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A New Ground and Reference Technique for Invasive EEG Recordings

Serge Vulliemoz, M.D.[1], Laurent Spinelli, PhD[1], Daniel Pellise[1], Margitta Seeck, M.D.[1], John R. Ives, B.Sc.[2]

[1]Presurgical Epilepsy Evaluation Unit
Department of Neurology
University Hospital of Geneva
Geneva, Switzerland
[2]Department of Clinical Neurological Sciences
University of Western Ontario
London, Ontario, Canada

ABSTRACT. ***Objective:*** *To demonstrate a subdermal wire electrode technique for establishing a ground (GND) and reference (REF) during long-term EEG monitoring (LTM) with intracranial electrodes. Usually, a separate GND and REF are required and this GND&REF pair can be selected contacts in the invasive electrode arrays themselves, special invasive electrodes, or standard surface disc electrodes which require frequent maintenance. We investigated the use of a pair of chronic Subdermal Wire Electrodes (SWE) for use as GND&REF.* ***Methods:*** *A pair of SWEs as GND&REF was tested in nine patients undergoing invasive EEG monitoring. SWE impedances were monitored in two patients and compared to disc electrode impedances.* ***Results:*** *Without maintenance, SWE impedances remained low and stable during the entire recording period (up to 20 days), whereas disc electrodes showed rapid impedance increase after the first day. In all nine patients, the consistent and durable integrity of the GND&REF pair of SWE allowed for a good quality EEG recording. No local skin complications were observed.* ***Conclusions:*** *A pair of SWE electrodes provides a GND&REF system that is easy to place, maintain, and provides a high quality recording with long-term stability when coupled with referential based EEG recording system from invasive electrodes.* ***Significance:*** *A more efficient means of*

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establishing a GND&REF pair during the monitoring of patients with invasive electrodes is described.

KEY WORDS. *EEG, electrode, ground, invasive monitoring, long-term monitoring, reference, subdermal wire electrode.*

INTRODUCTION

Most commercial long-term EEG monitoring (LTM) systems require a ground (GND) and a reference (REF) electrode for recording high quality signals from invasive electrodes. The invasive electrodes consist of depth, grid, or strip electrodes or a combination thereof depending on the clinical diagnostic problem being evaluated. The GND&REF are critical to the referential based recording method and the general quality of the entire EEG is directly tied to these GND&REF electrodes. Currently there are several techniques for establishing a GND&REF. One method is to use any of the invasive contacts as GND&REF. Another method is to place a special 2-contact depth or strip and use these contacts as GND&REF. A further option and one used up until now at the University Hospital of Geneva (HUG) was to apply standard disc electrodes to the scalp with collodion. The basic characteristic of these acute, "wet" disc electrodes is their persistent deterioration either due to drying out, or they become loose so that frequent physical monitoring coupled with maintenance consisting of jelling and adjustments is required to maintain a good quality EEG recording. This aspect is time consuming, inefficient, and leads to seizure activity being recorded with significant artifact caused by high GND&REF impedances.

Recently, a Subdermal Wire Electrode (SWE) (Ives 2005) with "ideal" silver-silver/chloride (Ag-Ag/Cl) properties (Tallgren et al. 2005) was developed and applied to EEG recording in patients in the ICU (Young et al. 2006). These SWE are sterile and designed for single use. They record with an impedance of less than 5 kOhms, but most importantly, they do not need adjustments and will record without any maintenance for days and weeks (Ives 2005, Young et al. 2006, Martz et al. 2009), in contrast to the disc electrodes. Therefore, a pair of SWEs is a suitable candidate as GND&REF during invasive LTM.

METHODS

The SWE (Ives EEG Solutions, Inc., Manotick, Ontario, Canada; part number: SWE) consists of a 5 cm length of a Teflon® coated, 0.25 mm in diameter, multi-stranded pure silver wire. Stripping off 3 mm of Teflon® insulation from the distal end and then chloriding the exposed silver creates the recording element/tip (Ives 2005). The chloriding process creates an "ideal" Ag-Ag/Cl EEG electrode (Tallgren

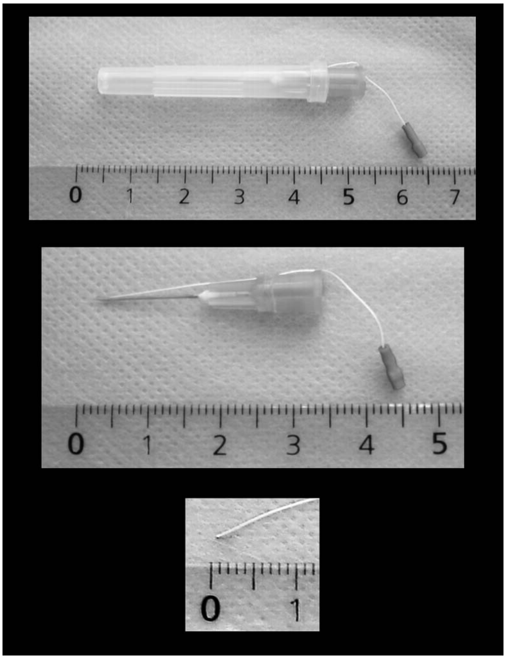

FIG. 1. The Subdermal Wire Electrode (SWE) is shown in its various stages of assembly (or application). The SWE assembly consists of a short 2.5 cm length of Teflon® insulated, 0.25mm diameter, multi-stranded, pure silver wire. A 25 gauge × 16 mm hypodermic needle and a plastic protective cap complete the assembly. The recording element is 3mm × 0.25mm exposed silver wire at the distal end that is silver-chlorided. This recording tip with an Ag-Ag/Cl coating is inserted into the lumen of the hypodermic needle. The proximal end of the SWE consists of an insulated female socket for connection via an adapter/extension wire to the input of the recording device. Once the insertion needle carrying the SWE is located in the subdermal space, the wire is released, folded back, and the needle immediately withdrawn and disposed of. This leaves the very flexible Ag-Ag/Cl recording element/tip in place to record the local biopotential (shown in the lower photo).

et al. 2005) which is essential for a high quality, low impedance GND&REF. During their assembly, the recording tip is inserted into the lumen of a 25 gauge × 16 mm hypodermic needle, as shown in Figure 1. The wire is established on the outside of the needle, which permits prior connection of the small female mating connector. The SWE is very similar in design as the original chronic sphenoidal (Ives and Gloor 1977, Ives and Gloor 1978). The hypodermic needle is used to carry the SWE into the subdermal space, the wire is released, and then the needle is immediately removed leaving the Ag-Ag/Cl recording contact behind permitting the recording of any local biopotential. Two SWEs are required for GND&REF. If the patient is under anesthesia, the electrodes can be quickly inserted in the midline subdermal space, during the surgery for the placement of the invasive electrodes. As an alternative, and in the procedure used at HUG, the SWEs can be placed once the patient comes back to the LTM unit and he/she is being connected to the LTM recording system. This venue also permits measurement of the head for accurate placement of other 10–20 System located SWEs, which could allow simultaneous surface and invasive EEG recordings. Subdermal scalp placement of just two SWEs in the fully awake, adult patient does not present too much discomfort, as they are very quick and easy to place. The insertion needle is relatively small, 25 gauge (0.50 mm diameter), and all sensation dissipates as soon as the hypodermic needle is withdrawn. There is no sensation of the wire itself as the SWE is only 0.25 mm in diameter and very flexible. A minimal amount of collodion was used to fixate the wire on the scalp to prevent the SWE from being pulled out because of head movements, seizures, or nursing manipulation of the head. The SWE's interconnection, 1-meter extension wire, is terminated with a standard safety connector to permit connection into the EEG recording equipment. For impedance comparison, standard gold-coated, pure silver, disc electrodes (Grass Technologies, Astro-Med, Inc. RI, USA) were placed close to the C3/C4 sites.

This GND&REF system was used in nine consecutive adult patients who underwent intracranial EEG recording at our institution with intracerebral depth electrodes or subdural strip/grid electrodes. All patients were fully awake during application of SWE and all were treated with oral non-steroidal analgesics during LTM. If necessary, they also received intravenous cefazoline (1g two times/day) during and after implantation of the intracranial electrodes.

In two patients, the impedance was measured daily during the monitoring using the local EEG recording system (Ceegraph, Biologic®, Natus Medical Inc. San Carlos, CA, USA). Patient 6 had direct impedance measurement of GND&REF electrodes against one intracranial contact by plugging the SWE electrodes into alternative jackbox positions, normally occupied by intracranial electrodes, and one intracranial electrode was transitorily used as REF. The impedance measured is, therefore, the impedance of the circuit constituted by the SWE and the REF-intracranial electrode, which overestimates the SWE proper impedance, by 4 to 7 kOhms (the actual impedance of the intracranial electrode). Patient 2 had impedance measurement of additional SWE located at the C3/C4 positions, as well as disc electrodes placed at C3/C4 positions.

RESULTS

Following invasive electrode implantation, at least two SWEs were placed subdermally in nine fully awake patients in the LTM unit. The placement of the SWEs was very well tolerated except for one patient who complained about some moderate transitory pain during placement of the SWE. No consequent bleeding was noticed at implantation or removal of the SWE. We observed neither skin irritation nor

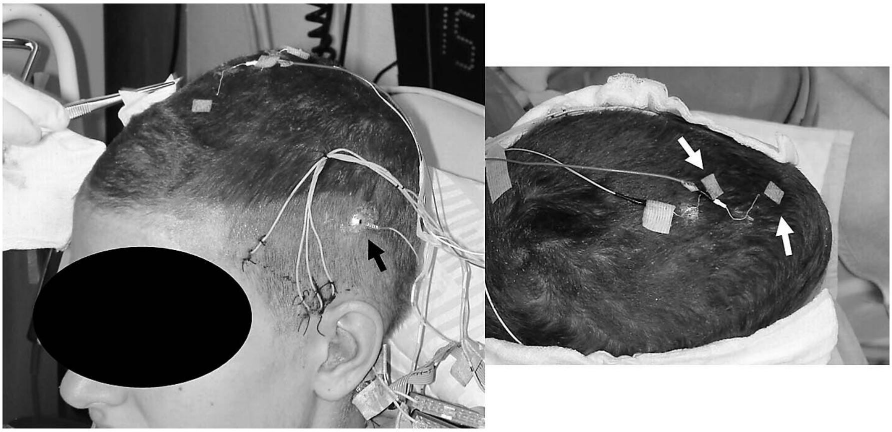

FIG. 2. A patient with bilateral depth electrodes. On the midline, two Subdermal Wire Electrodes (SWEs) have been placed to serve as a ground and reference (GND&REF). Two additional standard gold coated disc electrodes were also placed at the C3 and C4 positions to serve as redundant pair of GND&REF electrodes or for monitoring sleep stages during the recording of the patient's depth EEG. Extension leads were then attached to the SWE and connected to the usual GND and REF inputs of the invasive EEG recording system. The patient's head could then be bandaged to cover all the electrodes and maintain sterility.

infection (under intravenous prophylactic antibiotherapy) throughout the entire study on these nine patients. In one patient, severe, rhythmic head movement during the course of a generalized tonic-clonic seizure disconnected the pin connector of the SWE and this was promptly reconnected.

Figure 2 shows a patient with midline GND&REF with additional standard gold-coated disc electrodes placed at the C3/C4 sites.

Figure 3A demonstrates the high quality of the EEG that was obtained using a pair of SWE as GND&REF. No maintenance of the SWE was necessary during the entire duration of all recordings, with a maximum of 20 days (mean 9.6 ± 4.9 days). After 24 hours, the non-sterile, standard disc electrodes placed at C3/C4 already showed a significant signal decline (Figure 3B). Even by refilling them with jell every day, the impedances of C3/C4 steadily increased, accounting for 50 Hz artifacts that were not seen with SWE.

Figure 4 shows that the impedance for four SWEs in two patients remained well under 20 kOhms (this impedance measurement also included the invasive electrode's impedance as well). Over the entire seven day recording period the impedance of the two metal disc electrodes (ME) showed a marked increase after 24 to 48 hours, associated with significant artifacts disturbing the recording (as discussed above and shown in Figure 3B).

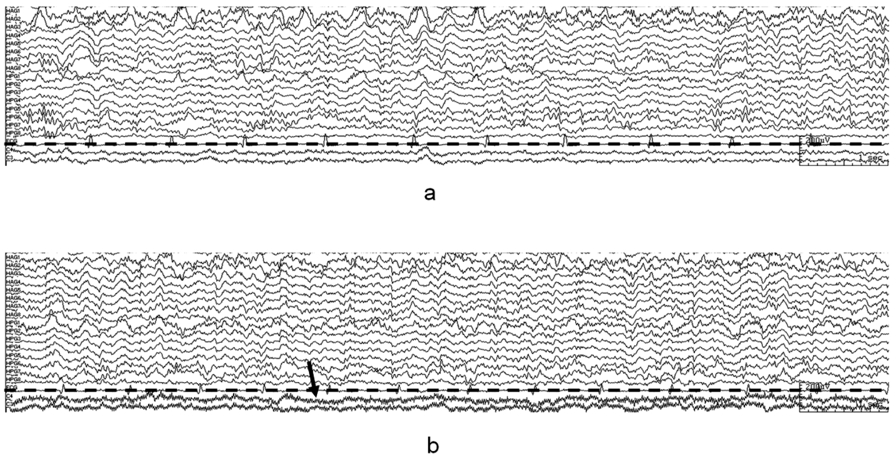

FIG. 3 **A**) Partial display of the high quality EEG obtained using the two Subdermal Wire Electrodes (SWEs) as ground and reference (GND&REF). During the entire recording process, the SWE did not need any adjustment nor maintenance as there was no deterioration in EEG quality attributed to the GND or REF electrodes. **B**) Deterioration of the signal of C3/C4 disc electrodes after 48 hours, requiring frequent maintenance in the context of sterile bandaging. The other channels show persisting good recording quality, with two SWEs as REF&GND. High Pass = 1 Hz, Low Pass = 100 Hz. Scale bar in right lower corner applies to all EEG channels except the two lowest (scalp C3/C4) where the vertical bar is 20 μV instead of 200 μV.

Clinical and electrophysiological data for the nine patients is summarized in Table 1.

DISCUSSION

In this technical report, we describe an alternate GND&REF electrode system for invasive monitoring which is based on a pair of Subdermal Wire Electrodes (SWE). As already reported in the case of EEG monitoring of comatose patients (Young et al. 2006), the SWE has superior recording characteristics compared to other scalp electrode systems. In these nine patients studied using the SWE as a GND&REF pair, no indication of increased impedance was noted during the continuous invasive EEG. Our measurements confirm those of Young et al. (2006) with excellent invasive EEG signals based on the maintenance-free SWEs used as GND&REF. In this application, low, steady impedance were maintained for up to 20 days. Serial impedance measures were obtained only in two patients (only one had additional scalp disc electrodes for comparison). These impedance measurements confirmed those of previous studies measuring consistently low impedance of the SWE (Young et al. 2006) compared to standard gold cup electrodes. In a more recent study of a patient whose

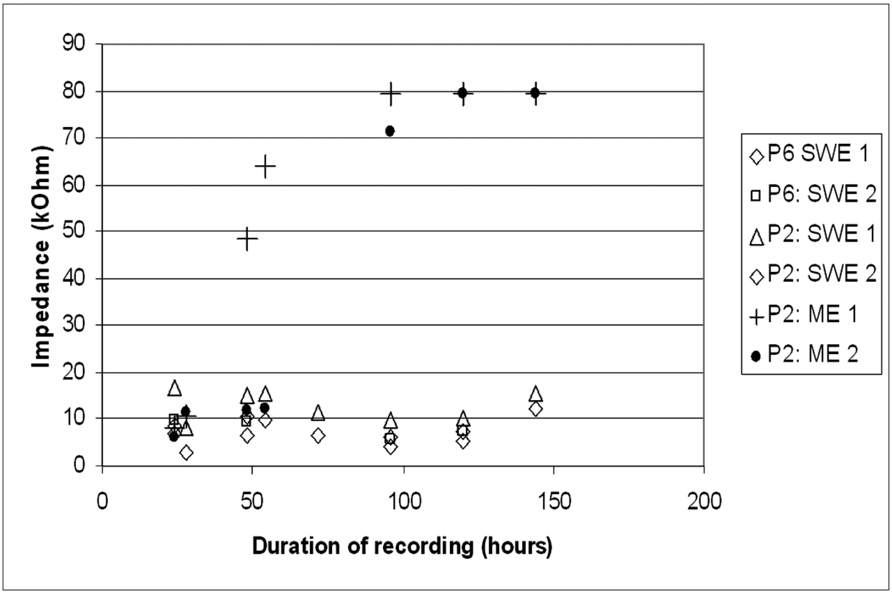

FIG. 4. Impedance evolution of a pair of Subdermal Wire Electrodes (SWEs) in two patients (P2 and P6) and compared with an additional pair of disc electrodes (ME) in Patient 2. The impedance remained stable during seven days of recording for four SWEs in two patients. The impedance of metal disc electrodes (ME) showed a sharp increase after 24 to 48 hours.

EEG was continuously recorded with 10 SWEs for 60 days with daily monitoring of the impedance, it was found that the impedance remained steady at less than 2.5 kOhms (Martz et al. 2009). At the end of 60 days there were no signs of irritation or infection associated with any of the 10 SWE placements. The antibacterial properties of silver have been well known for decades and are certainly beneficial here.

In the situation where a GND and a REF are selected from the array of invasive electrode contacts, these electrodes are removed from the recording field. The advantage of choosing an intracranial contact is to obtain a complete recording system made of the same electrode material. However, the site available/selected might not be optimum for a GND or a REF because, as a guideline, REF should be placed as far away from the recording electrode as possible. The same problem potentially arises when using a special 2-contact invasive electrode for GND&REF. Thus external, surface, non-invasive electrodes may be a reasonable choice, despite a basic guideline of using electrodes with similar materials in recording systems.

Similar to the SWE, a pair of sphenoidal electrodes (Ives and Gloor 1978) which have been commercially available since the late 1970s could also be used as a

Table 1. *Clinical and electrophysiological data of the nine patients recorded with Subdermal Wire Electrodes (SWEs) used for ground and reference (GND&REF).*

Patient, gender, age (years)	Epileptic Syndrome	Type of Invasive monitoring	Duration of recording (days)	Comments
P1, F, 18y	Nonlesional L TLE	Depth	9	
P2, F, 30y	Bilateral periventricular nodular heterotopia	Depth	14	C3/4: GCE: placed for comparison
P3, M, 45y	L HS + R frontal FCD	Depth	8	
P4, F, 35y	L mesial frontal FCD	Depth + Grid	10	
P5, F, 33y	L HS	Depth	3	
P6, M, 26y	R insular FCD	Depth + Grid	6	
P7, M, 18y	L HS + L temporal FCD	Depth + Grid	7	SWE placement transiently painful SWE disconnected during 1 GTCS
P8, M, 12y	R temporal porencephaly	Depth + Grid	9	
P9, M, 23y	Multiple bilateral early ischemic lesions	Depth + Grid	20	

P1 to 9: patient number. M/F: male/female. __y: age in years. R/L: right/left. TLE: temporal lobe epilepsy. HS: hippocampal sclerosis. FCD: focal cortical dysplasia. GCE: gold cup scalp Electrodes. SWE: Subdermal Wire Electrode. GTCS: generalized tonic-clonic seizure.

GND&REF pair; however, a citation for this application could not be found. The advantage of the SWE is they are placed with a smaller size needle (25 gauge × 16 mm) compared to the sphenoidal (22 gauge × 65 mm). Also, most commercial sphenoidal electrodes are stainless steel; while the SWE is Ag-Ag/Cl and thus more stable (Tallgren et al. 2005).

Up to now, the only available scalp electrode type was the standard disc electrode and its associated drawbacks of constantly degrading due to increasing impedance or becoming loose and thus requiring periodic random maintenance. In addition, the disc electrode and its accompanying gauze, collodion, and jell cannot be adequately sterilized, so they have to be placed away from the invasive electrodes' entry wounds. Moreover, they have to be placed at a spot which can be easily accessed by the technologists. Easy access for maintenance also means easy access for the patient who may scratch at these irritating electrodes, thereby increasing the risk of infectious complications and/or causing them to become loose.

In summary, the SWE offers a maintenance-free alternative for the GND&REF electrodes during intracranial recording that is minimally invasive and well tolerated. The only concern of the SWE is it can be dislodged without adequate fixation. This is easily controlled by some form of fixation such as collodion, Steri-Strips™, Tegaderm™, or medical grade "crazy-glue" such as Dermabond®. The SWE interconnection wire should also be secured with some form of strain-relief to prevent accidental disconnection. Finally, it is worth mentioning that the SWE is compatible with magnetic resonance imaging (MRI), computed tomography (CT), and digital subtraction angiography (Ives 2005, Vulliemoz et al. 2009), so that the system does not need to be removed if the patient needs acute or planned imaging during the invasive work-up.

DISCLOSURE

There is an obvious conflict of interest here as JRI developed, manufactured, and supplied the Subdermal Wire Electrodes (patent pending), for this study. However, this was inevitable during the first study using these new electrodes in this particular application. The Subdermal Wire Electrode is currently FDA 510k approved for recording the EEG in comatose patients in the ICU. It has been used “off-label” in this clinical situation where its advantages were identified as superior to traditional clinical practice and is not available from any other source.

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