly greater in the brain tumor group ($n = 35$, 30.4%) than in the appendicitis group ($n = 57$, 16.6%) ($p = 0.001$). Residential areas were unlikely to affect the results after controlling for regions, and large regional differences were not observed in either the radio wave environment or medical system in Japan. Known risk factors, such as a recent history of allergies (McCarthy et al. 2011), medical radiation

TABLE 3 | Characteristics of participants in the MOBI-Kids Japan study.

	Cases n (%)	Controls n (%)	p value
Participation	120 (71.9)	360 (65.9)	
Age at reference date (years)			
10–14	38 (31.7)	112 (31.1)	0.905
15–19	23 (19.2)	72 (20.0)	
20–24	22 (18.3)	75 (20.8)	
25–29	37 (30.8)	101 (28.1)	
Male	72 (60.0)	199 (55.3)	0.366
Education level of mothers			
High school or less	35 (30.4)	57 (16.6)	0.001
Residential area			
Tokyo	57 (47.5)	323 (89.7)	< 0.001
Kanto area (excluding Tokyo)	42 (35.0)	35 (9.7)	
Other areas in Japan	21 (17.5)	2 (0.6)	
Alcohol consumption, yes	44 (60.3)	132 (62.9)	0.695
Smoking, yes	18 (24.7)	62 (29.7)	0.414
Allergies, yes	45 (37.5)	132 (36.7)	0.870
Family history of brain tumors, yes	6 (5.0)	12 (3.3)	0.410
Medical radiation*, yes			
X-ray (head/neck)	29 (24.2)	80 (22.2)	0.660
CT scan	25 (20.8)	71 (19.7)	0.750
Timing of interview			
2011	17 (14.2)	62 (17.2)	0.229
2012	51 (42.5)	116 (32.2)	
2013	37 (30.8)	134 (37.2)	
2014	15 (12.5)	48 (13.3)	
Regular mobile phone use	81 (67.5)	273 (75.8)	0.094
Wi-Fi at home	185 (50.0)	53 (44.0)	< 0.001
At school/work	93 (25.1)	19 (15.8)	
At other places	85 (23.0)	22 (18.3)	

*Medical radiation included examinations performed more than 2 years before symptoms first appeared.

(Kojimahara et al. 2020), and a family history of brain tumors, were not associated with brain tumors in our data. The number of patients who regularly used mobile phones to make phone calls did not differ significantly between the groups ($n = 81$, 67.5% vs. $n = 273$, 75.8%). Furthermore, for the brain tumor and appendicitis groups, 185 (50.0%) and 53 (44.0%) individuals regularly used Wi-Fi at home, 93 (25.1%) and 19 (15.8%) at school or work, and 85 (23.0%) and 22 (18.3%) at other places such as malls, respectively.

3.3 | OR of Mobile Phone Use With Respect to Brain Tumors

Table 4 shows the crude ORs of mobile phone including VoIP use, years of mobile phone use, cumulative number of calls, and cumulative call duration until 1 year before the diagnosis date. Although the ORs of mobile phone use, years of mobile phone use, cumulative number of calls, and cumulative call duration showed a decreasing trend, no significant differences were observed after adjustments were made for sex, age, residential area, and SES.

Table 5 shows the ORs of mobile phone via weighted exposure indices for different mobile phone generations. Considering a weight of 135 for 2G mobile phones (PDCs), which had a high output and major distribution during the study period in Japan, the crude and adjusted did not increase.

4 | Discussion

The MOBI-Kids Japan study investigated an impact on tumor growth and on tumor progression and adverse effect of mobile phone use by employing a unique weighted exposure assessment based on the participants' mobile phone use history, including Japanese patients who did not meet the inclusion criteria of the MOBI-Kids International case-control study (Castaño-Vinyals et al. 2022). The declining trend of incidences with increasing age in these age range, may be associated those incidences slightly increase. Because increased growth rate of a tumor leads to earlier diagnosis, the age-incidence function is shifted to younger age. Consequently, if the age-incidence function has a declining trend, ORs indicate below one.

This study addressed criticisms against the MOBI-Kids international study (Hardell and Moskowitz 2023), as no association was observed even when the analysis included midbrain tumors using unconditional logistic regression after adjusting for variables such as sex, age, and residential area. Similar to the international MOBI-Kids results, the ORs in this study were less than 1.0, and might have been associated with selection bias, due to

TABLE 4 | ORs of mobile phone use with respect to brain tumors.

	Cases $n = 120$ n (%)	Controls $n = 360$ n (%)	Crude OR (95% CI)	Adjusted OR* (95% CI)
Regular mobile phone use until 1 year before the reference date				
Nonuser	39 (32.5)	87 (24.2)	1	1
Regular user	81 (67.5)	273 (75.8)	0.66 (0.42–1.04)	0.92 (0.48–1.77)
Length of use (years) until 1 year before reference date				
Nonuser	39 (32.5)	87 (24.1)	1	1
< 5.42	25 (20.8)	91 (25.3)	0.61 (0.34–1.10)	0.97 (0.48–1.94)
5.42–9.51	25 (20.8)	91 (25.3)	0.61 (0.34–1.10)	0.82 (0.34–1.98)
> 9.51	31 (25.9)	91 (25.3)	0.76 (0.44–1.33)	0.94 (0.30–2.92)
			p for trend = 0.365	p for trend = 0.852
Cumulative number of calls until 1 year before reference date				
Nonuser	39 (32.5)	87 (24.1)	1	1
< 825.6	33 (27.5)	91 (25.3)	0.81 (0.47–1.40)	1.07 (0.54–2.13)
825.6–2844.0	20 (16.7)	91 (25.3)	0.49 (0.27–0.91)	0.62 (0.26–1.47)
> 2844.0	28 (23.3)	91 (25.3)	0.69 (0.39–1.21)	0.80 (0.32–2.01)
			p for trend = 0.078	p for trend = 0.437
Cumulative call time (in hours) until 1 year before reference date				
Nonuser	39 (32.5)	87 (24.1)	1	1
< 61.6	31 (25.8)	91 (25.3)	0.76 (0.44–1.33)	1.04 (0.52–2.06)
61.6–338.7	26 (21.7)	91 (25.3)	0.64 (0.36–1.14)	0.74 (0.31–1.74)
> 338.7	24 (20.0)	91 (25.3)	0.59 (0.33–1.06)	0.58 (0.22–1.52)
			p for trend = 0.063	p for trend = 0.229

*Adjusted for age, sex, residential area, and socioeconomic status (mother's education).
Abbreviations: 95% CI, 95% confidence interval; OR, odds ratio.

TABLE 5 | ORs of weighted mobile phone use.

	Cases $n = 120$ n (%)	Controls $n = 360$ n (%)	Crude OR (95% CI)	Adjusted OR* (95% CI)
Weighted cumulative number of calls until 1 year before reference date				
Nonuser	39 (32.5)	87 (24.1)	1	1
< 1042.9	29 (24.2)	91 (25.3)	0.71 (0.41–1.25)	1.01 (0.50–2.02)
1042.9–30231.4	27 (27.5)	91 (25.3)	0.66 (0.37–1.17)	0.75 (0.33–1.72)
> 30231.4	25 (20.8)	91 (25.3)	0.61 (0.34–1.10)	0.56 (0.20–1.58)
			p for trend = 0.102	p for trend = 0.245
Weighted cumulative call time (in hours) until 1 year before reference date				
Nonuser	39 (32.5)	87 (24.1)	1	1
< 82.6	29 (24.2)	91 (25.3)	0.71 (0.41–1.25)	1.05 (0.53–2.08)
82.6–2605.9	28 (23.3)	91 (25.3)	0.69 (0.39–1.21)	0.67 (0.28–1.61)
> 2605.9	24 (20.0)	91 (25.3)	0.59 (0.33–1.06)	0.53 (0.19–1.47)
			p for trend = 0.086	p for trend = 0.179

*Adjusted for age, sex, residential area, and socioeconomic status (mother's education).
Abbreviations: 95% CI, 95% confidence interval; OR, odds ratio.

modest response rates, imbalances in mothers' education level, and Kanto versus non-Kanto area. According to patient surveys 2023, the total number of appendicitis patients decreased from 14,000 in 1985 (ICD9 code 540-543) to 9000 in 2002 (ICD10 code K35-K38), although more recent data are not available, it is thought to be slightly decreasing. Appendicitis patients were chosen as hospital-based controls due to challenges in recruiting representative population-based controls, especially among young adults. Appendicitis is common in adolescence and unrelated to mobile phone use or SES, and not linked to the study's exposures, making these patients suitable proxies for the general population and minimizing bias in case–control comparisons (Sadetzki et al. 2014). Therefore, we believe that the use of appendicitis-related surgical controls is acceptable, although we acknowledged that selection bias might have occurred due to the lower participation rate among controls.

Our results are consistent with those of a recent systematic review (Karipidis et al. 2024) concerning the WHO assessment of health effects related to RF-EMF exposure. Baseline results from the Cohort Study on Mobile Phones and Health, COSMOS study in five countries, revealed that brain tumor risk was not associated with mobile phone use (Reedijk et al. 2024; Toledano et al. 2018). This study included over 250,000 participants with a median follow-up of approximately 7 years, where 149 glioma, 89 meningioma, and 29 incident cases of acoustic neuroma were diagnosed. The adjusted hazard ratio per 100 regression-calibrated cumulative hours of mobile phone call-time was 1.00 (95% CI 0.98–1.02) for glioma (Feychting et al. 2024), supporting the generalizability of the results. The findings from the Cefalo study, an international case control study in 7–19-year-olds diagnosed with brain tumors in Denmark, Sweden, Norway, and Switzerland between 2004 and 2008, also suggest no causal association between mobile phone use and brain tumors (Aydin et al. 2011).

The questionnaire for the MOBI-Kids international study did not explicitly ask about PHS use; therefore, this study was also unable to conduct an analysis that included PHS use as an exposure factor. In Japan, although the number of PHS contracts has gradually decreased, there were still 4.61 million contracts as of 2010, with a penetration rate relatively high compared with that in Europe and the United States at approximately 3%–5%. Public PHS services ended in 2023; however, it may be necessary to examine the cumulative impact of PHS in Japan.

The INTERPHONE study (INTERPHONE Study Group 2010), which included individuals who used first-generation mobile phones observed a J-shaped relationship, but the findings from the present study show rather an inverse association. Since selection bias contributed to the reduced risks in the simulation study (Bouaoun et al. 2024), the evidence from the INTERPHONE simulation study showed less likely that heavy mobile phone use is causally related to an increased brain tumor risk. Furthermore, exposure from recent mobile phone devices has decreased, indicating that the relative exposure from Wi-Fi and base stations is no longer at a level that can be ignored (Niinuma et al. 2016; Vrijheid et al. 2009).

Compared to the MOBI-Kids international study, MOBI-Kids Japan had some advantages. It was able to indicate the impacts of decreased exposure, since both PDC (2G) and 3G devices (Kojimahara et al. 2024) were used in Japan, whereas only GSM (2G) was widely distributed in European Union countries during the MOBI-Kids international study period. Although the number of participants in the MOBI-Kids Japan was small, the effect of selection bias was likely minimal due to high participation rates. The differences in backgrounds between the respondents and non-respondents in the MOBI-Kids international study have been previously described (Turner et al. 2019). Moreover, this study included 10- to 29-year-old participants, allowing for longer exposure to mobile phone use than the 10- to 24-year-old patients in the MOBI-Kids international study. Although the risks of mobile phone use could be analyzed in a high-risk group with long cumulative call times, it cannot be denied that age had a strong influence on the results, and the results should be interpreted with caution. The MOBI-Kids international study reported a unique tendency for mobile phone use in Japan: the number of calls was high, but the cumulative call duration was short because of the specific pricing plans offered by Japanese phone companies (Langer et al. 2017). Consequently, this study provides a more realistic analysis of the risk of brain tumors associated with mobile phones among young people in Japan using a weighted exposure assessment unique to Japanese terminal device generation, even though we used an exposure assessment that was different from the center of gravity used in the MOBI-Kids international study.

This study has some limitations. First, the laterality of brain tumors and phone use were not considered because this study included all histological types of brain tumors, most of which were present in the center of the brain. Second, although data were collected through standardized interviews similar to those used in the MOBI-Kids international study, recall bias, which is characteristic of case–control studies, still could have affected all of the variables. Third, because the sample size of the MOBI-Kids Japan study was not sufficient for certain sub-analyses, such as examining the effects of alcohol and tobacco, and adults and minors separately. Similarly, only 47 glioma cases were noted; therefore, analysis for glioma alone could not be performed.

5 | Conclusion

Although the international criteria for histological type, age, and residential area in MOBI-Kids Japan were expanded for cases and controls, we did not find an increased risk of mobile phone use for all brain tumors. The OR did not increase when the PDC was highly weighted; due to the ever-changing exposure conditions from wireless technology further studies are needed to address their relation to young people's health.

Author Contributions

Noriko Kojimahara and Masao Taki contributed to the conception and design of MOBI-Kids Japan, modifying the MOBI-Kids international study. Gemma Castano-Vinyals and Noriko Kojimahara analyzed the data and drafted the manuscript. Kanako Wake and Kosuke Kiyohara interpreted the data. Naohito Yamaguchi, Masao Taki, Gemma Castano-Vinyals, and Yasuto Sato critically revised the manuscript. All of the authors approved the final version.

Acknowledgments

We would like to thank E. Cardis at IsGlobal for her contribution to the management and implementation of MOBI-Kids International and E.C. Langer at IsGlobal for her role as coordinator of the project. The authors also would like to thank all the participants and their relatives who participated in the MOBI-Kids study for their time and collaboration. We acknowledge all the fieldwork coordinators, research assistants, and interviewers in all the study centers and all the hospital services for their cooperation and collaboration in Japan.

We are grateful to the following neurosurgeons for collecting information on brain tumor cases as part of the MOBI-Kids Japan study group: Yoshikazu Okada, Department of Neurosurgery, Tokyo Women's Medical University; Ryo Nishikawa, Department of Neuro-Oncology/Neurosurgery, Saitama Medical University International Medical Centre; Keita Terashima, Division of Neuro-Oncology, Children's Cancer Centre, National Centre for Child Health and Development; Kazunari Yoshida, Department of Neurosurgery, Keio University School of Medicine; Yoshiteru Miyajima, Department of Neurosurgery, Kitasato University School of Medicine; Takao Fukushima, Department of Neurosurgery, Nihon University School of Medicine; Akio Morita, Department of Neurosurgery, Kanto Medical Centre, NTT Ec.; Yoshitaka Narita, Department of Neurosurgery and Neuro-Oncology, National Cancer Centre Hospital; Ichiro Sugiyama, Department of Neurosurgery, Tokyo Metropolitan Children's Medical Centre; Akitake Mukasa, Department of Neurosurgery, University of Tokyo Hospital; Shigeo Sora, Department of Neurosurgery, Tokyo Metropolitan Police Hospital; Motoki Inaji, Department of Functional Neurosurgery, Tokyo Medical and Dental University; Tetsuo Hara, Department of Neurosurgery, National Centre for Global Health and Medicine; Kazuo Tsutsumi, Department of Neurosurgery, Showa General Hospital; and Nobuo Sugo, Department of Neurosurgery, Toho University Omori Medical Centre.

We are also grateful to the following neurosurgeons for collecting information on the controls as part of the study group of MOBI-Kids Japan. Yuji Sato, Faculty of Medical Management and Informatics, Hokkaido Information University; Masayuki Hatanaka, Ryohei Itagaki, Department of Surgery, Itabashi Chuo Medical Centre; Kazunari Yoshida, Department of Surgery, Shiseikai Second Hospital; Yusuke Shimodairaau, Department of Gastrointestinal Surgery, St. Luke's International Hospital; Masataka Takahashi, Department of Pediatric Surgery, University of Tokyo Hospital; Shoko Kawashima, Department of Surgery, Tokyo Women's Medical University Medical Centre East; Takuji Yamada, Department of Surgery, Institute of Gastroenterology, Tokyo Women's Medical University; Kan Terawaki, Department of Pediatric Surgery, Saitama Medical University; Takao Katsube, Department of Surgery, Tokyo Women's Medical University Medical Centre East; Osamu Segawa, Department of Pediatric Surgery, Tokyo Women's Medical University; Yoh Isobe, Department of Surgery, National Hospital Organization Tokyo Medical Centre; Noriko Takeda, Division of Pediatric Surgery, Department of Surgery, Kitasato University School of Medicine; and Akiko Sakoda, Department of Pediatric Surgery.

Ethics Statement

Parental approval was required for the participation of patients under 18 years of age, and the Tokyo Women's Medical University Ethics Committee approved this study (No. 2394-R, 2011, revised in 2018).

Consent

Informed consent was obtained from all the participants and/or their legal guardians. All methods of this study have been performed in accordance with the Declaration of Helsinki.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available upon request from the corresponding author Noriko Kojimahara. The data are not publicly available owing to restrictions, including compromising the privacy of the study participants.

References

Aydin, D., M. Feychting, J. Schuz, et al. 2011. "Mobile Phone Use and Brain Tumors in Children and Adolescents: A Multicenter Case–Control Study." *JNCI Journal of the National Cancer Institute* 103, no. 16, 17: 1264–1276. https://doi.org/10.1093/jnci/djr244.

Baan, R., Y. Grosse, B. Lauby-Secretan, et al. 2011. "Carcinogenicity of Radiofrequency Electromagnetic Fields." *Lancet Oncology* 12: 624–626.

Bouaoun, L., G. Byrnes, S. Lagorio, et al. 2024. "Effects of Recall and Selection Biases on Modeling Cancer Risk From Mobile Phone Use: Results From a Case-Control Simulation Study." *Epidemiology* 35, no. 4: 437–446.

Castaño-Vinyals, G., S. Sadetzki, R. Vermeulen, et al. 2022. "Wireless Phone Use in Childhood and Adolescence and Neuroepithelial Brain Tumors: Results From the International MOBI-Kids Study." *Environment International* 160: 107069.

Deltour, I., A. H. Poulsen, and C. Johansen, et al. 2022. "Time Trends in Mobile Phone Use and Glioma Incidence Among Males in the Nordic Countries, 1979–2016." *Environment International* 168: 107487.

Foundation for Promotion of Cancer Research. 2025. "Cancer Statistics in Japan 2025." Last modified May 9. https://ganjoho.jp/public/qa_links/report/statistics/2025_en.html.

Feychting, M., J. Schüz, M. B. Toledano, et al. 2024. "Mobile Phone Use and Brain Tumour Risk—COSMOS, a Prospective Cohort Study." *Environment International* 185: 108552.

Goedhart, G., L. van Wel, C. E. Langer, et al. 2018. "Recall of Mobile Phone Usage and Laterality in Young People: The Multinational Mobi-Expo Study." *Environmental Research* 165: 150–157.

Hardell, L., and M. Carlberg. 2017. "Mobile Phones, Cordless Phones and Rates of Brain Tumors in Different Age Groups in the Swedish National Inpatient Register and the Swedish Cancer Register During 1998-2015." *PLoS One* 12, no. 10: e0185461.

Hardell, L., and J. M. Moskowitz. 2023. "A Critical Analysis of the MOBI-Kids Study of Wireless Phone Use in Childhood and Adolescence and Brain Tumor Risk." *Reviews on Environmental Health* 38: 409–421.

INTERPHONE Study Group. 2010. "Brain Tumor Risk in Relation to Mobile Telephone Use: Results of the INTERPHONE International Case-Control Study." *International Journal of Epidemiology* 39: 675–694.

Iyare, R. N., V. Volskiy, and G. A. E. Vandenbosch. 2021. "Comparison of Peak Electromagnetic Exposures From Mobile Phones Operational in Either Data Mode or Voice Mode." *Environmental Research* 197: 110902.

Karipidis, K., D. Baaken, T. Loney, et al. 2024. "The Effect of Exposure to Radiofrequency Fields on Cancer Risk in the General and Working Population: A Systematic Review of Human Observational Studies—Part I: Most Researched Outcomes." *Environment International* 191: 108983.

Kojimahara, N., Y. H. Lee, A. K. Lee, et al. 2024. "Impact of Radiofrequency Exposure From Mobile Phones on the Risk of Developing Brain Tumors in Korean and Japanese Adolescents: A MOBI-Kids Case-Control Study." *Journal of Epidemiology* 34: 180–186.

Kojimahara, N., T. Yoshitake, and K. Ono, et al. 2020. "Computed Tomography of the Head and the Risk of Brain Tumours During Childhood and Adolescence: Results From a Case-Control Study in Japan." *Journal of Radiological Protection* 40: 1010–1023. https://doi.org/10.1088/1361-6498/abacff.

Langer, C. E., P. de Llobet, A. Dalmau, et al. 2017. "Patterns of Cellular Phone Use Among Young People in 12 Countries: Implications for RF Exposure." *Environment International* 107: 65–74.

Lee, A. K., Y. Yoon, S. Lee, et al. 2016. "Numerical Implementation of Representative Mobile Phone Models for Epidemiological Studies." *Journal of Electromagnetic Engineering and Science* 16: 87–99.

Louis, D. N., A. Perry, P. Wesseling, et al. 2021. "The 2021 WHO Classification of Tumors of the Central Nervous System: A Summary." *Neuro-Oncology* 23, no. 8: 1231–1251.

Ministry for Internal Affairs and Communication of Japan. 2024. "Chapter 4—Trends in the ICT Market. In White Paper Information and Communications in Japan Year 2023. Part 2: Current Status and Issues in the Information and Communications Field." Last modified July 2024. https://www.soumu.go.jp/johotsusintokei/whitepaper/eng/WP2024/pdf/00_fullversion.pdf.

McCarthy, B. J., K. Rankin, D. Il'yasova, et al. 2011. "Assessment of Type of Allergy and Antihistamine Use in the Development of Glioma." *Cancer Epidemiology, Biomarkers & Prevention* 20, no. 2: 370–378.

Niinuma, Y., M. Taki, M. Ikuyo, T. Nagaoka, and K. Wake. 2016. "Evaluation of Far-Field Exposure From Mobile Phone Base Stations and Comparison With the Exposure From a Third-Generation Mobile Phone." *IEICE Technical Report* 115: 49–54.

Reedijk, M., L. Portengen, A. Auvinen, et al. 2024. "Regression Calibration of Self-Reported Mobile Phone Use to Optimize Quantitative Risk Estimation in the COSMOS Study." *American Journal of Epidemiology* 193: 1482–1493.

Sadetzki, S., C. E. Langer, R. Bruchim, et al. 2014. "The MOBI-Kids Study Protocol: Challenges in Assessing Childhood and Adolescent Exposure to Electromagnetic Fields From Wireless Telecommunication Technologies and Possible Association With Brain Tumor Risk." *Frontiers in Public Health* 2: 124.

Sato, Y., K. Kiyohara, N. Kojimahara, and N. Yamaguchi. 2016. "Time Trend in Incidence of Malignant Neoplasms of the Central Nervous System in Relation to Mobile Phone Use Among Young People in Japan." *Bioelectromagnetics* 37: 282–289.

Takebayashi, T., S. Akiba, Y. Kikuchi, et al. 2006. "Mobile Phone Use and Acoustic Neuroma Risk in Japan." *Occupational and Environmental Medicine* 63: 802–807.

Takebayashi, T., N. Varsier, Y. Kikuchi, et al. 2008. "Mobile Phone Use, Exposure to Radiofrequency Electromagnetic Field, and Brain Tumour: A Case-Control Study." *British Journal of Cancer* 98: 652–659.

Toledano, M. B., A. Auvinen, G. Tettamanti, et al. 2018. "An International Prospective Cohort Study of Mobile Phone Users and Health (COSMOS): Factors Affecting Validity of Self-Reported Mobile Phone Use." *International Journal of Hygiene and Environmental Health* 221: 1–8.

Turner, M. C., E. Gracia-Lavedan, F. Momoli, et al. 2019. "Non-participation Selection Bias in the MOBI-Kids Study." *Epidemiology* 30, no. 2019: 145–153.

Vrijheid, M., S. Mann, P. Vecchia, et al. 2009. "Determinants of Mobile Phone Output Power in a Multinational Study: Implications for Exposure Assessment." *Occupational and Environmental Medicine* 66: 664–671.

van Wel, L., A. Huss, H. Kromhout, et al. 2024. "Validation of Mobile Phone Use Recall in the Multinational MOBI-Kids Study." *Bioelectromagnetics* 45, no. 7: 313–328.

van Wel, L., I. Liorni, A. Huss, et al. 2021. "Radio-Frequency Electromagnetic Field Exposure and Contribution of Sources in the General Population: An Organ-Specific Integrative Exposure Assessment." *Journal of Exposure Science & Environmental Epidemiology* 31: 999–1007.

WHO. 2010. "Research Agenda for Radiofrequency Fields." Last modified 2010. http://apps.who.int/iris/bitstream/10665/44396/1/9789241599948_eng.pdf.

WHO. 2024. Report of the Advisory Group to Recommend Priorities for the IARC Monographs during 2020–2024. Last modified November 4. https://monographs.iarc.who.int/wp-content/uploads/2019/10/IARCMonographs-AGReport-Priorities_2020-2024.pdf.

Zumel-Marne, A., M. Kundi, G. Castaño-Vinyals, et al. 2020. "Clinical Presentation of Young People (10–24 Years Old) With Brain Tumors: Results From the International MOBI-Kids Study." *Journal of Neuro-Oncology* 147, no. 2: 427–440.

Supporting Information

Additional supporting information can be found online in the Supporting Information section.
Supplemental material0617.docx.