0008-3194/2004/273–281/$2.00/©JCCA 2004

Comparison of a triaxial fluxgate magnetometer and Toftness sensometer for body surface EMF measurement

John Zhang, MD, PhD*
Dave Toftness, DC***
Brian Snyder, DC*
Dennis Nosco, PhD*
Walter Balcavage, PhD**
Gabi Nindl, PhD**

Introduction*: The use of magnetic fields to treat disease has intrigued mankind since the time of the ancient Greeks. More recently it has been shown that electromagnetic field (EMF) treatment aids bone healing, and repetitive transcranial magnetic stimulation (rTMS) appears to be beneficial in treating schizophrenia and depression. Since external EMFs influence internal body processes, we hypothesized that measurement of body surface EMFs might be used to detect disease states and direct the course of subsequent therapy. However, measurement of minute body surface EMFs requires use of a sensitive and well documented magnetometer. In this study we evaluated the sensitivity and frequency response of a fluxgate magnetometer with a triaxial probe for use in detecting body surface EMF and we compared the magnetometer readings with a signal from a Toftness Sensometer, operated by an experienced clinician, in the laboratory and in a clinical setting.*

Methods*: A Peavy Audio Amplifier and variable power output Telulex signal generator were used to develop 50 μT EMFs in a three coil Merritt coil system. A calibrated magnetometer was used to set a 60 Hz 50 μT field in the coil and an ammeter was used to measure the current required to develop the 50 μT field. At frequencies other than 60 Hz, the field strength was maintained at 50 μT by adjusting the Telulex signal output to keep the current constant. The field generated was monitored using a 10 turn coil connected to an oscilloscope. The oscilloscope reading indicated that the field strength was the same at all frequencies tested. To determine if there was a correspondence between the signals detected by a*

Introduction *: L'utilisation des champs magnétiques pour traiter une maladie a toujours intrigué l'humanité depuis l'antiquité grecque. Récemment, il a été démontré qu'un traitement à l'aide d'un champ électromagnétique (EMF) permet une guérison osseuse et qu'une stimulation magnétique transcranienne répétitive (SMTr, ou rTMS en anglais) est efficace pour traiter la schizophrénie et la dépression. Puisque le champ électromagnétique externe influence le fonctionnement interne de l'organisme, nous avons posé l'hypothèse qu'une mesure du champ électromagnétique du corps doit être utilisée pour déterminer l'état de la maladie et orienter la thérapie subséquente. Toutefois, la mesure en minute du EMF exige l'utilisation d'un magnétomètre sensible et bien documenté. Au cours de cette étude, nous avons évalué la sensibilité et la réponse de fréquence d'un magnétomètre discriminateur de flux triaxial et nous avons comparé ses lectures au signal du détecteur de radiation Toftness, actionné par un clinicien compétent, dans le laboratoire et en clinique.*

Méthodologie *: Un amplificateur audio Peavy et un générateur de signaux avec puissance de sortie variable Telulex ont été utilisés pour développer un champ électromagnétique de 50 μT dans une bobine Merritt de trois axes. Un magnétomètre calibré a permis de réaliser un champ de 60 Hz 50 μT dans la bobine, et un ampèremètre a mesuré l'intensité de courant nécessaire pour développer un champ de 50 μT. Dans le cas des fréquences différentes de 60 Hz, la force du champ a été maintenue à 50 μT en réglant le signal de sortie Telulex afin de garder le courant constant. Le champ généré a été*

* Logan College of Chiropractic, 1851 Schoettler Road, Chesterfield, MO 63006-1065, USA.
Phone 636-227-2100, Ext. 320.
** Terre Haute Center for Medical Education, Indiana University School of Medicine 47803, USA.
*** In private practice.
© JCCA 2004.

fluxgate magnetometer (FGM1) and the Toftness Sensometer both devices were placed in the Merritt coil and readings were recorded from the FGM1 and compared with the ability of a highly experienced Toftness operator to detect the 50 μT field. Subsequently, in a clinical setting, FGM1 readings made by an FGM1 technician and Sensometer readings were made by 4 Toftness Sensometer operators, having various degrees of experience with this device. Each examiner obtained instrument readings from 5 different volunteers in separate chiropractic adjusting rooms. Additionally, one of the Toftness Sensometers was equipped with an integrated fluxgate magnetometer (FGM2) and this magnetometer was used to obtain a second set of EMF readings in the clinical setting.

***Results**: The triaxial fluxgate magnetometer was determined to be moderately responsive to changes in magnetic field frequency below 10 Hz. At frequencies above 10 Hz the readings corresponded to that of the ambient static geofield. The practitioner operating the Toftness Sensometer was unable to detect magnetic fields at high frequencies (above 10 Hz) even at very high EMFs. The fluxgate magnetometer was shown to be essentially a DC/static magnetic field detector and like all such devices it has a limited frequency range with some low level of sensitivity at very low field frequencies. The inter-examiner reliability of four Toftness practitioners using the Sensometer on 5 patients showed low to moderate correlation.*

***Conclusions**: The fluxgate magnetometer although highly sensitive to static (DC) EMFs has only limited sensitivity to EMFs in the range of 1 to 10 Hz and is very insensitive to frequencies above 10 Hz. In laboratory comparisons of the Sensometer and the fluxgate magnetometer there was an occasional correspondence between the two instruments in detecting magnetic fields within the Merritt coil but these occasions were not reproducible. In the clinical studies there was low to moderate agreement between the clinicians using the Sensometer to diagnosing spinal conditions and there was little if any agreement between the Sensometer and the fluxgate magnetometer in detecting EMFs emanating from the volunteers body surface.*
(JCCA 2004; 48(4):273–281)

surveillé à l'aide d'une bobine de 10 tours branchée à un oscilloscope. La lecture de l'oscilloscope a indiqué que la force du champ est demeurée stable peu importe la fréquence testée. Afin de déterminer s'il existe une correspondance entre les signaux détectés par le magnétomètre discriminateur de flux et le détecteur de radiation Toftness, les deux dispositifs ont été placés dans la bobine Merritt et les lectures ont été enregistrées à partir du magnétomètre et comparées à l'habileté d'un opérateur Toftness très compétent pour détecter un champ de 50 μT. Ensuite, en milieu clinique, les lectures du magnétomètre relevées par un technicien et les lectures du détecteur de radiation ont été effectuées par 4 opérateurs Toftness, possédant différents niveaux de compétence avec ce dispositif. Chaque examinateur a recueilli les lectures provenant de 5 volontaires de différentes salles d'ajustement chiropratique. De plus, un des détecteurs de radiation Toftness était doté d'un magnétomètre discriminateur de flux intégré. Ce dernier a permis d'obtenir un second groupe de lectures en milieu clinique.

***Résultats** : Le magnétomètre discriminateur de flux triaxial a démontré une réaction modérée aux modifications de fréquence inférieure à 10 Hz du champ magnétique. Les lectures à des fréquences supérieures à 10 Hz étaient similaires à celle d'un géochamp statique ambiant. Le médecin qui a actionné le détecteur de radiation Toftness n'a pu détecter un champ magnétique à de hautes fréquences (supérieures à 10 Hz) même lorsque le champ électromagnétique était très élevé. Le magnétomètre discriminateur de flux est donc essentiellement un détecteur de champ magnétique statique et, tout comme les autres dispositifs semblables, il possède une gamme limitée de fréquences et une faible sensibilité lors de très faibles fréquences de champ magnétique. L'interexamen de la fiabilité des quatre médecins qui ont utilisé le détecteur de radiation Toftness sur 5 patients a démontré une corrélation faible à moyenne.*

***Conclusions** : Même si le magnétomètre discriminateur de flux a démontré une forte sensibilité au champ magnétique statique, sa sensibilité est limitée aux champs de 1 et 10 Hz. De plus, il est insensible aux fréquences supérieures à 10 Hz. Lors de comparaisons en laboratoire entre le détecteur de radiation et le*

magnétomètre, on a remarqué une correspondance occasionnelle entre les deux instruments dans la détection des champs magnétiques situés à l'intérieur de la bobine Merritt mais ces occasions ne sont pas reproductibles. Au cours des études cliniques, les cliniciens qui ont utilisé le détecteur de radiation Toftness pour diagnostiquer les troubles vertébraux s'entendent peu ou modérément et il existe pratiquement aucune entente concernant la capacité du détecteur de radiation et du magnétomètre discriminateur de flux de détecter les champs magnétiques émanant des corps des volontaires.
(JACC 2004; 48(4):273–281)

KEY WORDS: Toftness, Magnetometer, EMF, Chiropractic.

MOTS CLÉS : Toftness, magnétomètre, EMF, chiropratique.

Introduction

The use of electric and magnetic forces to treat disease has intrigued the general public and the scientific community since the time of the ancient Greeks[1] and modern medicine has shown that electromagnetic field (EMF) therapy is beneficial for bone healing and perhaps for inflammation.[2,3,4] In recent years, however, concern over alleged cancer inducing effects of power frequency and cell phone frequency EMFs has dampened clinical interest in EMFs as a therapeutic or diagnostic tool[5–7] and, although there have been some attempts to measure body surface EMFs the predictive nature of the body's internal EMF responses to external stimuli has not been investigated.[8,9]

In order to determine if body surface EMFs have any clinical significance it is important to develop and characterize assessment tools capable of detecting and reporting changes in the body's EMF. A great deal of research has been applied to develop reliable instrumentation to measure electrical signals from major muscle groups (EMG), the brain (EEG) the heart (ECG) and measurement of body surface variations in temperature (thermograph), electromagnetic fields (EMF) and nerve impulses (nerve conduction velocity).[10–14] Although most of the instruments that make these measurements were developed by other medical specialties, over the last 20 years many of these tools have been applied to chiropractic. Chiropractic-specific assessment tools have been slow to develop, and the ones that do exist are often not adequately tested for sensitivity and specificity. An example of an assessment tool used by chiropractors in clinical practice is the Toftness Sensometer[14] (also referred to as Sensometer). Although originally thought to detect EMF radiations from body surfaces the proponents of this device have been unable to show what this device actually measures. As a result, the Toftness Sensometer has not gained general acceptance within the chiropractic community. Nevertheless, the literature contains a number of reports of the success of the Toftness Chiropractic technique (driven by the findings from the Sensometer) in clinical practice[14–16] as well as reports that indicate that use of the device in the hands of less trained users may result in poor diagnoses.[17–21]

The purpose of this study was to use electronic test equipment to determine the frequency sensitivity of a commercial hand-held, fluxgate magnetometer (FGM1) and to determine if a correlation could be found between the readings of the magnetometer and Toftness Sensometer readings obtained by a trained practitioner. Finally, we studied the ability of the fluxgate magnetometer and the Toftness Sensometer to produce clinically useful information in a small clinical trial using human volunteers to assess inter-examiner and inter-instrument reliability.

Methods

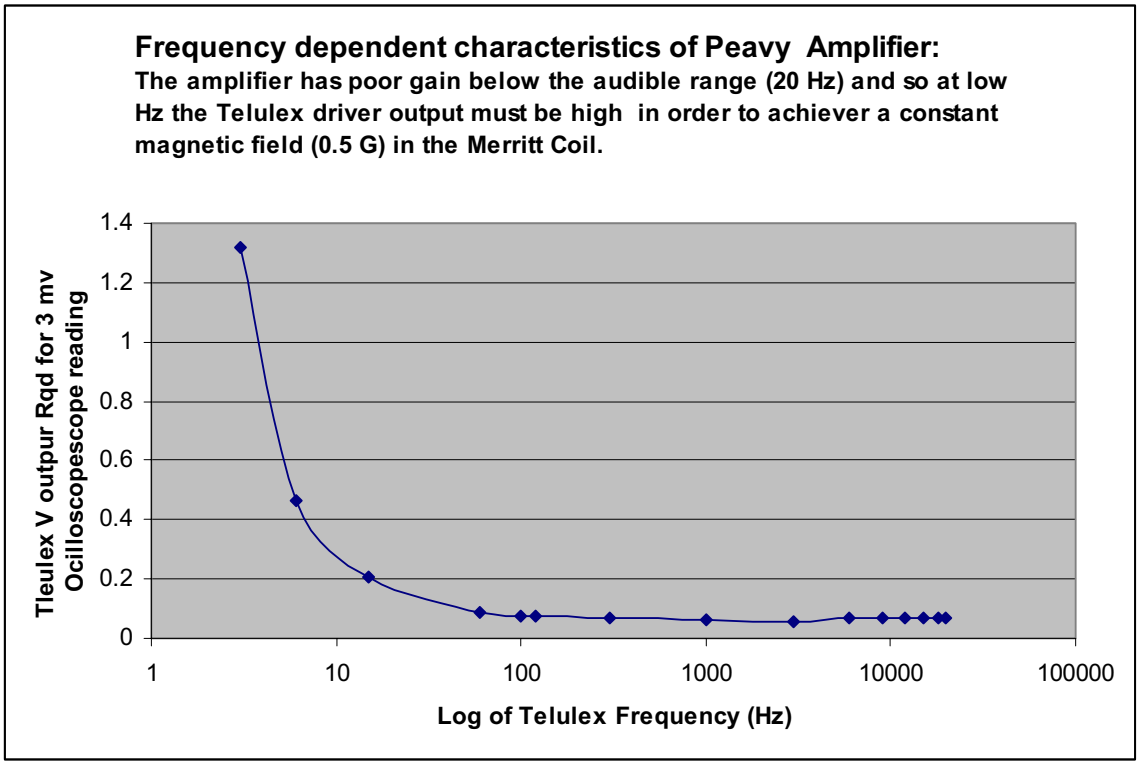
The inter-examiner and inter-instrument reliability study was approved through an IRB at Logan College of Chiropractic. All subjects signed consent forms and subject information was kept in a locked file cabinet to insure confidentiality. This project involved three separate sets of comparative studies:

1. A comparison of the ability of the Sensometer and the fluxgate magnetometer (FGM1) to pick up signals from an electromagnetic field generator in a laboratory setting.
2. A clinical comparison of inter-examiner reliability of Toftness practitioners using 5 volunteer clinical subjects.
3. A clinical comparison of Toftness Sensometer readings with readings from two fluxgate magnetometers (FGM1 and FGM2) on the same set of clinical subjects.

EMF testing

The EMF frequency response of FGM1 and a Sensometer were tested at Indiana University in Terre Haute IN. A Telulex signal generator with variable power output and operated in the sinusoidal mode was coupled to a Peavy Audio Amplifier that was operated at a constant volume setting (Figure 1). The output of the Peavy was fed to a 3 coil Merritt Coil system described earlier.[23] The field frequency and strength were monitored and regulated using a 2 inch diameter, 10 turn detector coil (16 gauge enameled copper wire) placed in the Merritt Coil and connected to a Tektronics model 5103N oscilloscope equipped with a 5A20N differential amplifier. In operation, when the test EMF-frequency was changed the power output of the Telulex was adjusted to achieve a constant current through the Merritt coil and a constant (3 mV) signal on the oscilloscope screen (sensitivity 0.5 mV/division). At 60 Hz, a 3 mV oscilloscope signal corresponded to a

Figure 1
Frequency response of the EMF testing equipment.



magnetic field of 50 μT as measured by a gauss meter (Magnetic Instruments Inc., model 908) which is optimized for 60 Hz analyses. Since current through the coil and the magnetic field detected by the oscilloscope reading were the same at all frequencies tested it can be assumed that the magnetic field strength was approximately 50 μT at all frequencies.

The commercial magnetometer tested in the study was a Triaxial Fluxgate Magnetometer FGM-5DTAA (Walker Scientific, Worcester, Massachusetts 1999) with five-digit display and reported resolution of 0.001 μT in a 100 μT field. Figure 2 shows a picture of the magnetometer. The Sensometer is shown in Figure 3 and consists of an open cone with a Mylar® membrane. To compare the ability of the two instruments to detect EMFs, the Sensometer and the probe of FGM1 were placed in the center of the Merritt coil and random EMF frequencies were generated by a Te-

Figure 2
Triaxial Fluxgate Magnetometer FGM-5DTAA. This is EMF1 in Table 2.

Figure 3
Toftness Sensometer used by DCs. The EMF2 in Table 2 looked like Toftness Sensometer except it has an EMF fluxgate magnetometer inside the device.

lulex operator. Blinded readings were obtained from the magnetometer and the Sensometer by skilled individuals.

Inter-examiner agreement in clinical testing

Four Toftness practitioners (20, 15, 10 and 5 years in practice with the Sensometer) and a researcher using the same fluxgate magnetometer, FGM1, described above[14] performed a comparative assessment on 5 human volunteers who reported experiencing pain. Each volunteer was in a separate chiropractic adjusting room equipped with wood non-motorized chiropractic adjustment tables. Each treatment room was assigned a number from 1 to 5.

The five examiners (four Toftness practitioners, one FGM 1 technician) were assigned at random to treatment rooms and after entering the room they asked the volunteer to lie face down on the table, a position the subject maintained during the entire examination period. The four Toftness examiners had been pre-instructed to rate the readings they obtained for the four spinal segments (cervical, thoracic, lumbar and sacral) on a 1–5 scale with 1 being no reading and 5 being the highest reading they normally see in practice. One Toftness examiner (doctor 2) also had a Toftness Sensometer equipped with an integrated fluxgate magnetometer (FGM2) also obtained from Walker Scientific (Worcester, Massachusetts 1999). Readings from this magnetometer are shown as FGM2 in Table 2. Doctor 2 made a Sensometer reading and an EMF reading on each patient he examined. All EMF readings were the actual reading from the fluxgate magnetometer corrected for the ambient magnetic field in each room. A data entry person was assigned to each room and after making their measurement(s) the examiner(s) reported their readings to the data entry person and left the room closing the door behind them. They then moved to the next highest numbered room (moving to Room #1 after completing Room #5) and waited for the examiner in that room to complete their task. This process was continued until each examiner had seen each subject once. The entire process, which was designed to minimize artifacts from extended patient time in the prone position, took 12 minutes and 55 seconds to complete. Data was entered into a spreadsheet for further analysis. Kappa analysis was used for the inter-examiner reliability comparisons and for all other comparison analyses. A Kappa reading closer to 1 indicates higher degree of correlation and a reading closer to 0 shows a low degree of correlation. All statistical analysis was performed using SPSS 11.5 (SPSS Inc, Chicago).

Results

Comparison of the ability of a Sensometer and a fluxgate magnetometer (FGM1) to detect sinusoidal magnetic fields

With the triaxial probe of the fluxgate magnetometer located in the Merritt coil we found the instrument to have decreasing sensitivity with increasing sinusoidal EMF frequency over the range of 3 Hz to 10 Hz. At frequencies below 10 Hz the instrument reported the sum of the local geofield plus some fraction of the applied oscillating test field. At frequencies above 10 Hz the magnetometer was insensitive to sinusoidal test frequencies reporting only the value of the local static geofield (data not shown). A Toftness Sensometer (with an integrated fluxgate magnetometer) was also located in the Merritt coil. Using the traditional chiropractic technique the highly experienced Toftness practitioner was unable to detect magnetic fields at frequencies above 10 Hz, even at very high Telulex power outputs while at frequencies below 10 Hz the Toftness practitioner occasionally reported detecting a change in the Sensometer output but this was not reproducible (Table 1). The fluxgate magnetometer (FGM2) associated with the Toftness device was

Table 1
EMF detection by a Toftness practitioner at varying EMF frequencies at a field intensity of 50 micro Tesla.

Frequency (Hz)	Field detected
5	No
5.2	No
5.4	Yes
5.6	No
5.8	No
6.0	No
6.2	No
6.4	No
6.6	No
6.8	No
5.4	No
7.0	No
7.2	No
7.4	No
7.6	Yes
7.8	No
8.0	Yes
7.6	No
8.2	No

also found to be somewhat sensitive to changes in magnetic field frequency in the 5 to 10 Hz range, much like the FGM1, and insensitive to fields above 10 Hz. Both of the fluxgate magnetometers, FGM1 and FGM2 are essentially DC/static magnetic field detectors and like all such devices they have a limited frequency range with some low level of sensitivity at very low field frequencies.

Clinical comparison of inter-examiner reliability of Toftness practitioners

The results of Kappa analysis presented in Table 2 show no correlation in any of the readings reported by doctors 1 and 2. On the other hand, Doctors 1 and 3 showed high correlation on lumbar and sacral reading but low correlation in the readings from the cervical and thoracic

Table 2
Inter-examiner and inter instrument agreement

Four Toftness practitioners (doctor 1–doctor 4) using Sensometers and one technician equipped with a magnetometer (FGM1) made serial readings on the spines of 5 volunteers experiencing pain. The inter-examiner Kappa correlations values are shown in rows 1–6. Rows 7–14 show Kappa correlation data between the fluxgate magnetometers (FGM1 or FGM2) and Sensometer readings made on the same patients. Row 15 is the Kappa correlation data for readings made on a single volunteer comparing FGM1 and FGM2. Statistical Kappa results were evaluated as follows Kappa values 0 = no correlation, Kappa values 0.1 – 0.3 = low correlation, Kappa value 0.4 = low to moderate correlation, Kappa values 0.5 and 0.6 = moderate correlation, Kappa value 0.7 = moderate to high correlation, Kappa values 8 and 9 = high correlation, Kappa value 1.0 = perfect correlation

= sum	Kappa Correlation	Cervical	Thoracic	Lumbar	Sacral
1	doctor 1:2	0.39	0.38	0.19	0
2	doctor 1:3	0.19	0.38	1	1
3	doctor 1:4	0.39	0.79	0.39	0.39
4	doctor 2:3	0.32	0.66	0.16	0.16
5	doctor 2:4	0.79	0.79	0.39	0.39
6	doctor 3:4	0.19	1	0.59	0.39
	Highly Correlated	**1**	**3**	**1**	**1**
7	doctor 1:FGM 1	0.39	0.02	0	0
8	doctor 1:FGM 2	0.39	0.59	0.39	0.19
9	doctor 2:FGM 1	0.02	0.39	0.59	0.59
10	doctor 2:FGM 2	0.38	0.59	0.18	0.59
11	doctor 3:FGM 1	0.02	0.39	0.19	0.08
12	doctor 3:FGM 2	0.01	0.79	0.39	0.19
13	doctor 4:FGM 1	0.18	0.19	0.19	0.39
14	doctor 4:FGM 2	0.19	0.39	0.39	0.18
	Highly Correlated	**0**	**1**	**0**	**0**
15	FGM1:FGM2	0.59	0.59	0.312	0.38

regions. Doctors 1 and 4 reported highly correlated Sensometer readings at the thoracic area but not on other three regions. Doctors 2 and 3 reported moderate to good agreement in Sensometer readings at the thoracic area but not on the other three regions. Doctors 2 and 4 reported highly correlated Sensometer readings at the cervical and thoracic areas but their lumbar and sacral correlations were low. Doctor 3 and 4 had high correlation on the thoracic area and moderate correlation in the lumbar region.

A clinical comparison of Sensometer readings with readings from two fluxgate magnetometers (FGM1 and FGM2)

Statistical comparisons were also made between Sensometer readings and the two fluxgate magnetometers (FGM1 and FGM2) used in this study. Out of the 32 correlations between Sensometer and magnetometer readings (Table 2, Doctors 1–4 vs. FGM1 or Doctors 1–4 vs. FGM2) there was one high correlation, 5 moderate correlations and the remaining correlations (26) were low or moderately low. The average Kappa value for these 32 correlations was 0.3 indicating a general lack of correlation between Sensometers and magnetometers readings. The two magnetometers FGM1 and FGM2 were also statistically compared one to the other by calculating Kappa values for readings made by both instruments on one of the patients (Table 2, FGM1:FGM2). The average Kappa value of the 4 comparisons is 0.47 indicating a low or moderate correlation between the two instruments.

Discussion

The fluxgate magnetometers we used to study body surface EMFs are most useful for monitoring static EMFs. These devices have markedly reduced sensitivity at frequencies up to 10 Hz and they are essentially insensitivity to EMFs with frequencies above 10Hz. This limits these magnetometers to use in static and low frequency measurements of body surface EMFs. Although there is only limited information on the actual frequency range of body surface EMFs a recent study suggests that they may be in the range of 0–70 Hz.[2,9] The fluxgate magnetometers used in this study are capable of detecting 0–10 Hz EMF with the digital display (tested in the study) and 0–50 Hz with analog display (not tested in the study).

Toftness practitioners have been using Toftness handheld device for 50 years to aid the location and adjustment of subluxation claiming that body surface energy in some form was detected by the device. This claim was partially supported by clinical studies that showed a beneficial effect of the Toftness-based adjustment in various clinical conditions. However it has not been determined whether the Sensometer can detect body surface EMFs. In the current study, an experienced Toftness practitioner was blinded and asked to verify the presence of a test EMF of constant field strength at varying frequencies. Under the controlled laboratory conditions it was found that the Toftness practitioner could not detect 50 μT EMF with sinusoidal frequencies between 10 Hz and 10,000 Hz. However the practitioner did detect some low frequency EMFs but these results could not be reproduced.

The inter-examiner agreement when examining volunteers with a Sensometer showed mixed results. Doctor 2 and 3 had perfect scores on the lumbar and sacral regions while doctor 1 and 2 showed no correlation of their Sensometer readings. Among the four body regions tested in the study, namely the cervical, thoracic, lumbar and sacral, with 24 pairs of comparisons, the thoracic region had 3 high correlated readings out of the 24 possible recordings. In general, the inter-examiner agreement was low. This modest level of agreement is typical for many subjective measurements.[19,20] One potential cause for the differences between the Toftness practitioners could have been the use of Toftness practitioners of different amounts of experience. Although it was not quantitatively analyzed casual inspection of the data seemed to show that for chiropractors with more experience, their findings tended to better correlated (higher Kappa) than when an experienced practitioner was compared to a less experience one.

The moderate to low correlation (Kappa 0.59, 0.59, 0.31, 0.38 from the four spinal regions) between the two fluxgate magnetometers demonstrated varying results even though the two fluxgate magnetometers came from the same manufacturer. Differences could be attributed to different housings for the electronic components of detectors and different spatial locations of the detectors probes. For example, the triaxial probe of FGM1 was closer to the spine than the probe of FGM2.

There are many limitations in the study. The most obvious limitation is the low sensitivity of the fluxgate magnetometers used to measure body surface EMFs with frequencies greater than 10 Hz. In addition environmental EMFs including static and ambient power frequency fields can modulate and obscure the comparatively miniscule body surface EMF generated by underlying tissues and organs. Finally, in the inter-examiner study, varying gender, age and pain level of the volunteers all could potentially affect the results.

Conclusions

It is clear that the under controlled laboratory conditions the Toftness Sensometer can not reliably detect sinusoidal EMFs of relatively high field strength (50 μT) in the frequency range between 5 Hz and 10,000 Hz. However if there is some relationship between measurements made using magnetometers and Toftness Sensometers it may be in the 5 Hz to 10 Hz frequency range where the Toftness Sensometer seemed to detect, albeit not reproducibly, 50 μT EMFs. This observation can be viewed as the starting point for developing a testable hypothesis. Finally, the inter-examiner reliability of the Sensometer/practitioner couple achieved moderate reliability (mean of inter-examiner Kappa values = 4.7) in patient testing but the fluxgate magnetomer/Sensometer comparisons yielded lower reliability correlations (mean Kappa value of 0.3 for Sensometer versus FGM1 and FGM2). More extensive test of the questions examined here would require a well-designed and controlled double-blind clinical studied.

References

1 Pilla AA. Low-intensity electromagnetic and mechanical modulation of bone growth and repair: are they equivalent? J Orthop Sci 2002; 7(3):420–428.

2 Pilla AA, Muehsam DJ, Markov MS, Sisken BF. EMF signals and ion/ligand binding kinetics: prediction of bioeffective waveform parameters. Bioelectrochem Bioenerg 1999 Feb; 48(1):27–34.

3 Nindl G, Balcavage WX, Vesper DN, Swez JA, Wetzel BJ, Chamberlain JK, Fox MT. Experiments showing that electromagnetic fields can be used to treat inflammatory diseases. Biomed Sci Instrum 2000; 36:7–13.

4 Ciombor DM, Lester G, Aaron RK, Neame P, Caterson B. Low frequency EMF regulates chondrocyte differentiation and expression of matrix proteins. J Orthop Res 2002 Jan; 20(1):40–50.

5 Ahlbom IC, Cardis E, Green A, Linet M, Savitz D, Swerdlow A; ICNIRP (International Commission for Non-Ionizing Radiation Protection) Standing Committee on Epidemiology. Review of the epidemiologic literature on EMF and Health. Environ Health Perspect 2001 Dec; 109 Suppl 6:911–933.

6 Freude G, Ullsperger P, Eggert S, Ruppe I. Microwaves emitted by cellular telephones affect human slow brain potentials. Eur J Appl Physiol 2000 Jan; 81(1–2):18–27.

7 Blackman CF, Most B. A scheme for incorporating DC magnetic fields into epidemiological studies of EMF exposure. Bioelectromagnetics 1993; 14(5):413–431.

8 Stojan M, Boudik F, Anger Z, Charvat A. The methodology of clinical analysis of electric heart field. Physiol Res 1993; 42(2):85–90.

9 Hart RA, Gandhi OP. Comparison of cardiac-induced endogenous fields and power frequency induced exogenous fields in an anatomical model of the human body. Phys Med Biol 1998 Oct; 43(10):3083–3099.

10 Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Heart rate variability: Standards of measurement, physiological interpretation, and clinical use. Circulation 1996; 93:1043–1065.

11 Soderberg GL, Knutson LM. A guide for use and interpretation of kinesiologic electromyographic data. Phys Ther 2000 May; 80(5):485–498.

12 Jensen-Urstad K, Saltin B, Ericson M, Storck N, Jensen-Urstad M. Pronounced resting bradycardia in male elite runners is associated with high heart rate variability. Scandinavian J Medicine & Science in Sports. 1997; 7(5):274–278.

13 Pape E. Sensory nerve somatosensory evoked potentials (SEP) in the evaluation of patients with sciatica: false P1 latency prolongation may be due to admixture of dermatomal SEP. Electromyogr Clin Neurophysiol 2001 Sep; 41(6):337–344.

14 Snyder BJ. Thermographic evaluation for the role of the sensometer: evidence in the Toftness system of chiropractic adjusting. Chiropractic Technique 1999; 11(2):57–61.

15 Snyder BJ, Sanders GE. Evaluation of the Toftness system of chiropractic adjusting for subjects with chronic back pain, chronic tension headaches, or primary dysmenorrhea. Chiropractic Technique 1996; 8:3–9.

16 Hawkinson EJ, Snyder BJ, Sanders GE. Evaluation of the Toftness system of chiropractic adjusting for the relief of acute pain of musculoskeletal origin. Chiropractic Technique 1992; 4:57–60.

17 Gemmell HA, Jacobson BH, Henge DJ. Effectiveness of Toftness sacral apex adjustment in correcting fixation of the sacroiliac joint: preliminary report. Am J Chiro Med 1990; 3:5–8.

18 Gemmell HA, Jacobson BH, Sutton L. Toftness spinal correction in the treatment of migraine: a case study. Chiropractic Technique 1994; 6:57–60.

19 Gemmell HA. Interexaminer agreement in locating the area of highest spinal stress using the Toftness electromagnetic radiation detector. Am Chiro 1987; Apr:10–13.

20 Gemmell HA, Jacobson BH, Edwards SW, Henge DJ. Interexaminer reliability of the electromagnetic radiation receiver for determining lumbar spinal joint dysfunction in subjects with low back pain. J Manipulative Physiol Ther 1990; 13:134–137.

21 Gemmell HA, Henge DJ, Jacobson BH. Interexaminer reliability of the Toftness radiation detector for determining the presence of upper cervical subluxation. Chiropractic Technique 1990; 2:10–12.

22 Triaxial fluxgate magnetometers, FGM-5DTAA. Walkerscientific.com. 1999

23 Vesper, D.N., Swez, J.A., Nindl, G., Fox, M.T., Sandrey, M.A. and Balcavage, W.X. Models of the uniformity of electromagnetic fields generated for biological experiments by Merritt Coils. Biomedical Sciences Instrumentation, 2000; 36:409–415.Table 2