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Clinical Neurophysiology 116 (2005) 1858–1869

www.elsevier.com/locate/clinph

Tibial somatosensory evoked potential intraoperative monitoring: Recommendations based on signal to noise ratio analysis of popliteal fossa, optimized P37, standard P37, and P31 potentials

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Accepted 27 April 2005

Abstract

Objective: To compare the intraoperative signal-to-noise ratio (SNR), reproducibility and rapidity of popliteal fossa (PF), optimized P37, standard P37 and P31 potentials.

Methods: Raw sweeps and 11 averages doubling sweep number from 2 to 2048 were compared in 37 patients undergoing scoliosis surgery. Optimized (highest amplitude or SNR) P37 derivations were Cz–CPc (22), CPz–CPc (27), Pz–CPc (7), iCPi–CPc (8), CPi–CPc (1), Cz–Pz (2) or Pz–FPz (3), and in two patients with non-decussation, Cz–CPi (1) or CPz–CPi (3). Standard P37 and P31 derivations were CPz–FPz and FPz–C5S. Signal amplitude was measured in 2048-sweep averages; peak noise was measured in raw sweeps and ± averages; SNR was amplitude/noise. Visual superimposability and $<$20–30% amplitude variation determined reproducibility. Sweeps to reproducibility determined rapidity.

Results: The SNR order was PF $\gg$ optimized P37 $>$ standard P37 $>$ P31. Mean optimized P37 SNR advantages over the standard P37 and P31 were 2.1:1 and 4.9:1. SNR had powerful non-linear correlations to reproducibility and rapidity. Median sweeps to reproducibility were PF: 2, optimized P37: 128, standard P37: 512 and P31: 1024. EEG noise was greatest in FPz derivations. Burst-suppression increased scalp potential SNR and rapidity.

Conclusions: Optimized P37 and PF recordings are most rapidly reproducible due to superior SNRs and are recommended. FPz should be avoided. Burst-suppression may be desirable.

Significance: CPz–FPz and FPz–C5S should no longer be standard.

Keywords: Tibial somatosensory evoked potentials; Signal to noise ratio; Intraoperative monitoring

1. Introduction

Rapid reproducibility is fundamental to effective somatosensory evoked potential (SEP) intraoperative monitoring (IOM). Low signal to noise ratio (SNR) potentials require averaging, which reduces noise by approximately the square root of the number of averaged sweeps (N). Reproducibility increases with the averaged SNR, but a surgical feedback delay theoretically proportional to $N = (\text{averaged SNR/raw SNR})^2$ occurs. Hence, very low raw SNR potentials may be too slowly resolved with the many sweeps needed for reproducibility, or non-reproducible, and therefore, unreliable with the few sweeps desired for rapidity.

Non-invasive tibial SEP monitoring is challenged by low raw SNRs. The popliteal fossa (PF) potential provides technical control while the standard cortical P37 recorded with CPz–FPz provides a proximal monitor (American Electroencephalographic Society, 1994b). However, P37

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doi:10.1016/j.clinph.2005.04.018

derivations optimized to highest amplitude seem to have higher SNRs than CPz–FPz (MacDonald et al., 2004b). The subcortical P31 from FPz–C5S is often recommended as another control or monitor resistant to anesthesia (American Electroencephalographic Society, 1994b; American Society of Neurophysiologic monitoring, 2004; Burke et al., 1999; Guerit et al., 1996), but is frequently noisy and sometimes omitted (MacDonald and Janusz, 2002; MacDonald et al., 2003; More et al., 1988; Mostegl et al., 1988; Nuwer, 1986, 1998). As no previous reports have based recommendations on SNR properties, we have analyzed the intraoperative SNR, reproducibility and rapidity of PF, optimized P37, standard P37 and P31 potentials to form a sound basis for recommending effective tibial SEP monitoring techniques.

2. Methods

2.1. Patients

The study included all 37 patients sequentially referred for routine upper and lower limb SEP and transcranial electric muscle motor evoked potential (MEP) monitoring of scoliosis surgery during the study period. There were 11 males and 26 females (ages 4–22 years, median 14 years). All had clinically normal sensorimotor function except for one patient with myopathy. Two patients had horizontal gaze palsy and progressive scoliosis with sensorimotor non-decussation shown by reversed lateralization of intraoperative median and tibial cortical SEPs and muscle MEPs (Jen et al., 2004; MacDonald et al., 2004a). Horizontal gaze palsy was obvious in one, but subtle and found postoperatively in the other. Both had a midline ventral cleft of the medulla on magnetic resonance imaging suggesting congenital absence of the sensorimotor decussations. Other diagnoses were idiopathic scoliosis (24), neurofibromatosis (4), congenital scoliosis (2), Marfan's syndrome (1), achondroplasia (1), osteomalacia (1), and diastamatomyelia (1). The surgeon obtained routine informed consent for surgery with SEP/MEP monitoring.

2.2. Anesthesia

Anesthesia followed our established routine and was adjusted to clinically determined surgical depth and satisfactory blood pressure. Pre-positioning anesthesia was either total intravenous anesthesia (TIVA) using propofol at 5–10 mg/kg/h and opioids in 20 patients or 0.5–2% sevoflurane sometimes with nitrous oxide in 17. This choice followed the preference of the anesthesiologist assigned to the surgery. Post-positioning anesthesia for surgery was TIVA in all patients and propofol occasionally reached 12 mg/kg/h. Neuromuscular blockade was omitted after intubation. Propofol blood levels and bispectral index were not performed and minimum alveolar concentration levels were not specifically noted.

2.3. General recording methods

The recording instrument was an Endeavor (Nicolet Biomedical Instruments, Madison, WS, USA). Scalp and neck electrodes were collodion-fixed gold-plated cups and PF electrodes were adhesive silver-silver chloride discs. Impedance was below 2 kΩ and recording leads were braided. Interleaved tibial nerve stimuli were constant-current rectangular pulses of 0.2 ms duration and fixed 4.7 Hz frequency at supra-maximal intensity for single-sweep PF responses. The SEP analysis time base was 100 ms.

2.4. P37 optimization

We routinely optimized P37 derivations to highest amplitude for each side as previously reported (MacDonald et al., 2004b). A referential recording of FPz, Cz, Pz, CP4, CP2, CPz, CP1 and CP3-mastoid was used to identify the P37 and N37 maximum sites for use as inputs 1 and 2. The N37 was infrequently absent and then FPz was sometimes optimal as input 2 instead. The Endeavor design allows extending this reported method to simultaneously include recording of all known potentially optimal derivations. Thus, Cz, Pz, CPz, iCPi and CPi to both CPc and FPz as well as Cz–Pz were also routinely recorded, where CPi and CPc were CP3 or CP4 ipsilateral and contralateral to the stimulated nerve and iCPi was CP1 or CP2, ipsilateral. Ipsilateral and contralateral sites were switched in these montages when referential recording showed non-decussation. The simultaneous bipolar recordings confirmed the referentially inferred optimal derivations or resolved any ambiguity. In one patient CPz–CPc was selected as optimal bilaterally because of less noise than CPz–FPz that had highest amplitude. The 5–10 min procedure took place after induction. Fig. 1 illustrates the technique and Table 1 lists the identified optimal derivations.

2.5. Other derivations and filtering

The PF was routinely recorded with a pair of electrodes separated by 3 cm placed just above the popliteal fossa crease. Standard P37 and P31 derivations were CPz–FPz and FPz–C5S. The bandwidth was 30–500 Hz for scalp potentials and 5–500 Hz for the PF (a 5 Hz high-pass filter gives a more level baseline before PF onset than a 30 Hz filter with our instrumentation). Notch filtering was not used. Free-running EEG was displayed using optimized P37, standard P37 and P31 derivations and filter settings.

2.6. SNR recordings

Bilateral PF, P37 and P31 recordings of 12 traces each were obtained concurrently. Trace 1 contained ongoing single sweeps and traces 2–12 were averages successively doubling sweep number from 2 to 2048. A second trial was superimposed. The automatic artifact rejection level was