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Safety of Exposure From Extremely Low Frequency Magnetic Fields During Prenatal Ultrasound Examinations in Clinicians and Pregnant Women

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Abstract: Investigations into the safety of ultrasonography in pregnancy have focused on the potential harm of ultrasound itself. However, no data have been published regarding the electromagnetic fields that ultrasound devices might produce. This study is the first to measure extremely low-frequency magnetic field (ELF-MF) exposure of clinicians and pregnant women during prenatal ultrasound examinations in the examination room from 2 different ultrasound devices and compare them with ELF-MFs during patient consultation in the consulting room.

The ELF-MF intensities that clinicians and pregnant women were exposed to were measured every 10 seconds for 40 prenatal ultrasound examinations using Philips iU22 or Accuvix V20 Prestige machines and 20 patient consultations in a consulting room using portable ELF-MF measurement devices.

The mean ELF-MF exposure of both clinicians and pregnant women was 0.18 ± 0.06 mG during prenatal ultrasound examination. During patient consultation, the mean ELF-MF exposures of clinicians and pregnant women were 0.10 ± 0.01 and 0.11 ± 0.01 mG, respectively. Mean ELF-MF exposures during prenatal ultrasound examination were significantly higher than those during patient consultations ($P < 0.001$ by Mann–Whitney *U* test).

Our results provide basic reference data on the ELF-MF exposure of both clinicians and pregnant women during prenatal ultrasound monitoring from 2 different ultrasound devices and patient consultation, all of which were below 2 mG, the most stringent level considered safe in many studies, thus relieving any anxiety of clinicians and pregnant women regarding potential risks of ELF-MFs.

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Abbreviations: ELF = extremely low-frequency, MF = magnetic field.

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INTRODUCTION

Ultrasound, widely accepted in clinical practice for more than 4 decades, can improve pregnancy outcomes by significantly reducing perinatal mortality.[1–3] However, while ultrasound examination is widely considered safe to the developing embryo or fetus, the evidence is still limited. Since ultrasound is a form of energy, it has the potential to produce biological effects that could constitute a health risk.[4] Therefore, all studies investigating the safety of the examination have focused on the potential harm of ultrasound itself. However, to the best of our knowledge, up to the present there have been no studies focused on the electromagnetic fields that ultrasound devices produce.

Between electric and magnetic fields (MFs), which comprise electromagnetic fields, most recent studies have focused on the health effects of MFs, since they are less easily blocked.[5] Along the MF spectrum, extremely low-frequency MFs (ELF-MFs), which include the 50- and 60-Hz frequencies used in power lines and electric appliances,[6] range from 3 to 3000 Hz. ELF-MF is classified as possibly carcinogenic to humans (Group 2B) by the International Agency for Research on Cancer.[7] Wertheimer and Leeper[8] first reported increased development of childhood cancer in association with proximity of the home to electrical power lines.

Little attention has been given to the potential ELF-MF risk of the many electrical devices critical to disease treatment and diagnosis in hospitals. Many groups have reported potential harmful effects of ELF-MFs including cardiovascular disease, breast cancer, cognitive dysfunction, and dementia.[9–14] Moreover, high ELF-MF exposure during pregnancy increased the risk of childhood leukemia and early pregnancy loss due to its effects on embryonic development.[15,16] Therefore, the effect of ELF-MFs produced by ultrasound devices should not be overlooked. However, there have been no reports regarding the EFL-MF levels that clinicians and pregnant women are exposed to during prenatal ultrasound examinations. To our knowledge, this study is the first to measure the ELF-MF exposure of clinicians and pregnant women during prenatal ultrasound examinations in the examination room from 2 different ultrasound devices and compare those exposure levels with ELF-MF exposure during patient consultations in the consulting room.

METHODS

Subjects

ELF-MF exposure levels of clinicians and pregnant women were measured from February to April 2015 during 40 prenatal ultrasound examinations in the examination room and 20 patient consultations in the consulting room at the Yonsei University Health System in Seoul, Korea. Twenty prenatal ultrasound examinations used a Philips iU22 (Philips Healthcare Solutions, Bothell, WA) ultrasound device, and 20 examinations used an

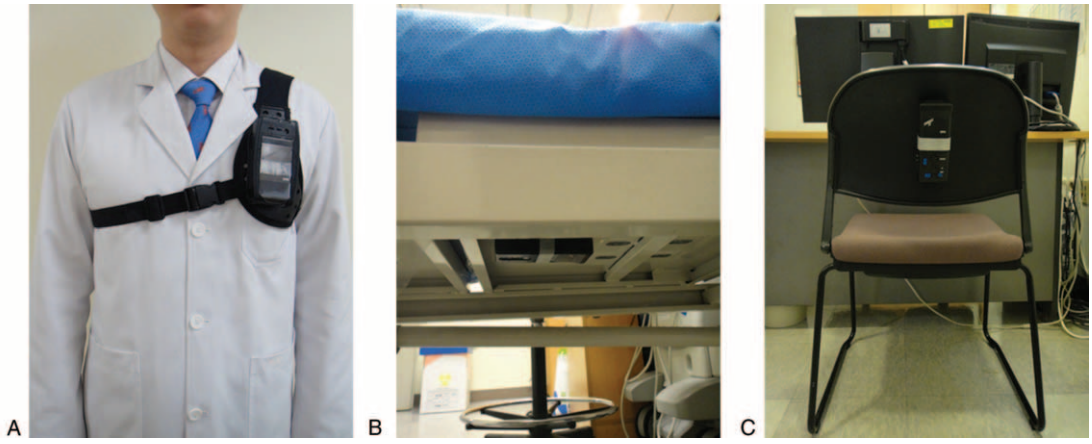

FIGURE 1. (A) The EMDEX Lite was fitted on over each clinician's heart. (B) Installation of the EMDEX II under the bed during prenatal ultrasound examination. (C) Installation of the EMDEX II at the back of the chair during patient consultation.

Accuvix V20 Prestige (Samsung Medison Co Ltd, Seoul, Korea) ultrasound device. All subjects were informed of the purpose and procedure of the experiments and provided written consent before joining the study. The Yonsei University Health System Institutional Review Board approved the study protocol (project no: 4-2015-0012).

Measurement of ELF-MFs

To measure the ELF-MF exposure levels of clinicians during prenatal ultrasound examinations and patient consultation, an EMDEX Lite (Enertech Consultants, Campbell, CA), a portable device to periodically measure ELF-MF intensity, was fitted into position over each clinician's heart during each prenatal ultrasound examination and patient consultation (Figure 1A). To measure ELF-MF exposure levels of the pregnant women during prenatal ultrasound examinations, an EMDEX II (Enertech Consultants), a portable device to periodically measure ELF-MF intensity, was installed under the bed as close as possible to the position of the maternal abdomen during prenatal ultrasound examination (Figure 1B). To measure the ELF-MF exposure levels of pregnant women during patient consultation, an EMDEX II (Enertech Consultants) was installed at the back of the chair where pregnant women typically sat during their visit with clinicians, corresponding to the nearest position to the maternal abdomen (Figure 1C). The EMDEX Lite can measure ELF-MFs between 40 and 1000 Hz and ranging from 0.1 to 700.0 mG with a resolution of 0.1 mG and accuracy of ±2%. The EMDEX II can measure ELF-MFs between 40 and 800 Hz, ranging from 0.1 to 3000.0 mG with a resolution of 0.1 mG and accuracy of ±1%. The ELF-MF intensity was sampled and stored by the devices every 10 seconds from the start to completion of each examination. The data were then retrieved by connecting the measuring device to a personal computer and analyzed by EMCALC 2000 (Enertech Consultants) analysis and graphical software.

Statistical Analyses

The mean and standard deviation of ELF-MF intensity during each examination were calculated. The Mann–Whitney *U* test was used to compare the mean ELF-MF exposures of clinicians and pregnant women during patient consultation and prenatal ultrasound examinations from 2 different ultrasound devices (Philips iU22 and Accuvix V20 Prestige). SPSS software version 20.0 (SPSS, Inc., Chicago, IL) was used for statistical analyses. All reported *P* values were 2-tailed, and *P* values <0.05 were considered statistically significant.

RESULTS

ELF-MF exposure levels during patient consultation in the consulting room and during prenatal ultrasound examination with either different ultrasound device, the Philips iU22, and the Accuvix V20 Prestige are presented in Tables 1–3, respectively. Table 4 shows the comparison of mean ELF-MF exposure of clinicians and pregnant women during patient consultation and prenatal ultrasound examination. In 40 total prenatal ultrasound examinations, mean ELF-MF exposure was 0.18 ± 0.06 mG for both clinicians and pregnant women. In 20 patient consultations, the mean ELF-MF exposures of clinicians and pregnant women were 0.10 ± 0.01 and 0.11 ± 0.01 mG, respectively. The mean ELF-MF exposures of both clinicians and pregnant women during prenatal ultrasound examination were significantly higher those during patient consultation. Furthermore, the mean ELF-MF exposures from the Philips iU22 and Accuvix V20 Prestige devices, analyzed separately, were both significantly higher ($P < 0.001$ by Mann–Whitney *U* test) than ELF-MF exposure during patient consultation (Table 5). Mean ELF-MF exposures of clinicians and pregnant women from the Philips iU22 device (0.24 ± 0.03 and 0.24 ± 0.02 mG) were significantly higher than those from the Accuvix V20 Prestige device (0.13 ± 0.02 and 0.13 ± 0.01 mG) ($P < 0.001$ by Mann–Whitney *U* test) (Table 6).

DISCUSSION

In our study, the mean ELF-MF exposure of both clinicians and pregnant women was 0.18 ± 0.06 mG ($n = 40$ each) during prenatal ultrasound examination in the examination room. During patient consultation in the consulting room, the mean ELF-MF exposures of clinicians and pregnant women were 0.10 ± 0.01 ($n = 20$) and 0.11 ± 0.01 mG ($n = 20$), respectively. Although mean ELF-MF exposure was higher during prenatal ultrasound examination than during patient consultation, all ELF-MF measurements were below 2 mG, which is considered a safe limit in many epidemiological studies and guidelines suggested by the Swedish Board for Technical Accreditation for computer monitors.[17–20] Moreover, the mean ELF-MF

TABLE 1. Exposure Levels of Clinicians and Pregnant Women to Extremely Low-Frequency Magnetic Fields During Patient Consultation in the Consulting Room

Case	Duration of Measurement (seconds)	Number of Measurements*	MF Exposure (mG) Min	Max	Mean	SD
C1	110	12	0.1	0.1	0.10	0.02
C2	50	6	0.1	0.1	0.10	0.03
C3	50	6	0.1	0.1	0.09	0.02
C4	170	18	0.1	0.1	0.12	0.02
C5	110	12	0.1	0.1	0.11	0.03
C6	110	12	0.1	0.1	0.10	0.03
C7	50	6	0.1	0.1	0.08	0.00
C8	110	12	0.1	0.1	0.09	0.02
C9	290	30	0.1	0.2	0.11	0.04
C10	410	42	0.1	0.2	0.11	0.04
C11	50	6	0.1	0.1	0.09	0.02
C12	230	24	0.1	0.1	0.10	0.03
C13	50	6	0.1	0.2	0.10	0.04
C14	110	12	0.1	0.1	0.12	0.02
C15	110	12	0.1	0.1	0.11	0.02
C16	230	24	0.1	0.1	0.12	0.03
C17	170	18	0.1	0.1	0.12	0.02
C18	50	6	0.1	0.1	0.10	0.03
C19	50	6	0.1	0.1	0.11	0.03
C20	110	12	0.1	0.1	0.11	0.03
P1	110	12	0.1	0.1	0.11	0.00
P2	50	6	0.1	0.1	0.11	0.00
P3	50	6	0.1	0.1	0.11	0.00
P4	170	18	0.1	0.1	0.12	0.01
P5	110	12	0.1	0.1	0.11	0.00
P6	110	12	0.1	0.1	0.11	0.00
P7	50	6	0.1	0.1	0.11	0.00
P8	110	12	0.1	0.2	0.12	0.03
P9	50	6	0.1	0.1	0.11	0.00
P10	230	24	0.1	0.1	0.11	0.00
P11	50	6	0.1	0.1	0.11	0.00
P12	110	12	0.1	0.1	0.12	0.01
P13	110	12	0.1	0.1	0.11	0.00
P14	230	24	0.1	0.1	0.11	0.00
P15	170	18	0.1	0.1	0.11	0.00
P16	50	6	0.1	0.1	0.11	0.00
P17	50	6	0.1	0.1	0.11	0.00
P18	110	12	0.1	0.1	0.11	0.00
P19	170	18	0.1	0.1	0.11	0.00
P20	110	12	0.1	0.1	0.12	0.01

C = clinician, P = pregnant woman, MF = magnetic field, SD = standard deviation.

* The number of measurements was counted on the basis of the repeated measurements every 10 seconds within the designated time.

TABLE 2. Exposure Levels of Clinicians and Pregnant Women to Extremely Low-Frequency Magnetic Fields During Prenatal Ultrasound Examinations in the Examination Room Using a Philips iU22 Ultrasound Device

Case	Duration of Measurement (seconds)	Number of Measurements*	MF Exposure (mG) Min	Max	Mean	SD
C1	230	24	0.2	0.5	0.27	0.09
C2	50	6	0.2	0.2	0.20	0.03
C3	170	18	0.1	1.8	0.23	0.38
C4	110	12	0.1	0.3	0.21	0.05
C5	110	12	0.1	0.5	0.21	0.13
C6	230	24	0.1	0.2	0.20	0.03
C7	110	12	0.1	0.3	0.22	0.05
C8	230	24	0.1	0.3	0.24	0.06
C9	350	36	0.1	0.4	0.22	0.07
C10	290	30	0.1	0.4	0.27	0.05
C11	170	18	0.2	0.4	0.30	0.07
C12	350	36	0.1	0.3	0.26	0.05
C13	350	36	0.1	0.4	0.23	0.08
C14	470	48	0.1	0.3	0.22	0.07
C15	110	12	0.2	0.2	0.20	0.03
C16	50	6	0.1	0.3	0.21	0.09
C17	290	30	0.1	0.5	0.21	0.08
C18	350	36	0.1	0.3	0.28	0.05
C19	230	24	0.1	0.4	0.29	0.07
C20	290	30	0.1	0.5	0.25	0.09
P1	50	6	0.1	0.3	0.22	0.07
P2	890	90	0.1	0.3	0.24	0.05
P3	1190	120	0.1	0.3	0.23	0.05
P4	1190	120	0.1	0.3	0.22	0.05
P5	50	6	0.2	0.3	0.24	0.02
P6	110	12	0.1	0.3	0.25	0.07
P7	410	42	0.1	0.3	0.23	0.03
P8	350	36	0.1	0.2	0.22	0.03
P9	110	12	0.2	0.2	0.22	0.01
P10	290	30	0.1	0.2	0.22	0.02
P11	470	48	0.2	0.2	0.22	0.01
P12	530	54	0.1	0.3	0.22	0.03
P13	230	24	0.1	0.3	0.24	0.05
P14	350	36	0.1	0.3	0.23	0.05
P15	290	30	0.1	0.3	0.23	0.04
P16	290	30	0.2	0.3	0.26	0.05
P17	230	24	0.2	0.4	0.27	0.05
P18	350	36	0.2	0.3	0.28	0.05
P19	350	36	0.1	0.4	0.25	0.06
P20	470	48	0.2	0.3	0.24	0.04

C = clinician, P = pregnant woman, MF = magnetic field, SD = standard deviation.

* The number of measurements was counted on the basis of the repeated measurements every 10 seconds within the designated time.

exposure levels during prenatal ultrasound examination and patient consultation were lower than the mean MF exposure level of 1.1 mG encountered in homes in North America.[21]

Despite the potential harmful effects of ELF-MFs in humans, few studies have investigated ELF-MFs in hospitals. We have reported on the extent to which anesthesiologists are exposed to ELF-MFs during surgery by spot measurement and repeated measurement, finding that mean ELF-MF exposures were 5.8 ± 5.2 mG.[22,23] Riminesi et al[24] measured ELF-MFs in neonatal intensive care units and reported high ELF-MF levels exceeding 2 mG. However, recent study of measuring surgeons' levels of exposure to ELF-MFs during laparoscopic and robotic

TABLE 3. Exposure Levels of Clinicians and Pregnant Women to Extremely Low-Frequency Magnetic Fields During Prenatal Ultrasound Examinations in the Examination Room Using an Accuvix V20 Prestige Ultrasound Device

			MF Exposure (mG)			
Case	Duration of Measurement (seconds)	Number of Measurements*	Min	Max	Mean	SD
C1	50	6	0.1	0.2	0.16	0.06
C2	230	24	0.1	0.1	0.12	0.02
C3	350	36	0.1	0.1	0.11	0.03
C4	50	6	0.1	0.4	0.13	0.15
C5	110	12	0.1	0.4	0.12	0.10
C6	110	12	0.1	0.1	0.11	0.03
C7	110	12	0.1	0.1	0.13	0.01
C8	230	24	0.1	0.3	0.14	0.04
C9	290	30	0.1	0.2	0.12	0.02
C10	110	12	0.1	0.1	0.11	0.05
C11	230	24	0.1	0.2	0.13	0.02
C12	290	30	0.1	0.2	0.12	0.03
C13	350	36	0.1	0.2	0.11	0.04
C14	170	18	0.1	0.3	0.16	0.05
C15	230	24	0.1	0.1	0.12	0.05
C16	290	30	0.1	0.1	0.11	0.05
C17	350	36	0.1	0.1	0.15	0.01
C18	110	12	0.1	0.4	0.14	0.02
C19	170	18	0.1	0.2	0.11	0.08
C20	350	36	0.1	0.1	0.12	0.03
P1	290	30	0.1	0.1	0.12	0.01
P2	50	6	0.1	0.1	0.12	0.01
P3	590	60	0.1	0.2	0.13	0.02
P4	350	36	0.1	0.2	0.14	0.02
P5	110	12	0.1	0.2	0.14	0.05
P6	170	18	0.1	0.2	0.13	0.02
P7	170	18	0.1	0.2	0.12	0.03
P8	230	24	0.1	0.2	0.13	0.04
P9	830	84	0.1	0.2	0.12	0.03
P10	590	60	0.1	0.2	0.12	0.02
P11	170	18	0.1	0.2	0.14	0.04
P12	50	6	0.1	0.2	0.12	0.06
P13	290	30	0.1	0.2	0.13	0.02
P14	110	12	0.1	0.1	0.12	0.04
P15	50	6	0.1	0.1	0.12	0.02
P16	110	12	0.1	0.2	0.13	0.03
P17	230	24	0.1	0.2	0.13	0.03
P18	110	12	0.1	0.2	0.12	0.03
P19	290	30	0.1	0.2	0.14	0.03
P20	350	36	0.1	0.2	0.13	0.04

C = clinician, P = pregnant woman, MF = magnetic field, SD = standard deviation.
* The number of measurements was counted on the basis of the repeated measurements every 10 seconds within the designated time.

surgeries showed mean exposure levels of 0.06 ± 0.01 and $0.03 \pm 0.00\,\mu T$, respectively, with significant differences.[25] Although ELF-MFs during laparoscopic and robotic surgeries were lower than those during prenatal ultrasound examination and patient consultation, ELF-MFs during prenatal ultrasound examination in the examination room and during patient consultation in the consulting room were below 2 mG, which is lower than those reported in most of other studies of ELF-MFs in hospitals.

We measured clinicians' exposure levels of ELF-MFs at the heart since many studies have reported the potential harmful influences of ELF-MFs on the heart.[9,26] Moreover, locating the measuring devices over the heart had the least interference over clinicians' activity. By contrast, we measured the ELF-MF exposure of pregnant women near the maternal abdomen, since our primary interest was the intensity of ELF-MFs near the fetus. ELF-MFs have been reported to influence embryonic development causing early pregnancy loss.[16] Measuring the ELF-MFs at the maternal abdomen could be informative regarding the influence of ELF-MFs on the fetus through the maternal body.

TABLE 4. Comparisons of the Mean Extremely Low-Frequency Magnetic Field Exposures of Clinicians and Pregnant Women During Patient Consultation and Prenatal Ultrasound Examination

	MF Exposure (mG)		
Cases	Patient Consultation	Prenatal Ultrasound Examination†	P*
Clinicians	0.10 ± 0.01 (n = 20)	0.18 ± 0.06 (n = 40)	<0.001
Pregnant women	0.11 ± 0.01 (n = 20)	0.18 ± 0.06 (n = 40)	<0.001
P*	0.017	0.510	

MF = magnetic field. Values are given as mean ± standard deviation.
* P values were obtained by the Mann–Whitney U test.
† MF exposures in clinicians and pregnant women with the Philips iU22 and Accuvix V20 Prestige systems were both significantly higher than MF exposure during patient consultation ($P < 0.001$ by Mann–Whitney U test) (Table 5).

TABLE 5. Comparisons of the Mean Extremely Low-Frequency Magnetic Field Exposures of Clinicians and Pregnant Women During Patient Consultation and Prenatal Ultrasound Examination Using Philips iU22 and Accuvix V20 Prestige Devices

	MF Exposure (mG)		
Cases	Patient Consult	Philips iU22	P*
Clinicians	0.10 ± 0.01 (n = 20)	0.24 ± 0.03 (n = 20)	<0.001
Pregnant women	0.11 ± 0.01 (n = 20)	0.24 ± 0.02 (n = 20)	<0.001
	Patient Consult	**Accuvix V20 Prestige**	**P***
Clinicians	0.10 ± 0.01 (n = 20)	0.13 ± 0.02 (n = 20)	<0.001
Pregnant women	0.11 ± 0.01 (n = 20)	0.13 ± 0.01 (n = 20)	<0.001

MF = magnetic field. Values are given as mean ± standard deviation.
* P values were obtained by the Mann–Whitney U test.

TABLE 6. Comparisons of the Mean Extremely Low-Frequency Magnetic Field Exposures of Clinicians and Pregnant Women During Prenatal Ultrasound Examination Using Philips iU22 and Accuvix V20 Prestige Ultrasound Devices

	MF Exposure (mG)		
Cases	**Philips iU22**	**Accuvix V20 Prestige**	P^*
Clinicians	0.24 ± 0.03 (n = 20)	0.13 ± 0.02 (n = 20)	<0.001
Pregnant women	0.24 ± 0.02 (n = 20)	0.13 ± 0.01 (n = 20)	<0.001
P^*	0.435	0.267	

MF = magnetic field. Values are given as mean ± standard deviation.
* *P* values were obtained by the Mann–Whitney *U* test.

The ELF-MFs from the Philips iU22 ultrasound device were significantly higher than those from the Accuvix V20 Prestige device, but the ELF-MF levels of both devices were below 2 mG. First, the monitor of the Philips iU22 is bigger than that of the Accuvix V20 Prestige device and since more powers and currents are consumed when the monitor is bigger,[27] the ELF-MF levels would be significantly higher from the Philips iU22 ultrasound device. Second, since the distance from the power line to the clinicians and pregnant women was closer in the case of the Philips iU22 than in the case of Accuvix V20 Prestige device and ELF-MFs decrease quickly as the inverse square of the distance,[28] this would cause the difference in ELF-MF levels between 2 ultrasound devices. Other than these, difference might be caused by the 2 systems adopting different monitors, electric circuits, and power systems. However, since there is no specific information regarding the components of 2 systems, we could not be certain. Although we do not know the precise reasons underlying the difference in ELF-MF levels between the Philips iU22 and Accuvix V20 Prestige devices, manufacturers should consider not only the performance of ultrasound itself but also the safety of ELF-MF exposure levels.

It is still unclear what level of ELF-MF is harmful to humans, especially over the stages of embryonic development. Several studies have investigated the harmful effects of ELF-MFs in animal and human cells,[29] but more research is needed to understand the exact pathogenesis underlying the effects of ELF-MFs in humans. Until the precise level of ELF-MFs that is harmful to humans is determined, the ELF-MFs from electronic devices should not be overlooked. These devices originally intended to aid in the diagnosis and treatment of disease should not cause harmful effects themselves.

Our study has several limitations. First, although we tried to maintain the same settings in every consultation, there may have been slight differences across cases. However, these slight differences are unlikely to significantly affect the observed ELF-MF exposure levels. Second, the ELF-MF exposure levels during prenatal ultrasound monitoring significantly differed according to the ultrasound device used. However, since our institution has only 2 different ultrasound devices, the Philips iU22 and Accuvix V20 Prestige, we could only compare ELF-MFs from these 2 devices. Future studies comparing ELF-MF levels from other ultrasound devices and exploring the factors underlying this difference would be valuable.

In conclusion, the mean ELF-MF exposures of clinicians and pregnant women during prenatal ultrasound examinations were significantly higher than the mean ELF-MF exposures of clinicians and pregnant women during patient consultation. However, ELF-MF exposure levels in both settings were considerably lower than 2 mG, the most stringent level considered safe in many studies. To our knowledge, this study is the first to provide basic reference data on the ELF-MF exposure levels of both clinicians and pregnant women during prenatal ultrasound monitoring and patient consultation. Moreover, we compared ELF-MFs from 2 different ultrasound devices and found that ELF-MF exposure significantly differed between 2 different ultrasound devices. Although our results indicated ELF-MF levels less than 2 mG, we should not overlook the effects of ELF-MFs and remain cautious.

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