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Combining Near- and Farfield Exposure for an Organ-Specific and Whole-Body RF-EMF Proxy for Epidemiological Research: A Reference Case

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Running title: OSA and WBA Exposure Dose for NF and FF Exposure

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Abstract

A framework for the combination of near-field and far-field radio frequency electromagnetic exposure sources to the average organ and whole body specific absorption rates (SAR) is presented. As a reference case, values based on numerically derived SARs for whole body and individual organs and tissues are combined with realistic exposure data, which have been collected during the Swiss Qualifex study using personal exposure meters. The framework presented can be applied to any study region where exposure data is collected by appropriate measurement equipment.

Based on the results derived for the data in the region of Basel in Switzerland the relative importance of near-field and far-field sources to the personal exposure is examined for three different study groups. The results show that the 24 hour whole-body averaged exposure of an average mobile phone user is dominated by the use of his or her own mobile phone when a global system for mobile communication (GSM) 900 or GSM 1800 phone is used. If only universal mobile telecommunications system (UMTS) phones are used the user would experience a lower exposure level on average caused by lower average output power of the UMTS phones. Data presented clearly indicates the necessity of collecting band selective exposure data in epidemiological studies related to electromagnetic fields.

The data for the whole body and organ specific SARs derived from the numerical model presented in this paper can be used to derive the exposure of multiple sources in an everyday environment for use in epidemiological studies on possible specific and non-specific health effects caused by radio frequency electromagnetic fields when combined with the corresponding band selective exposure data.

Key Words: Personal Exposure, SAR, Dose, Near-field, Far-field

Introduction

Technologies using electromagnetic (EM) fields are more and more employed in our society. Therefore, people are exposed to various sources in their vicinity such as mobile phones, cordless phones and base stations. In general, the contribution to the personal exposure can be divided into near-field (NF) and far-field (FF) sources with respect to the human body. NF sources, such as cell phones, are operating in the close vicinity of the body and are usually controlled by the user. They can cause temporarily high local exposure, whereas FF sources, such as radio base stations, are usually further away and thus lead to lower but rather continuous exposure levels. For a thorough study of potential specific and non-specific health effects, caused by radio frequency (RF) electromagnetic fields (EMF), the contribution of different radio frequency sources to the personal exposure of different organs, body tissues and for the whole body is required.

In the past different exposure proxies were used in order to classify different exposure groups. In Neubauer et al. [2007] the feasibility of epidemiological studies on possible health effects of mobile phone base stations is evaluated. An extensive discussion on previous approaches can be found together with a collection of references. In conclusion epidemiological studies are considered as feasible if the contribution of the different sources to the RF exposure can be assessed by appropriate means such as personal exposure meters. However, the combination of FF and NF sources by weighting with exposure data collected in the corresponding study area was not discussed so far.

In this paper a reference case for combining the contributions of NF and FF radio frequency electromagnetic exposure sources to the average organ and whole body specific exposure is investigated. Therefore, a detailed collection of numerically derived specific absorption rates (SAR) of whole-body averaged (WBA) and organ-specific averaged (OSA) for NF and FF exposure scenarios are required. The corresponding SAR values are derived from numerical simulations using anatomical human body models as presented in Christ et al. [2010a]. Although a few studies have been performed to calculate WBA and OSA SAR values for different scenarios as in Kuehn et al. [2009], Dimbylow et al. [2008], Catarinucci et al. [2003] and Meyer et al. [2003] these results aimed to test compliance with given exposure limits from regulatory bodies and do not provide results of all sources which we are exposed to in everyday life. In order to close this gap, the WBA SAR and the OSA SAR are calculated using the Virtual Family Model (VFM) 'Duke' that is considered as representative of average male humans in the population [Gosselin et al., 2011] and the SAR values are provided for both NF and FF exposure sources at the required carrier frequencies of the RF services. The NF exposure scenario is represented by a cell phone, operating at the right head side of the human model, whereas the FF exposure scenario is characterized by the irradiation of the human model by plane waves. The normalized results from the numerical calculations are combined and weighted with the corresponding exposure values collected in the Qualifex study [Frei et al., 2009] to calculate the personal dose values in terms of time averaged SAR. The results show the relative importance of NF and FF sources to the personal exposure in the specific study area and can be used as exposure proxies in epidemiological studies on potential specific and non-specific health effects caused by RF sources.

Material and methods

Simulated exposure scenarios

For the simulations the commercially available simulation platform SEMCAD X (Version 14, Schmid & Partner Engineering AG, Zurich, Switzerland) and the 'Duke'-model [Christ et al., 2010a] of 'The Virtual Family' were used. The 'Duke'-model is generated from a set of magnetic resonance images of whole body scans from a 34 year old male. The male is 1.74 m tall, weighs 72 kg and has a body mass index of 23.1 kg/m^2. The dielectric tissue properties have been assigned according to the integrated material database in SEMCAD X that is based on previous databases updated according to additional published literature values. The database is documented on the download site [Database of tissue properties, 2012]. The values given in the database correspond to average values. Standard deviations of the tissue properties together with literature references are also reported in the documentation provided on the webpage. The resolution of the model was chosen to be 2×2×2 mm resulting in a total of about 110 million voxels. The computational domain is terminated by uniaxial anisotropic perfectly matched layer (UPML) boundary conditions.

Far-field

As FF sources the following radio frequency (RF) services are considered: frequency modulation (FM) radio stations, television (TV) broadcast stations, wireless fidelity (WiFi) hotspots and mobile phone base stations, including global system for mobile communication (GSM) 900, GSM 1800, universal mobile telecommunications system (UMTS) and digital enhanced cordless telecommunications (DECT). Therefore, simulations at the following frequencies were performed: 100 MHz (FM), 650 MHz (TV), 900 MHz (GSM 900), 1800 MHz (GSM 1800), 1950 MHz (UMTS, DECT) and 2450 MHz (WiFi). As a FF exposure scenario the human model is irradiated by 12 identical plane waves coming from the six major incident directions with two polarizations each is selected. The WBA SAR_{FF} and the OSA SAR_{FF} is calculated for each configuration separately and the results are averaged over all incident directions resulting in a maximum average value for the number of plane waves considered. The simulation results are normalized to a power flux density of 1 W/m^2.

Near-field

The main contribution to the exposure from NF sources is caused by the cell phones and the cordless phones. These phones use either the GSM 900, GSM 1800, UMTS or DECT standard. This exposure scenario is modeled by a cell phone, operating at the right side of the human model's head. As a phone model the (T250, Motorola, Schaumburg, IL, USA) is selected. Simulations are performed at the operating frequencies of the services at 900 MHz, 1750 MHz and 1950 MHz. For both UMTS and DECT the simulation results from 1950 MHz are used, due to the low frequency separation of the UMTS uplink and the DECT band. The numerical computation was carried out according the procedure described in Christ et al. [2010b]. The WBA SAR and the OSA SAR are calculated for each carrier frequency separately and the results are normalized to an output power of the phone of 1 Watt.

Realistic exposure data

The simulated results of the WBA and OSA SAR are used to analyze the relative importance of NF and FF sources to the personal whole body or organ and tissue specific dose. Furthermore, the following calculations serve as an example how the simulation-derived data can be applied to exposure data collected with exposimeters in epidemiological studies. Figure 1 shows a flow graph of the applied method to calculate realistic FF and NF exposure doses. The required parameters for these calculations as well as their sources are listed. Within this scope, we used data from a Swiss personal RF EMF exposure survey (Qualifex study) [Frei et al., 2009]. In the

Swiss survey 166 study participants carried a personal exposimeter (EME SPY120, Satimo, Courtaboeuf, France) in the region of Basel over a period of one week.

According to [Frei et al., 2009] three different exposure groups are defined: Group I: persons with residency close to a broadcast transmitter, Group II: self-selected volunteers, Group III: persons with residency close to a mobile phone base station.

Table 1 shows the average incident measured fields for the three exposure groups in terms of the power flux density *S*. The values represent FF exposure values, since measurements that have been taken during the use of mobile and cordless phones were excluded from the calculation of mean values [Frei et al., 2009]. The personal FF dose averaged over 24 hours of a group is determined as a sum over the contributions of all services. The contribution of a service *i* is computed as the normalized WBA SAR_{FF} induced by the specific service weighted by the corresponding power flux density *S*. The dose of a group can be written as:

$$WBADose_{FF}(Group, 24h) = 24 \times 3600\text{s}\left(\sum_i WBASAR_{FF}(service_i) \times S_{service_i}\right) \quad \text{Equation 1}$$

Regarding exposure close to body sources we used data from the Qualifex main study, i.e., 1375 study participants that were randomly selected from the urban and suburban area of Basel, Switzerland. The results show that the volunteers used their cell phone on average 25.6 min/week and their DECT phone 61.6 min/week, see [Mohler et al., 2009].

In addition to the usage data, we used data of the average output power measured at the antenna feed point of typical cell phones provided by literature. Table 2 summarizes the average transmission (TX) powers of the different services and the average call times. The values for GSM 900 and GSM 1800 are taken from Vrijheid et al. [2009], where the average output power of GSM 900 and GSM 1800 cell phones was evaluated with software modified phones considering more than 500 volunteers in 12 countries. The average transmission power of UMTS phones was evaluated in Gati et al. [2009]. In our analysis we are assuming that 50% of the phone calls are made in buildings and 50% outdoor (in a large city). This leads to an average output power of 0.65 mW. In general, a DECT phone uses one of 24 time slots with a constant transmission power of 250 mW. This leads to an average output power of 250 mW/24 = 10.4 mW.

The resulting personal NF dose is determined by the normalized WBA SAR_{NF} and the normalized OSA SAR_{NF} weighted by the average output power P_i of the phone and the average call time T_i of the specific used mobile service i. The results are calculated for a 24-hour exposure:

$$WBADose_{NF}(service_i, 24h) = 24 \times 3600\mathrm{s}\left(\sum_i WBASAR_{NF}(service_i) \times P_i \times \frac{T_i}{T}\right) \quad \text{Equation 2}$$

where T is the reference time of T_i . When T_i is given in min per week then T would be 7×24×60 min. The "OSA Dose ($service_i$, 24h)" can be obtained from the OSA SAR in a similar way.

Results

Simulation results

Whole-body averaged specific absorption rate

Far-field

Figure 2 shows the WBA SAR_{FF} calculated at 100 MHz, 650 MHz, 900 MHz, 1800 MHz, 1950 MHz and 2450 MHz. The simulation results are normalized to a power flux density of 1 W/m^2. The results show a higher absorption for lower frequencies which can be explained by resonance effects and a larger penetration depth for lower frequencies.

Near-field

The normalized WBA SAR_{NF} is calculated for the human model with a cell phone that is placed to the right side of the head for 900 MHz, 1800 MHz and 1950 MHz. The results are given in Table 3 and they are normalized to an output power of the phone of 1 Watt. The results show a higher WBA SAR for higher frequencies.

Organ-specific averaged absorption rate

With regard to potential health effects caused by RF EMF exposure, organs and tissues that directly or indirectly influence hormonal balance or cell growth are of greater interest, because they can serve as an indicator of possible influences of electromagnetic exposure. Therefore, we will focus only on the OSA SAR for the most important organs and tissues. In this context we chose 24 different organs and tissues as listed in Table 4.

The simulation setup for the calculation of the OSA SAR is the same as for the WBA SAR calculation, see section Simulated exposure scenarios.

Far-field

Table 4 shows the OSA SAR_{FF} for 100 MHz, 650 MHz, 900 MHz, 1800 MHz, 1950 MHz and 2450 MHz. The data are normalized to a power flux density of 1 W/m^2. The results are highly frequency dependent and do not follow the trend of the normalized WBA SAR_{FF}. For example, the heart muscle has a maximum absorption at 100 MHz and a minimum at 2450 MHz, whereas the skin has a maximum at 2450 MHz and a minimum at 100 MHz. The reason for that is the higher penetration depth for lower frequencies.

Near-field

The OSA SAR_{NF} is also calculated for NF exposure with a mobile phone that is attached to the head of the human body model. Table 5 summarizes the OSA SAR_{NF} for 900 MHz, 1800 MHz and 1950 MHz. The data are normalized to an output power of the phone of 1 W. The results show the highest absorption for the skin and head organs.

Example with real exposure data

In a next step the WBA SAR and OSA SAR results of the NF and FF simulations with the Virtual Family Model 'Duke' are weighted with personal exposure data collected within the Qualifex study. The results are evaluated for the three different FF exposure groups and for NF exposure.

The calculations follow the method shown in Figure 1.

WBA dose

Far-field

Figure 3 summarizes the results for the three examined study groups. It can be seen that people of Group I feature a higher "WBA $Dose_{FF}$(24h)" than people of Group II and Group III. This can be explained by higher measured mean values [Frei et al., 2009] and a higher mean contribution of TV and radio stations to the FF exposure and the higher energy absorption at lower frequencies. The lowest "WBA $Dose_{FF}$(24h)" is 35.2 mJ/kg for people of the study Group II.

Near-field

Table 6 summarizes the "WBA $Dose_{NF}$(24h)" for the three different mobile phone standards and for DECT. The transmission power for GSM 900, GSM 1800, UMTS and DECT and the call times are provided in Table 2.

Far-field vs. Near-field

Figure 4 shows the difference between the NF and FF WBA dose in logarithmic scale for an average mobile phone user of Group II (self-selected volunteers). The NF exposure was either caused by a GSM 900, GSM 1800, UMTS or DECT phone. The results show that the WBA SAR for NF is 5 dB higher than for FF exposure, when the GSM 900 mobile service is used exclusively. Using the GSM 1800 service leads to a difference of 2.9 dB, for UMTS to −16.9 dB and for DECT to 1.1 dB. In order to encounter the same WBA SAR for NF and FF sources the call time has to be decreased from 25.6 min/week to 8.1 min/week when using the GSM 900 standard, 13.1 min/week for GSM 1800 and 19.8 min/week for the DECT standard. In contrast, if only the UMTS standard is used, the call time could be increased to 20.9 hours/week. The overall personal dose "WBA $Dose_{all}$(24h)" consists of contributions from NF and FF sources. It can be calculated by the sum of the dose for NF (Equation 2) and FF (Equation 1) sources.

Assuming a person of Group II, who uses the mobile phone for 25.6 min/week in GSM 900 and the DECT phone for 61.6 min/week, the "WBA $Dose_{all}$(24h)" can be calculated to:

$$WBADose_{all}(24h) = WBADose_{FF}(\mathrm{II,24h}) + WBADose_{NF}(\mathrm{GSM900,24h}) +$$
$$WBADose_{NF}(\mathrm{DECT,24h}) = 35.2\mathrm{mJ/kg} + 111\mathrm{mJ/kg} + 27.2\mathrm{mJ/kg} = 173.4 mJ/kg$$

The contribution of the different services to the "WBA $Dose_{all}$(24h)" is shown in Figure 5. The self-induced NF-exposure dose is indicated in the legends with the abbreviation 'self'. The results highlight that 80% of the dose is caused by the person's own mobile phone (GSM900self=64%, DECTself=16%) rather than by non-controlled sources in the surrounding environment. For a GSM1800 user the cell phone features a contribution of 52% and the DECT phone of 20%, whereas for a UMTS user the cell phone has a contribution of 1% and the DECT phone of 43% to the total exposure.

OSA dose

Far-field

The "OSA $Dose_{FF}$(24h)", which is caused by various FF sources, can be calculated by the summed product of the OSA SAR_{FF} and the mean RF EMF exposure for different study groups, according to Equation 1. The first three columns in Table 7 summarize the "OSA $Dose_{FF}$(24h)" for the three different study groups.

Near-field

In order to compare OSA dose values, caused by NF and FF sources for an average user, the "OSA SAR_{NF}(24h)" is calculated according to Equation 2. The used transmission power levels and the call times are given in Table 2. The columns "OSA $Dose_{NF}$(24h)" in Table 7 shows the OSA dose values for an average mobile phone user, using either a GSM 900, GSM 1800 or UMTS phone. Furthermore, the OSA dose for an average DECT user is also listed. The results show that UMTS standard leads to the smallest OSA dose values, whereas GSM 900 caused the highest organ specific dose values due to the higher transmission power level of this standard.

Far-field vs. Near-field

Using the results of Table 7, the "OSA $Dose_{FF}$(24h)" can be compared with "OSA $Dose_{NF}$". The results show that the UMTS user encounters in average smaller exposure levels by NF than by FF sources for all analyzed organs. The reason for this is the lower average output power of a UMTS phone. Figure 6 compares the induced exposure for five different organs (brain grey matter, brain white matter, heart muscle, spinal cord and testis), caused by NF and FF sources. The results show that the NF sources dominate the total exposure for the head for GSM 900, GSM 1800 and DECT. Only UMTS induces smaller OSA dose values than the FF sources. In order to encounter the same OSA dose for FF sources (Group II) and NF sources (UMTS phone) for the brain (grey matter) the call time can be increased by a factor of 8.1 leading to a call time of 207 min/week.

Discussion

In this paper a set of numerically derived specific absorption rates of whole body and individual organs are presented for NF and FF exposure sources. This allows calculating the absorbed dose inside the body for given exposure data from multiple sources assessed by studies using exposimeters. The results can be used to support deriving exposure proxies for epidemiological studies of e.g., non-specific health effects caused by RF EMF. The use of the data is demonstrated for exposure data collected during the Qualifex study. Based on these results the relative importance of NF and FF sources to the total personal exposure dose is examined.

The results show that the "WBA Dose(24h)" of an average mobile phone user (25.6 min/week) is dominated by the use of his or her own mobile phone when a GSM 900 or GSM 1800 phone is used. The UMTS user encounters on average smaller exposure levels by NF than by FF sources for whole body and all analyzed organs. This is also true for organs close to the phone, i.e., brain. The reason for this is the lower average output power of a UMTS phone. For example, an average person that uses the UMTS standard exclusively, can increase his call time by a factor of 8.1 leading to total call time of 207 min/week in order to encounter the same dose caused by FF sources inside the grey matter of the brain.

The simulation results in the database refer each to a selected reference scenario, which are obviously subject to variations. For FF exposure, a scenario that represents an equal irradiation from the six main directions (2 polarizations each) was chosen. Analysis in the scope of variations for different irradiation scenarios showed in Vermeeren et al. [2009] that the whole-body averaged SAR for a realistic exposure exceeds the maximum average case of single plane wave exposure in approximately 10% of the exposure samples. A further variation is generally implied by the used human model in the simulations, see Kuehn et al. [2009]. Due to the highly diverse human population the simulation results of a single model cannot be generalized. In Conil et al. [2008] six numerical human models have been compared, and their variability in terms of morphology and behavior toward RF exposure for frequencies from 20 MHz to 2.4 GHz were analyzed. The results show that the standard deviation of the WBA SAR of adult models can reach up to 40%.

The NF exposure scenario is represented by a phone model that is placed on the right head side of the virtual family male. Different factors such as the position of the phone model, type of the phone and the use of personal hand-free kits are affecting body exposure. When looking at the measured SAR values (averaged over 10g of tissue) of different mobile phone types in a homogeneous head, a factor higher than 13 between different devices can be observed in worst case, see SAR database [2011]. This fact leads to a variation of OSA and WBA SAR for different phones, which has to be examined separately and is out of the scope of this paper. Therefore, further analysis are required in order to evaluate the variations of the WBA and OSA SAR such as phone type, phone position, human model and exposure scenario. However, the case presented here can be taken as a reference case where average scenarios were chosen together with available data from the literature on average power levels. Further work should focus on designing exposure assessment studies involving equipment able to record as much data as possible, in particular transmission power, position and operation mode of the mobile phone. Here, it has been shown that all the parameters involved in a “dose” definition based on time averaged power deposition in tissues, organs or the whole-body have a significant influence on the relation between the different contributions arising from different NF and FF RF sources.

Therefore, in future epidemiological studies careful exposure assessment has to be carried out using appropriate equipment delivering the necessary data. Further, as long as no reproducible effect is detected and no explicit site of interaction is identified also different dose measures such as the power spectrum or band-selective data should be considered including as much information as possible for the case of retrospective analysis. For these cases the same framework presented here can be applied.

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Figure 1: Picture of the flow graph for the dose calculations. The graph shows the required parameter for the calculations and also the sources of the parameters that were used.

Figure 2: Whole-body averaged (WBA) specific absorption rate $(SAR)_{FF}$ for plane waves coming from the six major incident directions with two polarizations each at 100 MHz, 650 MHz, 900 MHz, 1800 MHz, 1950 MHz and 2450 MHz. The results are averaged over all incident directions and normalized to a power flux density of 1 W/ m^2.

Figure 3: Contribution of different far field (FF) services to the "WBA $Dose_{FF}$(24h)" for different study groups. Group I: persons with residency close to a broadcast transmitter, Group II: self-selected volunteers, Group III: persons with residency close to a mobile phone base station.

Figure 4: "WBA Dose ratio(24h)" caused by near field (NF) and far field (FF) sources for an average mobile phone user of Group II.

Figure 5: Contribution of the different services to the total "WBA $Dose_{all}$(24h)" for a person from the study Group II. We assume that the person uses the GSM 900 service for 25.6 min/week and the DECT service for 61.6 min/week. The contribution of the self-induced exposure dose is indicated in the legends with the abbreviation 'self'.

Figure 6: Comparison of OSA dose for the study group II and the usage of different mobile and cordless phone standards. The average call time is 25.6 min/week for GSM 900, GSM 1800 and UMTS. For DECT an average call time of 61.6 min/week is assumed.

Table 1: Average incident fields from far field (FF) sources of three different exposure groups measured during the Qualifex study. The fields are given as electromagnetic field values E and the corresponding power flux density S.

Table 2: Average transmission power of a cell phone and a cordless phone. The average call time for the different evaluated scenarios is also given.

Table 3: WBA SAR_{NF} caused by a cell phone which is placed to the right side of the head of the human model. The results are normalized to an output power of the phone of 1 W.

Table 4: OSA SAR_{FF} for plane wave exposure coming from the six major incident directions with two polarizations each at 100 MHz, 650 MHz, 900 MHz, 1800 MHz, 1950 MHz and 2450 MHz. The results are averaged over all incident directions and are normalized to a power flux density of 1 W/m^2. The labels of the organs are taken from the 'Duke'-model, see Christ et al. [2010a].

Table 5: OSA SAR_{NF} for NF exposure from a cell phone which is attached to the head of the human model at 900 MHz, 1800 MHz and 1950 MHz. The results are normalized to an output

power of the phone of 1 W. The labels of the organs are taken from the ‘Duke’-model, see Christ et al. [2010a].

Table 6: “WBA $Dose_{NF}$(24h)” caused by a phone which is attached to the head of the human model for different mobile phone standards. The average call time is 25.6 min/week for GSM 900, GSM 1800 and UMTS. For DECT an average call time of 61.6 min/week is assumed.

Table 7: Table of OSA dose(24h) caused by FF sources for different study groups, exposed to various FF sources, and the NF-dose(24h) caused by a mobile phone which is attached to the head for different mobile phone standards. (Group I: persons with residency close to a broadcast transmitter, Group II: self-selected volunteers, Group III: : persons with residency close to a mobile phone base station). A call time T_i of 25.6 min/week for GSM 900, GSM 1800, UMTS and 61.6 min/week for DECT is assumed. The labels of the organs are taken from the ‘Duke’-model, see Christ et al. [2010].

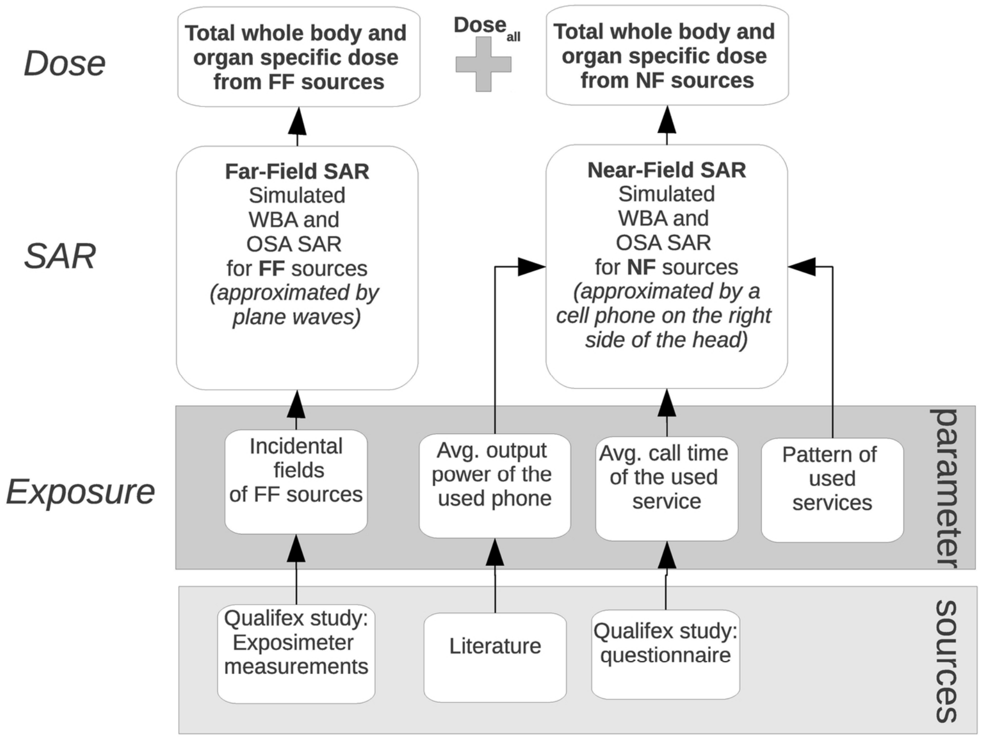

Figure 1: Picture of the flow graph for the dose calculations. The graph shows the required parameter for the calculations and also the sources of the parameters that were used.
135x103mm (300 x 300 DPI)

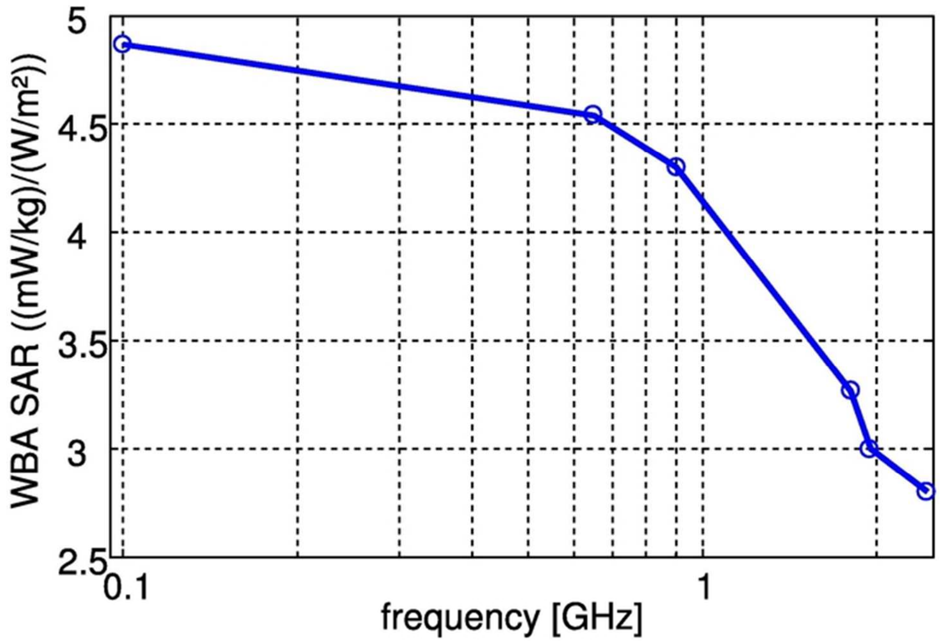

Figure 2: Whole-body averaged (WBA) specific absorption rate $(SAR)_{FF}$ for plane waves coming from the six major incident directions with two polarizations each at 100 MHz, 650 MHz, 900 MHz, 1800 MHz, 1950 MHz and 2450 MHz. The results are averaged over all incident directions and normalized to a power flux density of 1 W/m^2.
65x49mm (300 x 300 DPI)

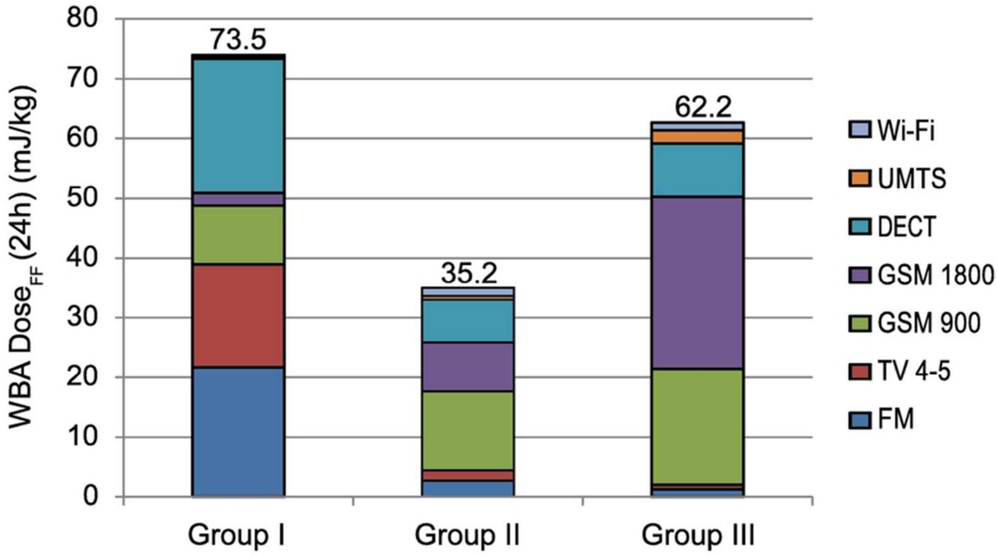

Figure 3: Contribution of different far field (FF) services to the “WBA DoseFF(24h)” for different study groups. Group I: persons with residency close to a broadcast transmitter, Group II: self-selected volunteers, Group III: persons with residency close to a mobile phone base station.
74x41mm (300 x 300 DPI)

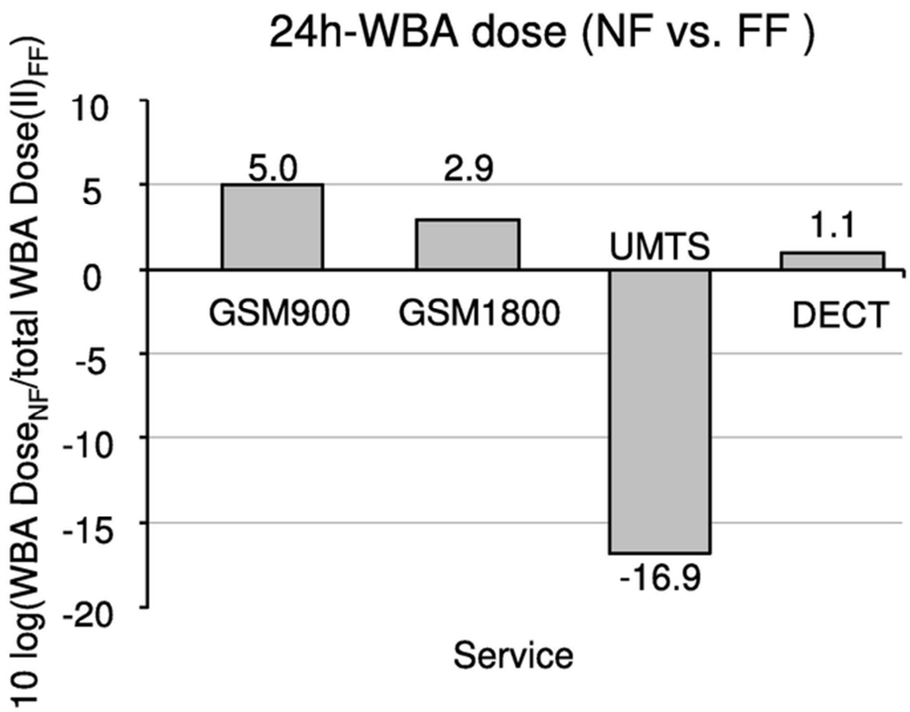

Figure 4: "WBA Dose ratio(24h)" caused by near field (NF) and far field (FF) sources for an average mobile phone user of Group II.
63x46mm (300 x 300 DPI)

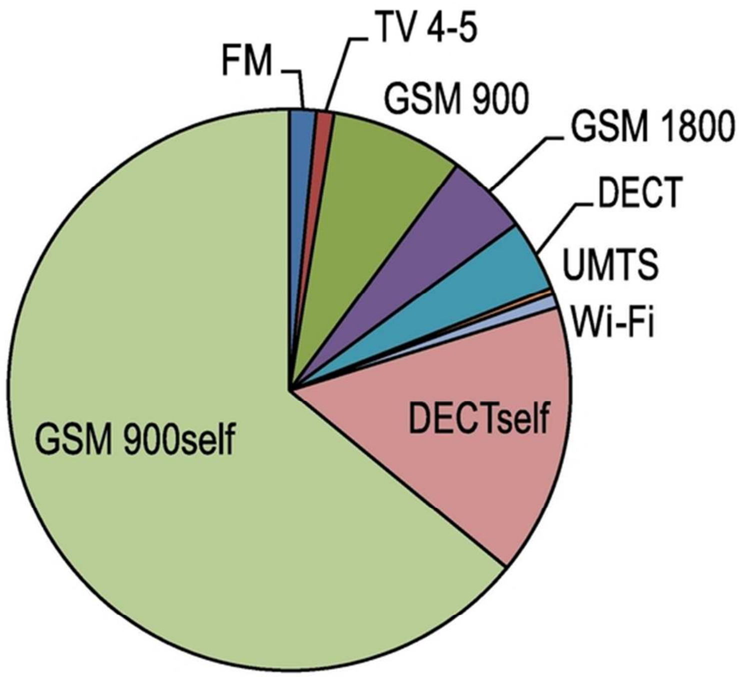

Figure 5: Contribution of the different services to the total "WBA Doseall(24h)" for a person from the study Group II. We assume that the person uses the GSM 900 service for 25.6 min/week and the DECT service for 61.6 min/week. The contribution of the self-induced exposure dose is indicated in the legends with the abbreviation 'self'.
65x49mm (300 x 300 DPI)

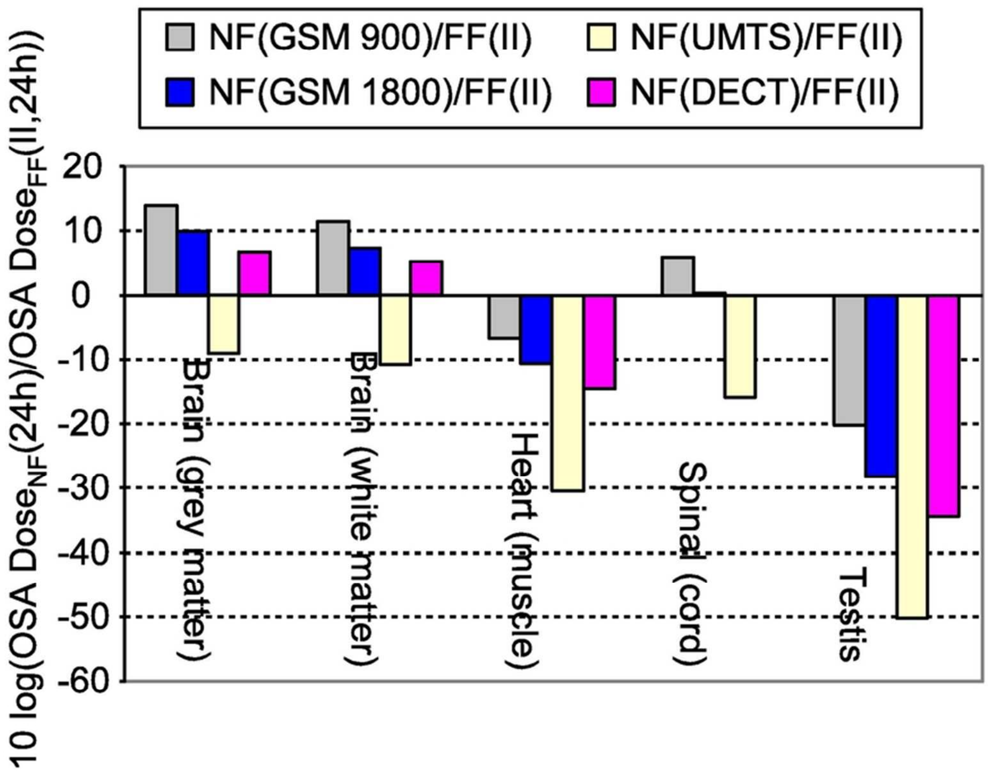

Figure 6: Comparison of OSA dose for the study group II and the usage of different mobile and cordless phone standards. The average call time is 25.6 min/week for GSM 900, GSM 1800 and UMTS. For DECT an average call time of 61.6 min/week is assumed.
74x63mm (300 x 300 DPI)

Table 1

Table 1			
Service	S (µW/m²)		
	Group I	Group II	Group III
FM	51.6	6.32	2.89
TV 4-5	44.1	4.48	2
GSM 900	26.32	35.53	52.28
GSM 1800	7.43	29.27	102.17
DECT	85.5	27.2	33.9
UMTS	1.11	2.35	8.28
Wi-Fi	1.38	5.85	5.25

Table 2

Table 2		
Service	average transmission (TX) power (mW)	average call time (min/week)
GSM 900	133	25.6
GSM 1800	62.2	25.6
UMTS	0.65	25.6
DECT	10.4	61.6

Table 3

Table 3	
Frequency (MHz)	WBA SAR ((W/kg)/(W/m²))
900	3.85
1800	4.99
1950	4.95

Table 4

Table 4						
Organs/Tissues	OSA SAR_{FF} ((μW/kg)/(W/m²))					
	100 MHz	650 MHz	900 MHz	1800 MHz	1950 MHz	2450 MHz
Adrenal gland	807.3	1090.1	108.2	14.7	6.1	0.6
Brain grey matter	1433.2	7608.1	6874.5	3246.5	2911.1	2288.9
Brain white matter	915.2	5301.1	4120.6	1943.7	1600.8	1095.9
Cerebellum	1381.9	5229.0	8913.6	1804.3	1690.6	1262.3
Cerebrospinal fluid	3524.3	16120.1	12381.7	5264.6	4712.6	3977.6
Eye lens	1404.4	7840.1	5071.3	3091.2	4716.3	6793.9
Heart muscle	2026.6	1072.4	972.9	224.7	218.6	185.8
Hippocampus	657.4	3706.3	3796.9	1069.8	868.4	456.3
Hypophysis	342.3	1849.7	813.9	103.9	53.5	16.9
Hypothalamus	507.9	7970.2	6717.8	586.3	426.4	40.1
Kidney medulla	2275.2	1756.8	838.3	209.4	113.8	44.4
Marrow red	2268.7	2551.0	2738.3	1744.3	1638.6	1626.6
Medulla oblongata	214.3	1750.7	2870.4	274.8	172.7	30.4
Midbrain	341.8	5062.0	3101.1	554.8	360.6	93.0
Nerve	1594.0	1073.1	1121.5	381.1	291.6	141.7
Pineal body	829.9	7962.0	5180.7	729.1	638.0	121.5
Pons	245.0	1883.4	2168.8	98.7	62.5	14.8
Skin	6541.2	9637.5	11424.8	12259.6	11799.4	12443.3
Spinal cord	946.1	1801.2	1074.6	216.1	127.0	44.1
Testis	17103.8	13370.3	6024.1	7641.2	7749.7	8014.8
Thalamus	463.9	7831.5	4227.7	1323.0	773.7	141.5
Thymus	2672.4	2984.3	1731.3	309.7	737.8	1199.6
Thyroid gland	3802.6	13433.4	2515.0	7014.4	9047.9	4520.0
Vertebrae	254.8	201.1	225.4	95.7	76.8	51.2

Table 5

Table 5			
Organs/Tissues	OSA SAR_{NF} [(μW/kg)/(W/m²)]		
	900 MHz	1800 MHz	1950 MHz
Adrenal gland	2.3	0.3	1.6
Brain grey matter	34319.9	29456.9	35865.0
Brain white matter	11622.7	9586.9	14647.3
Cerebellum	20584.8	19225.3	22239.1
Cerebrospinal fluid	40566.4	25729.2	37429.8
Eye lens	14424.5	11984.3	22280.3
Heart muscle	41.6	36.2	37.2
Hippocampus	37256.9	34057.1	79183.0
Hypophysis	27141.1	1215.8	2919.7
Hypothalamus	38010.9	9657.6	34089.0
Kidney medulla	8.2	3.0	6.9
Marrow red	1583.5	2447.8	1703.9
Medulla oblongata	8889.2	1647.2	4793.4
Midbrain	18961.9	8002.0	26059.7
Nerve	788.7	314.7	638.4
Pineal body	8904.1	5782.9	26887.3
Pons	8823.9	1224.4	4771.7
Skin	7210.5	13444.0	11297.6
Spinal cord	724.9	411.6	969.8
Testis	25.0	8.6	5.3
Thalamus	13339.4	6274.6	25476.5
Thymus	48.3	76.1	58.6
Thyroid gland	1606.8	2891.5	2567.6
Vertebrae	270.5	181.1	280.9

Table 6

Table 6	
Service	WBA $Dose_{NF}$(24h) (mJ/kg)
GSM 900	111
GSM 1800	68.5
UMTS	0.71
DECT	27.2

Table 7

Table 7							
Organs/Tissues	DoseFF(24h) (mJ/kg)			DoseNF(24h) (mJ/kg)			
	Group I	Group II	Group III	GSM 900	GSM 1800	UMTS	DECT
Adrenal gland	8.0542	1.2478	1.0307	0.0657	0.0042	0.0002	0.009
Brain grey matter	75.1546	41.6289	73.026	1001.591	403.9805	5.1154	196.942
Brain white matter	47.0083	24.7568	43.2435	339.1977	131.4774	2.0891	80.4311
Cerebellum	60.3167	39.6575	64.1688	600.746	263.661	3.1719	122.119
Cerebrospinal fluid	144.414	73.5274	125.037	1183.89	352.8581	5.3386	205.535
Eye lens	85.7567	42.6606	72.1646	420.964	164.3566	3.1778	122.346
Heart muscle	17.1356	5.7278	7.9504	1.2136	0.4966	0.0053	0.2044
Hippocampus	32.9275	18.602	30.7686	1087.305	467.0693	11.294	434.81
Hypophysis	10.8944	3.8092	5.2001	792.0851	16.6739	0.4164	16.0326
Hypothalamus	51.4839	26.5766	38.5918	1109.311	132.4475	4.8621	187.189
Kidney medulla	19.7342	5.3374	6.9412	0.2391	0.0416	0.001	0.0379
Marrow red	39.6372	20.0476	35.4825	46.212	33.5704	0.243	9.3563
Medulla oblongata	15.6263	10.7572	16.389	259.4218	22.5896	0.6837	26.3216
Midbrain	30.9304	14.0365	21.2186	553.3837	109.7424	3.7169	143.099
Nerve	16.1886	6.5076	10.1403	23.0176	4.3153	0.0911	3.5054
Pineal body	51.0771	22.9728	33.796	259.856	79.309	3.8349	147.644
Pons	13.7333	7.9369	11.287	257.5164	16.7915	0.6806	26.2026
Skin	189.519	109.786	211.767	210.4326	184.3752	1.6114	62.0373
Spinal cord	14.6193	5.4052	7.791	21.1557	5.645	0.1383	5.3251
Testis	204.748	76.1599	133.12	0.7303	0.1176	0.0008	0.0291
Thalamus	48.1802	21.6558	35.1249	389.298	86.0515	3.6337	139.897
Thymus	33.0857	11.2013	14.9688	1.4086	1.0437	0.0084	0.3215
Thyroid gland	146.608	58.1179	111.57	46.8943	39.6548	0.3662	14.0992
Vertebrae	3.057	1.3726	2.2641	7.8947	2.4835	0.0401	1.5427