

Investigation of the use of three electroencephalographic electrodes for long-term electroencephalographic recording in awake and sedated dogs

Fiona M. K. James, DVM, MSc; Dana G. Allen, DVM, MSc; Alexa M. E. Bersenas, DVM; W. Larry Grovum, PhD; Carolyn L. Kerr, DVM, DVSc, PhD; Gabrielle Monteith, BS; Joane M. Parent, DMV, MVetSc; Roberto Poma,† DMV, DVSc

Objective—To compare electroencephalography (EEG) artifact associated with use of the subdermal wire electrode (SWE), gold cup electrode (GCE), and subdermal needle electrode (SNE) over an 8-hour period in sedated and awake dogs.

Animals—6 healthy dogs.

Procedures—8 EEG channels were recorded during 20-minute video-EEG recording sessions (intermittently at 0.5, 2, 4, 6, and 8 hours) with and without chlorpromazine sedation. Nonphysiologic artifacts were identified. Duration of artifact was summed for each channel. Number of unaffected channels (NUC) was determined.

Results—NUC was significantly affected by electrode type and sedation over time; median for SWE (2.80 channels; 95% confidence interval [CI], 0.84 to 5.70 channels) was significantly different from medians for GCE (7.87 channels; 95% CI, 7.44 to 7.94 channels) and SNE (7.60 channels; 95% CI, 6.61 to 7.89 channels). After 4 hours, NUC decreased in awake dogs, regardless of electrode type. In awake dogs, duration of artifact differed significantly between SWE and GCE or SNE; medians at 8 hours were 61.55 seconds (95% CI, 21.81 to 173.65 seconds), 1.33 seconds (95% CI, 0.47 to 3.75 seconds), and 21.01 seconds (95% CI, 6.85 to 64.42 seconds), respectively.

Conclusions and Clinical Relevance—The SWE had a significant duration of artifact during recording periods > 2 hours, compared with results for the GCE and SNE, in awake dogs. The GCE, SNE, and sedation resulted in significantly more channels unaffected by artifact. For longer recordings, caution should be exercised in selecting EEG electrodes and sedation state, although differences among electrodes may not be clinically relevant. (*Am J Vet Res* 2011;72:384–390)

Electroencephalography is the practice of recording and interpreting the electrical activity of the brain as well as the science relating to the electrical activity of the brain.¹ It is performed by means of electrodes placed on the surface of the head and connected to an

Received December 2, 2009.

Accepted February 11, 2010.

From the Department of Clinical Studies, Ontario Veterinary College, University of Guelph, ON N1G 2W1, Canada (James, Allen, Bersenas, Grovum, Kerr, Monteith, Poma); and the Département de Sciences Cliniques, Faculté de Médecine Vétérinaire, Université de Montréal, St-Hyacinthe, QC J2S 7C6, Canada (Parent).

This manuscript represents a portion of a thesis submitted by the senior author to the University of Guelph Office of Graduate Studies as partial fulfillment of the requirements for a Doctor of Veterinary Science degree.

Supported by grants from the Ontario Veterinary College Pet Trust and the Canadian Foundation for Innovation.

Presented in part as an oral abstract at the 26th Annual American College of Veterinary Internal Medicine Forum, Montreal, June 2009.

The authors thank Robert Cook and John R. Ives for technical assistance.

Address correspondence to Dr. James (jamesf@uoguelph.ca).

†Deceased.

ABBREVIATIONS

CI	Confidence interval
EEG	Electroencephalography
GCE	Gold cup electrode
NUC	Number of unaffected channels
SNE	Subdermal needle electrode
SWE	Subdermal wire electrode

electroencephalograph, an instrument used specifically for this purpose.¹

In human EEG recordings, the metal disk or cup electrode (made of tin, pure silver, pure silver with a gold coating, silver-silver chloride, conductive plastic, or gold) is the most commonly used electrode.^{2–4} The cup electrode is noninvasive, usually attached with colloidion to the skin, and filled with electrode paste for electrical conduction.^{2,5} However, this type of electrode requires regular and careful maintenance every 12 to 24 hours because the electrode paste may become dry, which would introduce artifact as contact and conduction are lost. Moreover, available types of needle and

cup electrodes are not compatible with computed tomography and magnetic resonance imaging without alteration, which typically involves removal and replacement for these other procedures.⁶

Electroencephalography is performed by most veterinary neurologists. In a survey of personnel at 34 practices, 17 of 19 respondents indicated that they performed this test in dogs and cats for clinical or research purposes.⁷ The most common EEG electrode in veterinary use has been the SNE.⁷ However, although this electrode is convenient to use, it is likely to result in movement artifact, pulls out easily, is invasive, and may not be practical for long-term (> 30 or 40 minutes) EEG recordings. An example of the need for such long-term recordings is a status epilepticus patient in an intensive care unit, where the recording is used to evaluate response to antiepileptic medication, monitor and assess cortical function in comatose patients, or identify seizure foci prior to surgical intervention.^{8,9} Another reason for the use of long-term EEG recordings is to differentiate between rare seizure events and other events such as syncope and behavioral episodes that may be triggered by specific environments. Similar to the use of a Holter monitor by veterinary cardiologists, a portable EEG recording unit and electrodes may be fitted to veterinary patients that are then returned to their home environment for several days in an attempt to record the rare event.

Introduction of a revised SWE has provided the possibility of a more appropriate electrode for use in EEG.¹⁰ This electrode is conveniently and rapidly positioned via a hypodermic needle in a subdermal location. In contrast to the SNE, the SWE reportedly has minimal movement artifact because of its flexibility and embedded recording tip.¹⁰ In contrast to cup electrodes, there is no need for periodic maintenance of the SWE.¹⁰ Additionally, the SWE is compatible with both computed tomography and magnetic resonance imaging.^{6,10-12} However, as mentioned in another study,¹⁰ the SWE is easily pulled from the skin.¹⁰ It is also an invasive electrode (similar to the SNE) and caused local bleeding in 40% of placements in humans.¹⁰ Direct comparison of the SWE and GCE in a long-term human intensive care unit revealed less artifact for the SWE.⁴ However, to the authors' knowledge, there have been no published comparisons of the SNE and SWE.

Artifacts may be divided into patient-origin artifact, physiologic artifact, and external nonphysiologic artifact.¹³ Examples of physiologic artifact are whole body or muscle movements, including those of the extraocular muscles and cardiac muscle (ie, other generators of electrical activity within the body).¹³ Examples of nonphysiologic artifacts include instrumental, electrode, environmental, and digital artifacts, such as those resulting from the 60 Hz derived from the alternating current supplying a building, faulty electrode application, and problems with equipment connections.^{13,14} Any unusual event confined to 1 (or a common) electrode is likely an artifact and should be resolved with replacement or adjustment of the electrode.¹³ This is because most electrode artifacts result from poorly attached electrodes, high resistance, broken wires, or changes in the scalp-electrode interface caused by drying of the electrode gel.¹³

The objective of the study reported here was to compare the performance of the SWE with that of the traditional standards of the SNE and GCE over an 8-hour period of EEG recording in clinically normal dogs. Additionally, the effect of sedation on electrode performance was evaluated. Performance quality was determined on the basis of the duration of nonphysiologic artifact seen in an EEG trace and the NUC per recording session. Only nonphysiologic artifact (referred to simply as artifact) was evaluated. Our hypothesis was that there would be no difference in performance of the 3 types of electrodes, regardless of whether the dogs were sedated.

Materials and Methods

Animals—Six hound-crossbred mature adult female dogs were included in the study. Body weight ranged from 24 to 28 kg. Dogs were selected from a colony of dogs maintained at a research facility. Dogs were assessed as healthy on the basis of results for physical and neurologic examinations. The dogs were cared for and maintained in kennel facilities in accordance with a protocol approved by the University of Guelph for animal care and use. The study protocol was approved by the University of Guelph Animal Care Committee.

Study design—An EEG recording was obtained from each dog on each of 6 days (1 for each of the 3 electrode types for both the sedated and awake states). Order of recording days for specific dogs, sedation state, and electrode type were randomized by use of a modified Latin square design to minimize effects of period and carryover. Thus, there was an interval of 1 to 9 days between successive recordings in each dog. The EEG recordings were obtained from 2 to 4 dogs (typically 3 dogs) on any study day.

EEG recordings—The EEG was recorded (20-minute sessions) at 0.5 (baseline), 2, 4, 6, and 8 hours after electrode placement. This generated 180 recordings for evaluation.

Recordings were conducted in a quiet room designated for EEG collection. Between EEG recording sessions on each recording day, dogs were provided with bedding and chew toys and were continuously monitored. Water and food were offered throughout a recording day.

All EEG recordings were made with a digital EEG system^{a,b} that collected synchronized video and EEG traces. Eight EEG channels were recorded in a referential montage. The camera was mounted on a post attached to the cart that contained the computer and EEG electrode input point. For each 20-minute recording session, dogs were placed on a table; dogs were manually restrained in lateral recumbency facing toward the camera. Technical recording settings were a 60-Hz notch filter, 0.3-Hz low-frequency filter, 70-Hz high-frequency filter, and electrode impedances ≤ 5 k Ω . After data acquisition, the EEG data were stored in the digital system for subsequent review and analysis.

Electrode placement—A 20-gauge catheter^c was inserted in a cephalic vein, and propofol^d was administered (up to 6 mg/kg, IV) to achieve sedation (sedated

dogs had spontaneous respiration and maintenance of lateral and medial palpebral reflexes) to enable the electrodes to be placed. The head of each dog was shaved. The method of EEG electrode placement depended on the type of electrode. Each SWE^c was inserted SC via a 25-gauge hypodermic needle.^f Each 30-gauge SNE^g was inserted SC. Each GCE^h was positioned on the skin surface by use of an electrode pasteⁱ that filled but that did not overflow the cup.

Nomenclature of electrodes was consistent with that used for the human EEG ten-twenty system.¹⁵ Electrode positioning was modified on the basis of a suggestion for mesocephalic dogs.¹⁶ Ten electrodes were placed in each dog. The reference electrode was positioned immediately dorsal to a line connecting the medial canthi because dogs were intolerant to insertion of this electrode at the rostral tip of the nose. The ground electrode was inserted in the dorsum of the neck. The left and right frontal electrodes (F3 and F4, respectively) were placed 0.5 to 1 cm cranial to the junction of the temporal lines at the midline. Temporal electrodes (T3 and T4) were placed on the skin or SC at the base of the pinna just dorsal to the most caudally palpable point of the zygomatic arch. Occipital electrodes (O1 and O2) were placed on a line in the transverse plane between the mastoid processes and aligned on the sagittal plane with F3 and F4. Central electrodes (C3 and C4) were placed at the midpoint of a sagittal line between the frontal and occipital electrodes and slightly caudal to a line on the transverse plane between the temporal electrodes.

Subsequent to electrode placement, a flexible adhesive film^j was applied over the electrodes to affix them in place. An elastic adhesive bandage^k was applied over the flexible adhesive film as an extra security measure. This method of securing the electrodes also served to blind the EEG reviewers to the type of electrode used. Each dog was fitted with an Elizabethan collar^l; the braided cable from the electrodes was positioned under the collar along the dorsum of the neck and was secured to a body harness on the dogs between recording sessions for the duration of the day. A loose elastic gauze wrap was placed around the neck of each dog to protect the EEG cable and prevent the cable from being inadvertently removed if the dog scratched at the wires or the cervical area. All EEG electrodes and bandage materials were removed from each dog at the end of a recording day.

For EEG recording days on which dogs were sedated, chlorpromazine^m was administered (0.5 mg/kg, IV) immediately after electrode placement and again 4 hours after electrode placement. This dose rendered the dogs docile; they were visibly sedated but able to walk.

Data analysis—Two reviewers (FMKJ and RP) each analyzed 20 EEG sessions. Reviewers were blinded as to the type of electrode as well as the dog's sedation state. This was achieved by bandaging of the electrodes and shuffling of the EEG recording files. Reviewers examined each of the 8 channels for each 20-minute recording session. Although the data were recorded referentially to an inactive site between the eyes, the digital display montage during analysis could be reformatted as desired to display the differential recording obtained

between any 2 electrode locations. Artifacts were identified and confirmed by reviewing the synchronized video recording. Duration of artifact was summed for each channel. The NUC was also recorded.

Agreement between reviewers was calculated. Agreement between the 2 reviewers for 20 randomly selected, independently assessed sessions was evaluated with a coefficient of concordance analysis. The agreement between reviewers was tested for bias via a paired *t* test. In addition, a regression analysis and *R*² value were calculated. If agreement was good (concordance coefficient > 0.75), only 1 reviewer (FMKJ) would analyze the remaining EEG sessions.

To compare the outcome variables (NUC and duration of artifact) among the 3 electrodes, a generalized linear mixed modelⁿ was used. Dog and period were accounted for as random effects in the model. Because the NUC was expressed as a percentage (the percentage of 8 channels), a logarithmic transformation was applied prior to analysis. Because the data were repeatedly measured over time, the Akaike information criterion was used to determine an error structure for the autoregression.

Assumptions of an ANOVA were assessed by use of comprehensive residual analysis. The Shapiro-Wilk test, Kolmogorov-Smirnov test, Cramér-von Mises test, and Anderson-Darling test were conducted to assess overall normality of the data. To meet the assumptions of an ANOVA, data for the duration of artifact were logarithmically transformed. Residuals were plotted against predicted values and explanatory variables to enable investigators to detect patterns in the data that suggested outliers, unequal variance, or other problems.

Depending on the results of the overall *F* test, post hoc tests included a Tukey adjustment, a multivariate adjustment for the *t* test, a Dunnett test, or a combination of these. Significance was set at values of *P* ≤ 0.05.

Results

For the agreement between reviewers, which was tested by use of 20 randomly selected recordings, the coefficient of concordance was 0.9939. There was no significant bias, as determined by testing with a paired

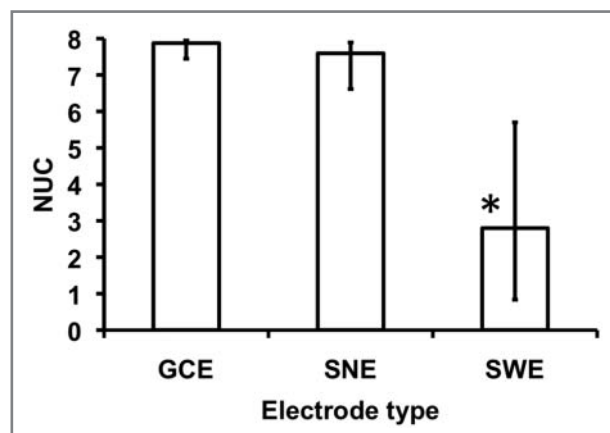


Figure 1—Median (95% CI) NUC (maximum of 8 channels) for 3 electrode types used for EEG recordings over an 8-hour period in awake and sedated dogs (*n* = 6). *Median value for the SWE differs significantly (*P* = 0.004) from the values for the other 2 electrode types.

t test. The adjusted R^2 (maximum value of 1; indicates the amount of variance explained by the model) was found to be 0.9885 ($P < 0.001$). Therefore, the remaining 160 recordings were reviewed by only 1 reviewer (FMKJ).

Fixed effects in the generalized linear mixed model were electrode, sedation, time, and their interactions. For the duration of artifact, the fixed effects of carry-over, location of electrode on the head, and side of the head (left vs right) were removed from the model because they did not exert a significant effect. Electrode location was also not a factor in the NUC model.

The NUC per recording session (minimum, 0 unaffected channels; maximum, 8 unaffected channels) was significantly affected by the type of electrode, regardless of sedation state or time of recording (Figure

1). The median NUC for the SWE was 2.80 channels (95% CI, 0.84 to 5.70 channels), whereas median NUC for the GCE was 7.87 channels (95% CI, 7.44 to 7.94 channels) and for the SNE was 7.60 channels (95% CI, 6.61 to 7.89 channels). The median NUC for the SWE was significantly ($P = 0.004$) different from the median NUC for each of the other 2 electrode types.

Sedation state and time also had a significant effect on the NUC (Figure 2). In the awake state, regardless of electrode, the NUC was significantly different from the baseline value at time points ≥ 4 hours after electrode placement. In the sedated state, regardless of electrode type, the NUC did not differ significantly from the baseline value. Comparison between the awake and sedated states revealed that the NUC differed significantly ($P = 0.010$) only at 8 hours after electrode placement.

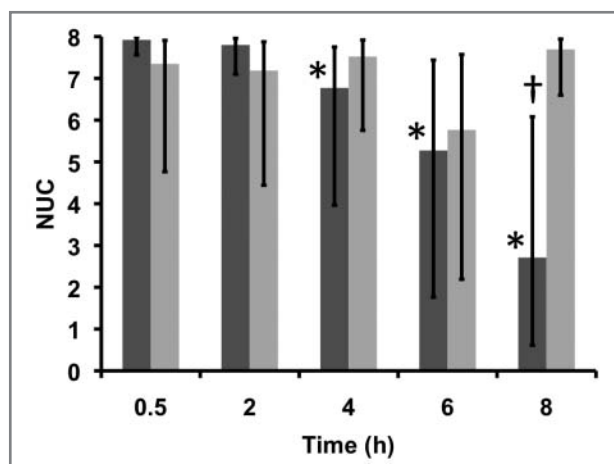


Figure 2—Median (95% CI) NUC (maximum of 8 channels) for awake (dark-gray bars) and sedated (light-gray bars) dogs ($n = 6$) during EEG recordings over an 8-hour period. *For the awake state, the NUC differs significantly ($P \leq 0.05$) from the values for the 0.5-hour (ie, baseline) and 2-hour session. †Within a time point, the NUC for the awake state differs significantly ($P = 0.010$) from the value for the sedated state.

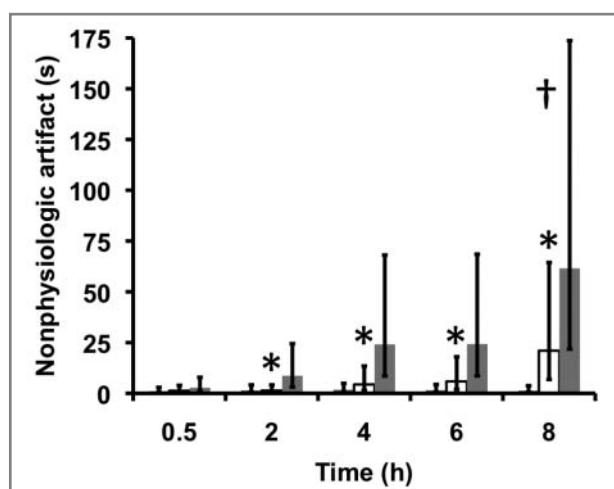


Figure 3—Median (95% CI) duration of nonphysiologic artifact for the GCE (black bars), SNE (white bars), and SWE (gray bars) during an 8-hour recording period in awake dogs ($n = 6$). *Within a time point, the value for the SWE differs significantly ($P \leq 0.05$) from the value for the GCE. †Within a time point, the value for the SNE differs significantly ($P = 0.001$) from the value for the GCE.

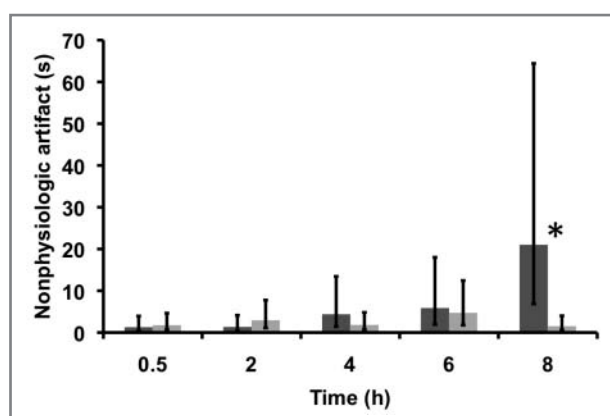


Figure 4—Median (95% CI) duration of nonphysiologic artifact for the SNE between awake (dark-gray bars) and sedated (light-gray bars) dogs ($n = 6$) during EEG recordings over an 8-hour period. *Within a time point, the value differs significantly ($P = 0.002$) from the value for the sedated state.

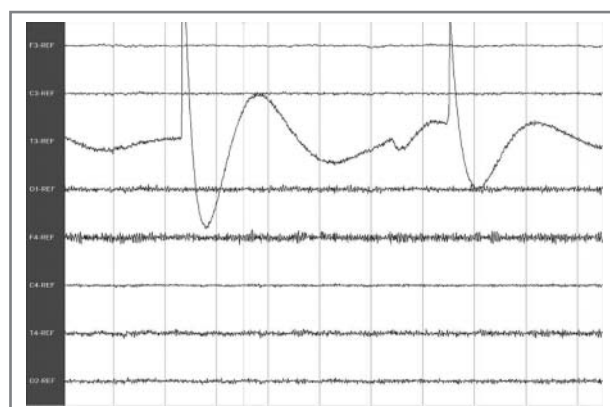


Figure 5—An EEG recording obtained from an awake (ie, unsedated) dog by use of an SWE. The recording contains representative examples of 2 consecutive transient electrical discharges, usually an upward deflection with a rapid increase and a second, slower phase of return to baseline values as the charge decayed (ie, an electrode pop) in the T3-REF channel. The peak of the first electrode pop was cut off in the recording. Notice there is also a physiologic (muscle) artifact that is most prominent in the F4-REF channel. For the x-axis, vertical gray lines are at intervals of 1 second. C3 = Left central electrode. C4 = Right central electrode. F3 = Left frontal electrode. F4 = Right frontal electrode. O1 = Left occipital electrode. O2 = Right occipital electrode. REF = Reference electrode. T3 = Left temporal electrode. T4 = Right temporal electrode.

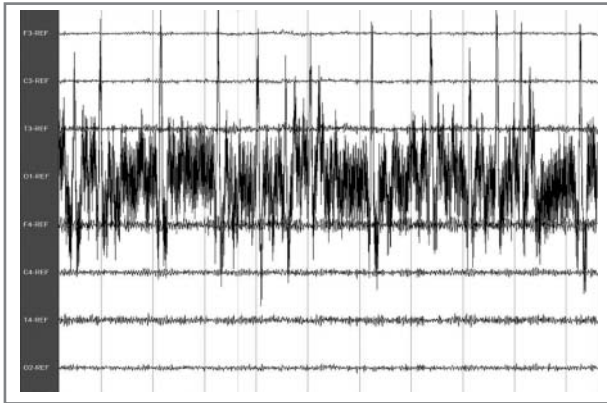


Figure 6—An EEG recording obtained from an awake (ie, unsedated) dog by use of an SNE. The recording contains examples of artifact resulting from loss of contact between the electrode and tissue. Notice that the O1-REF channel was lost. There is also physiologic (muscle) artifact that is most prominent in the F4-REF channel. For the x-axis, vertical gray lines are at intervals of 1 second. See Figure 5 for remainder of key.

The duration of artifact was summed for each channel in each 20-minute recording session. In the awake state, the SWE caused a significantly different duration of artifact, compared with that for the GCE, at the 2-hour recording session or later (Figure 3). The GCE and SNE were significantly ($P = 0.001$) different at only the 8-hour recording session. At the 8-hour recording session, the median duration of artifact for the 20-minute recording session was 61.55 seconds (95% CI, 21.81 to 173.65 seconds) for the SWE, 1.33 seconds (95% CI, 0.47 to 3.75 seconds) for the GCE, and 21.01 seconds (95% CI, 6.85 to 64.42 seconds) for the SNE.

In sedated dogs, the median duration of artifact for each of the 3 electrodes did not differ significantly until the 8-hour session. At 8 hours after placement, the median duration of artifact for each 20-minute recording session was 14.28 seconds (95% CI, 4.66 to 43.78 seconds) for the SWE, 1.67 seconds (95% CI, 0.54 to 5.13 seconds) for the GCE, and 1.52 seconds (95% CI, 0.57 to 4.00 seconds) for the SNE. The value for the SWE was significantly different at this recording session from the values for the other 2 electrodes.

Neither the GCE nor SWE had a significant difference in duration of artifact between awake and sedated states for all recording sessions (Figure 4). The SNE had a significant ($P = 0.002$) difference in duration of artifact between sedated and awake states at only the 8-hour recording session.

The typical appearance of an artifact was of transient electrical discharges, usually an upward deflection with a rapid increase and a second, slower phase of return to baseline values as the charge decayed (ie, an electrode pop; Figure 5). Another common artifact was the loss of contact between electrode and subject, which resulted in loss of a single channel (Figure 6) or loss of all channels if the detached electrode was the reference electrode.

Discussion

In the study reported here, we detected a significant difference in results between the SWE and the

traditional GCE and SNE. The SWE developed a significant duration of artifact over prolonged (> 2 hours) recording periods, compared with results for the GCE and SNE, in awake dogs. The GCE and SNE differed at only the 8-hour recording session in awake dogs. The SWE also differed significantly from the GCE and SNE when the NUC was tallied, regardless of sedation state or time of the recording session. For both measures of artifact, the SWE had poorer results than did the GCE or SNE. The 95% CIs for the SWE were wide, which indicated that variability could not be linked to any variables tested.

The observed artifacts often were electrode pops, a frequent event that was commented on by the authors of one of the first reports⁴ in which SWE use in a clinical setting was described. Pops result from fluctuations of charge that build up on the electrode surface.⁴ They may be corrected by removal and reapplication of the offending electrode.¹⁷ It has been speculated that capillary bleeding secondary to electrode placement may contribute to the frequency of electrode pops and that reducing the diameter of the hypodermic needle used for electrode delivery would reduce this frequency.⁴ In our study, we used a new smaller-gauge delivery needle and still encountered both capillary bleeding and electrode pops. It was also previously observed that the SWE is prone to physiologic motion artifact (not examined in our study), and it was suggested that this was secondary to electrode wires that were insufficiently secured at the skin surface.⁴ In a study⁴ in which investigators compared the SWE with the GCE in human patients, electrode pops were not counted as artifacts, which prevents a direct comparison between results for that study (with the SWE less prone to artifact than was the GCE) and results for the study reported here (with the SWE causing more artifact than did the GCE).

Data collection and analysis in our study were not configured to characterize the frequency and duration of each type of nonphysiologic artifact, nor was the study designed to evaluate the frequency, location, and severity of bleeding or hematomas associated with electrode placement. Post hoc analysis of the data set would be useful to delineate the types of error encountered. However, the data regarding capillary bleeding secondary to electrode placement were not recorded in the study. It is possible that hematomas that form around the recording tip of an electrode may change the electrical properties of the electrode-tissue interface and could be a cause of the variance seen in the artifact data for the SWE, especially over the longer study periods as the physiologic state of the clot changed. There is extensive information on the reaction of brain tissue to implanted electrodes of various metals, including consequences of intracerebral hematomas as well as the development of fibrous tissue reactions to long-term cardiac pacemaker and cochlear implant electrodes.^{18,19} Future studies conducted with the SWE may involve recording of the location, size, and duration of subcutaneous or surface hemorrhage as a result of SWE placement to better elucidate the effects of hemorrhage on SWE function.

It must be mentioned that the median duration of artifact for the SWE in the awake state (8 hours after electrode placement) was 61.55 seconds (95% CI, 21.81

to 173.65 seconds), which represented a median duration of approximately 1 minute, with an upper limit for the 95% CI of approximately 3 minutes. For application in a veterinary clinical setting, a total duration of 3 minutes of artifact during a 20-minute recording may not be a substantial problem. The design of this study was such that we could not objectively score the quality of recordings when they were free of artifact (ie, determine the quality of an artifact-free trace). One method to determine this might involve scoring the ability of an electrode to record changes in the arousal state (eg, between drowsiness and sleep). However, in this study, there were an insufficient number of recording sessions in which demonstrable changes in the arousal state were detected. One solution would be to design a study similar to a study²⁰ conducted to determine arousal states in the equine EEG. Still, a subjective scoring of artifact-clear recordings could be extracted from our data set for future evaluation.

From a veterinary clinical practice perspective, the 3 types of electrodes were easy to place with the propofol sedation protocol that was used. Our study protocol was based on initial reports^{4,10} of the use of the SWE in humans in which infiltration of the scalp with a local anesthetic was performed prior to electrode placement. Instead, we placed the electrodes while the dogs were sedated with propofol. Maintenance of local analgesia with repeated infiltration would have necessitated removal and replacement of the electrode bandages during the experiment. None of the dogs displayed signs of discomfort related to the electrodes or bandaging, other than scratching at exposed wires. Had there been increased activity related to discomfort from the invasive SWE or SNE, it may have been expected that both these electrode types would have had early failure. The bandaging protocol, which was determined by use of trial and error prior to the commencement of data collection, appeared sufficient to protect the electrodes from most accidental removals by scratching. It was simple to remove the electrodes and bandage from a dog at the end of a recording day. For veterinary clinical patients, use of only the SNE and SWE would avoid shaving of the head, which is an aesthetic concern for some clients. Additionally, the GCE would not be an ideal electrode for long-term monitoring in veterinary patients because of the requirement for reapplication of electrode paste every 12 to 24 hours, which would necessitate removal and replacement of bandaging materials.

Another concern during EEG of animals is the difficulty in preventing a patient from moving during recording and causing physiologic movement artifact. It is possible to physically restrain an awake dog from moving, with methods such as use of a leash and collar, manual physical restraint, or taping the limbs.^{21–23} The use of certain sedatives raises the possibility of activating the EEG, which enhances the probability of interictal paroxysmal discharges seen in epileptic patients.^{24,25} Chlorpromazine appears to be the sedative of choice in dogs with epilepsy, although there is an increase in interictal paroxysmal discharges associated with its administration.^{23,26} Propofol was selected as the initial sedative for electrode placement because of its rapid-

ity of action and noninterference with the recording of spontaneous epileptiform activity.²⁷

In the study reported here, sedation had an impact on the results for the electrodes, with a difference between the duration of artifact recorded by all 3 electrode types evident at only the 8-hour recording session in sedated dogs. Similarly, the NUC in the awake dogs, regardless of type of electrode, differed significantly from that in sedated dogs at the 8-hour recording session. The 95% CIs were wide in awake dogs, which suggested great variance in the data, whereas the 95% CIs were narrow in sedated dogs. This may be attributable to one or more other variables that were dependent on the sedation state and caused artifact to develop. For example, an awake dog may have been more active between or during recording sessions, thus displacing the electrodes or disrupting the contact between the electrode and tissue.

For the study reported here, we concluded that the choice of EEG electrode and degree of sedation did not affect the overall recording quality in EEG sessions lasting up to 2 hours. With longer EEG recording sessions, caution should be used in the selection of EEG electrodes and a sedation state, although the difference in results among electrodes may not be clinically important.

-
- a. Stellate Harmonie System, model HSYS-REC-DUO, Stellate Systems Inc, Montreal, QC, Canada.
 - b. Stellate Harmonie System, model HSYS-REC-WP2, Stellate Systems Inc, Montreal, QC, Canada.
 - c. 20GA 1.88IN BD Insyte-W, Becton Dickinson Infusion Therapy Systems Inc, Sandy, Utah.
 - d. Propofol injection, Novopharm Ltd, Toronto, ON, Canada.
 - e. Subdermal wire electrode, model F-SWEL-48, Grass Technologies, an Astro-Med Inc Product Group, West Warwick, RI.
 - f. 25-gauge X 5/8-inch hypodermic needle, Terumo, Tokyo, Japan.
 - g. Stainless steel subdermal needle electrode, model F-E3M-48, Grass Technologies, an Astro-Med Inc Product Group, West Warwick, RI.
 - h. Surface electrodes, gold, model FS-E5GH, Grass Technologies, an Astro-Med Inc Product Group, West Warwick, RI.
 - i. Ten20 conductive paste, Weaver and Co, Aurora, Colo.
 - j. OpSite, Smith & Nephew Medical Ltd, Hull, Yorkshire, England.
 - k. Kendall Expandover, Covidien AG, Mansfield, Mass.
 - l. V Buster, Kruuse, Denmark.
 - m. Chlorpromazine hydrochloride injection Sandoz standard, Sandoz Canada Inc, Boucherville, QC, Canada.
 - n. PROC MIXED, SAS OnlineDOC 0.1.3, SAS Institute Inc, Cary, NC.
-

References

1. Noachtar S, Binnie C, Ebersole J, et al. A glossary of terms most commonly used by clinical electroencephalographers and proposal for the report form for the EEG findings. The International Federation of Clinical Neurophysiology. *Electroencephalogr Clin Neurophysiol Suppl* 1999;(52):21–41.
2. Reilly EL. EEG recording and operation of the apparatus. In: Niedermeyer E, Lopes da Silva F, eds. *Electroencephalography: basic principles, clinical applications, and related fields*. 5th ed. Philadelphia: Lippincott, Williams & Wilkins, 2004;139–159.
3. Ives JR, Rotenberg A, Poma R, et al. Electroencephalographic recording during transcranial magnetic stimulation in humans and animals. *Clin Neurophysiol* 2006;117:1870–1875.
4. Young GB, Ives JR, Chapman MG, et al. A comparison of subdermal wire electrodes with collodion-applied disk electrodes in long-term EEG recordings in ICU. *Clin Neurophysiol* 2006;117:1376–1379.

5. Kamp A, Pfurtscheller G, Edlinger G, et al. Technological basis of EEG recording. In: Niedermeyer E, Lopes da Silva F, eds. *Electroencephalography: basic principles, clinical applications, and related fields*. 5th ed. Philadelphia: Lippincott, Williams & Wilkins, 2004;127–138.
6. Mirsattari SM, Ives JR, Bihari F, et al. Real-time display of artifact-free electroencephalography during functional magnetic resonance imaging and magnetic resonance spectroscopy in an animal model of epilepsy. *Magn Reson Med* 2005;53:456–464.
7. Steiss JE. A survey of current techniques in veterinary electrodiagnostics: EEG, spinal evoked and brainstem auditory evoked potential recording. *Vet Res Commun* 1988;12:281–288.
8. Scheuer M. Continuous EEG monitoring in the intensive care unit. *Epilepsia* 2002;43(suppl 3):114–127.
9. Serrano S, Hughes D, Chandler K. Use of ketamine for the management of refractory status epilepticus in a dog. *J Vet Intern Med* 2006;20:194–197.
10. Ives JR. New chronic EEG electrode for critical/intensive care unit monitoring. *J Clin Neurophysiol* 2005;22:119–123.
11. Mirsattari SM, Ives JR, Jones D, et al. MRI compatible EEG electrode system for routine use in the epilepsy monitoring unit and intensive care unit. *Clin Neurophysiol* 2004;115:2175–2180.
12. Mirsattari SM, Ives JR, Leung LS, et al. EEG monitoring during functional MRI in animal models. *Epilepsia* 2007;48:37–46.
13. Klem G. Artifacts. In: Ebersole J, Pedley T, eds. *Current practice of clinical electroencephalography*. Philadelphia: Lippincott, Williams & Wilkins, 2003;271–287.
14. Young GB, Campbell VC. EEG monitoring in the intensive care unit: pitfalls and caveats. *J Clin Neurophysiol* 1999;16:40–45.
15. Jasper HH. The ten twenty electrode system of the International Federation. *Electroencephalogr Clin Neurophysiol* 1958;10:371–375.
16. Pellegrino FC, Sica RE. Canine electroencephalographic recording technique: findings in normal and epileptic dogs. *Clin Neurophysiol* 2004;115:477–487.
17. Barlow JS. Automatic elimination of electrode-pop artifacts in EEG's. *IEEE Trans Biomed Eng* 1986;33:517–521.
18. Ward MP, Rajdev P, Ellison C, et al. Toward a comparison of microelectrodes for acute and chronic recordings. *Brain Res* 2009;1282:183–200.
19. Mase H, Tamura K, Hiromoto A, et al. Histopathological study of tissue reaction to pacemaker electrodes implanted in the endocardium. *J Nippon Med Sch* 2005;72:52–59.
20. Williams DC, Aleman M, Holliday TA, et al. Qualitative and quantitative characteristics of the electroencephalogram in normal horses during spontaneous drowsiness and sleep. *J Vet Intern Med* 2008;22:630–638.
21. Croft P. The EEG as an aid to diagnosis of nervous diseases in the dog and cat. *J Small Anim Pract* 1962;3:205–213.
22. Fox MW. Postnatal development of the EEG in the dog. I. Introduction and EEG techniques. *J Small Anim Pract* 1967;8:71–76.
23. Holliday TA, Cunningham JG, Gutnick MJ. Comparative clinical and electroencephalographic studies of canine epilepsy. *Epilepsia* 1970;11:281–292.
24. Holliday TA, Williams DC. Interictal paroxysmal discharges in the electroencephalograms of epileptic dogs. *Clin Tech Small Anim Pract* 1998;13:132–143.
25. Holliday TA, Williams C. Clinical electroencephalography in dogs. *Vet Neurol Neurosurg J* 1999;1:1–38.
26. Redman HC, Wilson GL, Hogan JE. Effect of chlorpromazine combined with intermittent light stimulation on the electroencephalogram and clinical response of the Beagle dog. *Am J Vet Res* 1973;34:929–936.
27. Jaggy A, Bernardini M. Idiopathic epilepsy in 125 dogs: a long-term study. Clinical and electroencephalographic findings. *J Small Anim Pract* 1998;39:23–29.