Effect of Steady Hypothermia and Normothermia on Multimodality Evoked Potentials in Human Poikilothermia

Marius A. MacKenzie, MD; Dick M. Vingerhoets, MD; Ernst J. Colon, MD; Alfred J. L. G. Pinckers, MD; Servaas L. H. Notermans, MD

Objective: To assess the effects of steady-state spontaneous hypothermia on multimodality evoked potentials and on peripheral nerve conduction in human poikilothermia.

Design and Setting: Case series at a university hospital.

Patients: Four patients (four women, aged 28 to 37 years) with acquired poikilothermia.

Main Outcome Measures: Short-latency somatosensory, brain-stem auditory, and visual evoked potentials as well as motor and sensory peripheral nerve conduction velocity during steady-state spontaneous hypothermia and normothermia.

Results: The marked latency prolongation of all evoked potentials and decreased peripheral nerve conduction velocity observed during steady-state spontaneous hypothermia (mean $\pm$ SD core temperature, $33.5 \pm 0.3^\circ\text{C}$) compared with normothermia ($36.9 \pm 0.4^\circ\text{C}$) agrees with previous findings during short-term induced hypothermia.

Conclusions: The unequivocal effect of sustained mild spontaneous hypothermia on evoked potentials and peripheral nerve conduction velocity underlines the importance of meticulous attention to even small alterations in core temperature in interpreting neurophysiological investigations.

(Arch Neurol. 1995;52:52-58)

RECORDINGS OF evoked potentials and electroencephalograms are the two main neurophysiologic methods for intraoperative monitoring of the functional integrity of the central nervous system in patients undergoing cardiovascular surgical procedures under hypothermia; furthermore, evoked potentials play an increasingly important role in the diagnosis and management of many neurological disorders.^{1,2}

Temperature changes have a major impact on the function of the nervous system by induction of alterations in synaptic gain, synaptic and conduction delays, and amplitudes and durations of action potentials.³⁻⁷ The neurophysiological effects of temperature changes should be taken into account in the clinical interpretation of evoked potentials, as has been demonstrated for brain-stem auditory evoked potentials (BAEPs),⁸⁻¹⁷ visual evoked potentials (VEPs),^{11,18-21} and somatosensory evoked potentials (SSEPs).^{6,11,15,20,22-28} To date, the major knowledge of hypothermia-related alterations in evoked potentials in man has been

derived from studies in patients with short-term induced or accidental hypothermia. In contrast, the effects of sustained steady-state spontaneous hypothermia on the various evoked potentials and peripheral nerve conduction are still largely unknown.

We have investigated the effect of steady-state spontaneous hypothermia and normothermia on multimodality evoked potentials and peripheral nerve conduction parameters in four women with acquired poikilothermia. Poikilothermia is defined as fluctuation in core temperature of more than 2°C caused by changes in the ambient temperature²⁹; we have demonstrated previously that our patients meet the requirements of this definition.^{30,31}

RESULTS

Identification of the main peaks of the later components of the various evoked potentials was sometimes difficult, especially

See Patients and Methods
on next page

From the Division of Endocrinology, Department of Medicine (Dr MacKenzie), the Department of Clinical Neurophysiology (Drs Vingerhoets, Colon, and Notermans), and the Department of Ophthalmology (Dr Pinckers), University Hospital Nijmegen, the Netherlands. Dr Colon is now with the Department of Psychiatry, Delta Municipal Hospital Rotterdam, Poortugaal, and Erasmus University Rotterdam, the Netherlands.

PATIENTS AND METHODS

PATIENTS

We investigated four female patients (aged 28 to 37 years) with acquired poikilothermia, most likely of hypothalamic origin. A more detailed description of the patients has been reported recently.³¹

Patient 1 was a 28-year-old woman treated in 1983 by surgery and radiation therapy for a large tumor near the corpus callosum with bilateral extension into the suprasellar cisterns. Histologically, it could not be determined whether the tumor was a neuroblastoma, dysgerminoma, or atypical pinealoma; no signs of tumor recurrence had been found at the time of this report. Postoperatively, she exhibited epilepsy, frontal lobe syndrome, and hypothalamic dysfunction, including poikilothermia.

Patient 2 was a 37-year-old woman with no relevant medical history until, in 1982, epilepsy, secondary amenorrhea, and poikilothermia were demonstrated. Clinical evaluation revealed no signs for well-known causes of thermolability; computed tomographic scans and magnetic resonance imaging of the cerebrum showed no evidence of hypothalamic or pituitary lesions.

Patient 3 was a 33-year-old woman in whom, in 1982, panhypopituitarism and marked thermolability were demonstrated. Computed tomographic scanning of the cerebrum at the time revealed no abnormalities; magnetic resonance imaging in 1990 showed an empty sella.

Patient 4 was a 30-year-old woman who suffered from epilepsy, posttraumatic encephalopathy, and marked thermolability following a traffic accident at the age of 16 years. Computed tomographic scanning of the cerebrum in 1978 revealed marked central atrophy of the hemispheres, including bilateral thalamic lesions.

METHODS

Approval for the study was obtained from the Ethical Committee of the University Hospital Nijmegen, the Netherlands. Informed consent was obtained from all patients.

Patients were hospitalized during the study to control core temperature. All studies were performed during steady mild spontaneous hypothermia and steady normothermia. Maintenance of the rectal temperature at a virtually constant level for at least 4 days preceding the investigation was achieved by modulation of ambient temperature and clothing and by means of an electric blanket. The rectal temperature was measured every 10 minutes using a probe with a thermistor (depth of insertion, 10 cm) and recorded by a portable datalogger (model SQ-1201, Grant Instruments Ltd, Cambridge, England).

Multimodality evoked potentials (short-latency SSEPs, BAEPs, and VEPs) and peripheral nerve conduction (motor conduction velocity and distal motor and sensory latencies) were investigated in all patients during both hypothermia and normothermia. The evoked potentials were obtained according to standard procedures, using a Pathfinder II for nerve stimulation and data acquisition (Nicolet Biomedical Instruments, Madison, Wis). The latencies of all evoked potentials were determined in duplicate by cursor measurements and evaluated independently by two investigators.

Somatosensory Evoked Potentials

The SSEPs were elicited in response to median nerve stimulation at the right wrist. The stimulus duration was 0.1 ms; stimulus strength was adjusted to the twitch level of the thenar muscles. The sampling rate was 512 data points per channel and per sweep. For the short-latency SSEPs, two computed averages of 1000 regular 3.3/s stimuli were ob-

Continued on next page

during hypothermia. Only the latencies and interpeak latencies that could be identified with adequate reliability are presented. The rectal temperature was significantly lower during steady-state spontaneous hypothermia than during steady-state normothermia ($33.5 \pm 0.3^\circ\text{C}$ vs $36.9 \pm 0.4^\circ\text{C}$, $P < .01$).

SOMATOSENSORY EVOKED POTENTIALS

The SSEP interpeak latencies that could be determined during both thermal conditions are depicted in **Table 1**. Individual short-latency SSEPs are shown in **Figure 1**, and a typical example is depicted in **Figure 2**. During hypothermia, the latency of the N₂₀ peak and the central conduction time were significantly increased compared with the recordings during normothermia ($P < .01$ by Student's paired *t* test); compared with normal values, all latencies were significantly prolonged during hypothermia ($P < .01$ by Student's unpaired *t* test).

VISUAL EVOKED POTENTIALS

The VEPs elicited by pattern reversal (N₁₀₀) and flash stimulation are depicted in **Table 1**. Individual latencies

are shown in **Figure 3**. During hypothermia, both the N₁₀₀ and flash responses were significantly prolonged compared with values during normothermia ($P < .05$ by Student's paired *t* test) and compared with values for normal subjects ($P < .01$ by Student's unpaired *t* test).

BRAIN-STEM AUDITORY EVOKED POTENTIALS

The BAEPs are shown in **Table 1** and **Figure 4**; a representative example is depicted in **Figure 5**. A decline in mean rectal temperature of 3.3°C induced marked prolongation of the latencies of waves III and V as well as of the interpeak latency wave I—wave V, although the differences were not significant; compared with values in normal subjects, however, these latency parameters were significantly prolonged during hypothermia ($P < .01$ by Student's unpaired *t* test). The BAEP latencies could be identified in patient 2 only during hypothermia; they were comparable to BAEP latencies in the other patients during hypothermia.

PERIPHERAL NERVE CONDUCTION STUDIES

The motor nerve conduction velocity was significantly reduced and the distal sensory conduction time was sig-

tained. Band-pass filters were set at 5 and 1000 Hz; analysis time was 100 ms (25 ms preanalysis delay). Simultaneous two-channel recording was used. Cortical responses were measured between the C_3' electrode (between C_3 and P_3 , international 10-20 system) and the right ear and the cervical response between the C-5 vertebra and the right ear. For the short-latency SSEPs, the N_{13} (cervical response) and N_{20} (parietal cortex) latencies were analyzed; the central conduction time (CCT) was computed as $N_{20} - N_{13}$ latency.

Visual Evoked Potentials

The VEPs were measured using a reversing checkerboard pattern with a galvanometer mirror system (Medilog VPS-20, Vickers Medical Nederland, Nieuwkoop, the Netherlands) with a field size of 9° and a check size of $17'$ (minutes of arc). The contrast between the checks was 80%, and the reversal rate was 2/s. The active electrode was placed at O_2 and the passive electrode at T_3 , and grounding was done with an electrode on the earlobe (A_1). After 100-dB amplification analog band-pass filtering (band pass 0.16 to 70 Hz) the evoked response signals were digitized. In addition, a digital low-pass filter (zero phase) with a cutoff frequency of 40 Hz was applied to the averaged evoked response. Sixty-four VEP signals of 1000-ms duration were analyzed by a personal computer to assess the N_{100} response. Additionally, flash VEPs were induced by means of a No. 3182 photic stimulator from Devices Instrument Ltd (Welwyn Garden City, England), as described previously³²; the responses to pattern reversal and flash stimulation are presented for the left eye.

Brain-Stem Auditory Evoked Potentials

The BAEPs were elicited for the right and left ears separately by 0.1-ms rarefaction clicks of 80 dB (sound pressure level) presented binaurally at a rate of 11.1 Hz. Bipolar

recordings were obtained from C_2 to the ipsilateral ear and filtered through a band pass of 150 to 3000 Hz. Two computer averages of 1000 sweeps were plotted at each steady-state temperature. The analysis time was 16 ms (4 ms preanalysis delay). An analysis was made of the stimulus-to-peak latencies of waves I, III, and V as well as of the interpeak latency wave I-wave V.

Peripheral Nerve Conduction

Peripheral nerve conduction was studied using surface electrodes according to standard techniques with a Nicolet Viking. Supramaximal stimuli of 0.2-ms duration were applied; filters were set at 5 and 5000 Hz. The motor conduction velocity and distal conduction time of the nervus peroneus profundus and nervus ulnaris were obtained. The distal sensory conduction time was determined by orthodromic stimulation at the ankle (nervus suralis) and index finger (nervus medianus); the responses were derived at the calf (12 cm proximal to the stimulus point) and wrist, respectively. At the sites of stimulation and measurement, the local skin temperature was recorded immediately before each test (Dicitometer type K, Ancom S Ltd, Cheltenham, England).

STATISTICAL ANALYSIS

The results were analyzed using Student's paired *t* test for comparisons between hypothermia and normothermia and using Student's unpaired *t* test for comparisons between patients and normal subjects of comparable age. In the case of a missing value for a variable during one of the thermal conditions, the subject was excluded from the analysis for that variable. For all procedures, $P \leq .05$ was required for statistical significance; the significance level was adjusted for the number of simultaneous comparisons. All results are expressed as mean $\pm$ SD unless otherwise indicated.

nificantly prolonged during hypothermia compared with values during normothermia (**Table 2** and **Figure 6**).

The distal conduction time of the nervus peroneus profundus increased from 3.2 ± 0.4 ms during normothermia to 3.8 ± 0.2 ms during hypothermia ($n=3$; P , not significant); comparable data for the nervus ulnaris were 2.1 ± 0.1 and 2.5 ± 0.4 ms ($n=4$; P , not significant), respectively.

The mean Q_{10} (temperature coefficient) values for the motor conduction velocity, distal motor conduction time, and distal sensory conduction time of the nervus medianus were 1.5, 2.1, and 2.0, respectively.

COMMENT

In interpreting the neurophysiological effects of short-term induced hypothermia in man, it must be taken into account that because of rapidly changing temperatures (not homogeneously distributed within the body), neural activity is elicited and the actual brain temperature is difficult to assess; furthermore, anesthetic agents may have a profound effect on evoked responses.^{6,11,21,33} A prerequisite to assess adequately the effects of hypothermia on evoked responses is steady-state temperature, a condition very difficult to achieve in a

clinical setting.^{6,8} To our knowledge, the present study is the first report on neurophysiological effects of sustained steady-state "spontaneous" hypothermia. Since the rectal temperature was virtually constant for several days preceding the study, we assume it approximately reflects the brain temperature during the experiments.

Our findings reveal that during mild spontaneous sustained hypothermia, both the latencies of evoked potentials and peripheral nerve conduction velocities are markedly delayed. Unlike the findings during hypothermia, the short-latency SSEPs and the central conduction times during steady normothermia were within the normal range in every patient. The latency prolongation induced by steady-state hypothermia was computed from only two different levels of core temperature in each patient; the percentage delay was markedly greater for the central conduction time (reflecting conduction through the lemniscal and thalamic systems) than for the conduction times that included the more peripheral components. These observations are in agreement with the finding that the more profound effect of hypothermia on the components in the somatosensory pathways must be attributed to both slowed conduction velocity and increased synaptic delay.^{6,11,15,22,24,26} Since it has been dem-

Table 1. Evoked Potentials During Hypothermia and Normothermia*

	Controls (n=10)	Patients (n=4)		P†
		Hypothermia	Normothermia	
Somatosensory Evoked Potentials				
Rectal temperature, °C	Normal	33.5±0.3	36.9±0.4	<.01
Peak latency, ms				
N ₁₃	13.4±0.6	15.2±0.7‡	13.6±0.6	NS
N ₂₀	19.4±0.7	22.6±1.2‡	19.3±0.5	<.01
Central conduction time (N ₂₀ —N ₁₃)	6.0±0.8	7.4±0.5‡	5.7±0.8	<.05
P ₄₅	40.8±2.2	48.5±2.5‡	43.3±2.3	NS
Visual Evoked Potentials				
Rectal temperature, °C	Normal	33.9±1.0	37.0±0.4	<.05
Peak latency, ms				
N ₁₀₀ (pattern reversal)	105.9±6.2	128.0±5.7‡	111.0±5.0	<.01
Flash	107.3±8.1	130.0±16.5‡	116.0±9.8	<.05
Brain-Stem Auditory Evoked Potentials§				
Rectal temperature, °C	Normal	33.6±0.4	36.9±0.5	<.05
Peak latency, ms				
Wave I	1.53±0.09	1.68±0.07	1.57±0.17	NS
Wave III	3.64±0.09	4.45±0.23‡	3.81±0.13	NS
Wave V	5.46±0.25	6.82±0.08‡	5.80±0.30	NS
Central conduction time (wave I — wave V)	3.93±0.24	5.14±0.02‡	4.24±0.43	NS

*Values are mean±SD.

†Student's paired t test for hypothermia vs normothermia. NS indicates not significant.

‡P<.01 by Student's unpaired t test for patients vs controls.

§For brain-stem auditory evoked potentials, for patients, n=3.

Figure 1. Short-latency somatosensory evoked potentials during steady-state hypothermia and normothermia.

onstrated that synaptic transmission is more susceptible than axonal propagation to reduced temperature,^{3-5,7,15} we assume that the increased latency of SSEPs during steady hypothermia is caused predominantly by attenuated synaptic function.

Analogous to the short-latency SSEPs, the BAEPs showed progressive latency prolongation of successive waves. It is of note that in all patients, during mild steady hypothermia the wave I—wave V interpeak latency (representing the central conduction time) and the latencies

Figure 2. Typical example of short-latency somatosensory evoked potential (patient 1), representing the responses in duplicate during hypothermia (A) (rectal temperature, 34.0°C) and normothermia (B) (rectal temperature, 36.8°C).

Figure 3. Visual evoked responses of the left eye to pattern reversal and flash stimulation during steady-state hypothermia and normothermia.

Figure 4. Brain-stem auditory evoked responses of the right ear for waves I and V and the central conduction time (wave I—wave V) during steady-state hypothermia and normothermia.

of waves III and V were markedly prolonged, whereas during steady normothermia these parameters were within the normal ranges. The VEP responses to pattern reversal and flash stimulation were markedly prolonged in all patients during steady mild hypothermia compared with normothermia. The temperature sensitivity (expressed as the Q_{10} value and based on the relatively small differences in core and skin temperatures between normothermia and hypothermia) of peripheral nerve propagation was approximately similar to values reported previously during induced hypothermia.^{6,34,35}

An interesting but unexpected finding in the present study was the neurophysiological effect of the normalization of core temperature in patient 2, who was previously not known to have cerebral damage. In contrast to the other patients and to the recordings during hypothermia in this patient, during normothermia the BAEP could not be identified with certainty because of severely distorted morphologic characteristics of the components. We wondered to what extent the observed phenomenon could be attributed to neuronal desynchronization of the cerebral pathways caused by el-

Figure 5. Typical example of brain-stem auditory evoked response (right ear, patient 4), representing the response in duplicate during hypothermia (A) (rectal temperature, 33.2°C) and normothermia (B) (rectal temperature, 37.4°C).

Figure 6. Motor conduction velocity (nervus peroneus profundus) and sensory conduction time (nervus medianus) during steady-state hypothermia and normothermia.

Table 2. Peripheral Nerve Conduction Studies*

	Controls (n=20)	Patients (n=4)		P†
		Hypothermia	Normothermia	
Rectal temperature, °C	Normal	33.5±0.3	36.9±0.4	<.01
Motor conduction velocity, m/s (local skin temperature, °C)				
Nervus peroneus profundus	50.0±3.8	41.8±1.9‡ (29.6±0.3)	47.3±2.1 (33.3±0.2)	<.01 <.01
Nervus ulnaris	62.0±8.2	51.5±1.9 (30.2±1.5)	59.3±6.7 (35.4±0.6)	NS <.01
Distal sensory conduction time, ms (local skin temperature, °C)				
Nervus medianus	2.6±0.2	3.2±0.2‡ (30.1±2.3)	2.6±0.4 (35.5±0.2)	NS NS
Nervus suralis	3.7±0.4	4.0±0.8 (29.7±0.2)	3.4±0.8 (33.7±1.1)	NS <.01

*Values are mean±SD.

†Student's paired t test for hypothermia vs normothermia. NS indicates not significant.

‡P<.01 by Student's unpaired t test for patients vs controls.

evaluation in the core temperature in this patient, who had been chronically hypothermic for several years. Therefore, the BAEP was reassessed after she had been virtually normothermic for several months, but no improvement in the BAEP was observed (unpublished data, 1990).

The neurophysiological effects of prolonged periods of spontaneous hypothermia, as observed in human poikilothermia, have not been reported previously. A major problem in poikilothermia is how to preserve adequate cerebral function during large temperature fluctuations that cause imbalances in coordinated nervous system function.⁷ Clinically, considerable fluctuations in core temperature and particularly marked hypothermia for prolonged periods seriously affect both mental and physical activity in patients.³¹ The most striking neuropsychiatric symptoms of prolonged hypothermia include progressively impaired mentation, lethargy, bradyphrenia, confusion, disorientation, disorders in (short) memory, stumbling gait, slurred speech, and the occurrence of epileptic seizures. We assume that

these findings are caused by attenuated nervous propagation velocity and synaptic transmission in the central nerve fibers, resulting in impaired coordination and specificity of the higher cerebral functions. Since hypothermia provokes a fall in both metabolic rate and cerebral blood flow of about 7% per 1°C decrease in core temperature,³⁶ it remains to be established to what extent the impaired cerebral function can be attributed exclusively to the reduction in core temperature.

The present study has some limitations. First, our results are based on only four patients with poikilothermia and on two levels of core temperature; the neurophysiological effects of more severe spontaneous hypothermia remain to be elucidated. Second, identification of the various peaks of the evoked responses was sometimes difficult, especially during hypothermia. Third, at least two of our patients had (proven) intracerebral lesions as the cause of their poikilothermia, which affected brain integrity and compromised the neurophysi-

ological parameters to be studied; however, since all patients served as their own controls, this did not affect the observed differences between thermal conditions. Furthermore, we cannot exclude the possibility that the existence of intermittent sustained hypothermia for several years might itself have affected the functional integrity of the nervous system by inducing structural or metabolic changes. However, since the present results were obtained during genuine steady-state conditions for core temperature (including the brain temperature) and since both hypothermia and normothermia were achieved and maintained without the aid of thermal stress or anesthetic drugs, we believe our study can contribute to better insight into the neurophysiological effects of reduced core temperature.

We conclude that mild steady-state spontaneous hypothermia induces unequivocal alterations in multimodality evoked responses and peripheral nerve conduction compared with normothermia. Since marked latency differences can occur despite slight changes in temperature, we emphasize that deviations in core temperature should be taken into account meticulously in interpreting evoked potentials and electromyograms in clinical practice. The markedly attenuated neurophysiological and neuropsychological function despite only mild hypothermia underlines the importance to maintain normothermia in patients with poikilothermia to improve their physical and mental function and thus their quality of life.

Accepted for publication December 7, 1993.

We thank Henny Janssen (Department of Clinical Neurophysiology) for practical support in obtaining the data, José Bor and Wilma Raymann (Department of Clinical Neurophysiology) for technical assistance, and Alec Ross, PhD (Division of Endocrinology, Department of Medicine), for statistical advice (all from University Hospital Nijmegen, the Netherlands). We thank P. W. C. Kloppenborg, MD (Division of Endocrinology, Department of Medicine, University Hospital Nijmegen) for his critical review of the article.

Reprint requests to Division of Endocrinology, Department of Medicine, University Hospital Nijmegen, PO Box 9101, 6500 HB Nijmegen, the Netherlands (Dr MacKenzie).

REFERENCES

- Chiappa KH, Ropper AH. Evoked potentials in clinical medicine. *N Engl J Med*. 1982;306:1140-1150.
- Aminoff MJ. Evoked potential studies in neurological diagnosis and management. *Ann Neurol*. 1990;28:706-710.
- Katz B, Miledi R. The effect of temperature on the synaptic delay at the neuromuscular junction. *J Physiol Lond*. 1965;181:656-670.
- Bénita M, Condé H. Effects of local cooling upon conduction and synaptic transmission. *Brain Res*. 1972;36:133-151.
- Weight F, Erulkar SD. Synaptic transmission and effects of temperature at the squid giant synapse. *Nature*. 1976;261:720-722.
- Markand ON, Warren C, Mallick GS, et al. Effects of hypothermia on short latency evoked potentials in humans. *Electroencephalogr Clin Neurophysiol*. 1990;77:416-424.
- Montgomery JC, MacDonald JA. Effects of temperature on nervous system: Implications for behavioral performance. *Am J Physiol*. 1990;259:R191-R196.
- Stockard JJ, Sharbrough FW, Tinker JA. Effects of hypothermia on the human brainstem auditory response. *Ann Neurol*. 1978;3:368-370.
- Kaga K, Takiguchi T, Myokai K, Shiode A. Effects of deep hypothermia and circulatory arrest on the auditory brainstem responses. *Arch Otorhinolaryngol*. 1979;225:199-205.
- Marshall NK, Donchin E. Circadian variation in the latency of brainstem response and its relation to body temperature. *Science*. 1981;212:356-358.
- Markand ON, Warren C, Moorthy SS, et al. Monitoring of multimodality evoked potentials during open heart surgery under hypothermia. *Electroencephalogr Clin Neurophysiol*. 1984;59:432-440.
- Bridger MWM, Graham JM. The influence of raised body temperature on auditory evoked brainstem responses. *Clin Otolaryngol*. 1985;10:195-199.
- Markand ON, Lee BI, Warren C, et al. Effects of hypothermia on brainstem auditory evoked potentials in humans. *Ann Neurol*. 1987;22:507-513.
- Bastuji H, Garcia Larrea L, Bertrand O, Mauguière F. BAEP latency changes during nocturnal sleep are not correlated with sleep stages but with body temperature variations. *Electroencephalogr Clin Neurophysiol*. 1988;70:9-15.
- Sohmer H, Gold S, Cahani M, Atlas J. Effects of hypothermia on auditory brainstem and somatosensory evoked responses. *Electroencephalogr Clin Neurophysiol*. 1989;74:50-57.
- Eggermont JJ, Schmidt PH. The auditory brainstem response. In: Colon EJ, Visser SL, eds. *Evoked Potential Manual: A Practical Guide to Clinical Applications*. 2nd ed. Boston, Mass: Kluwer Academic Publishers; 1990:41-77.
- Durrant JD, Gerich JE, Mitrakou A, Jenssen T, Hyre RJ. Changes in BAEP under hypoglycemia: temperature-related? *Electroencephalogr Clin Neurophysiol*. 1991;80:547-550.
- Wollin LR, Massopust LC, Meder J. Electroretinogram and cortical evoked potentials under hypothermia. *Arch Ophthalmol*. 1964;72:521-524.
- Reilly EL, Condo C, Brunberg JA, Doty DB. Visual evoked potentials during hypothermia and prolonged circulatory arrest. *Electroencephalogr Clin Neurophysiol*. 1978;45:100-106.
- Matthews WB, Read DJ, Pountney E. Effect of raising body temperature on visual and somatosensory evoked potentials in patients with multiple sclerosis. *J Neurol Neurosurg Psychiatry*. 1979;42:250-255.
- Russ W, Kling D, Loesewitz A, Hempelmann G. Effect of hypothermia on visual evoked potentials in humans. *Anesthesiology*. 1984;61:207-210.
- Budnick B, McKeown KL, Wiederholt WC. Hypothermia-induced changes in rat short latency somatosensory evoked potentials. *Electroencephalogr Clin Neurophysiol*. 1981;51:19-31.
- Dubois M, Coppola R, Buchsbaum MS, Lees DE. Somatosensory evoked potentials during whole body hyperthermia in humans. *Electroencephalogr Clin Neurophysiol*. 1981;52:157-162.
- Coles JG, Taylor MJ, Pearce JM, et al. Cerebral monitoring of somatosensory evoked potentials during profoundly hypothermic circulatory arrest. *Circulation*. 1984;70(suppl 1):96-102.
- van Rheineck Leyssius AT, Kalkman CJ, Bovill JG. Influence of moderate hypothermia on posterior tibial nerve somatosensory evoked potentials. *Anesth Analg*. 1986;65:475-480.
- Hume AL, Durkin MA. Central and spinal somatosensory conduction times during hypothermic cardiopulmonary bypass and some observations on the effects of fentanyl and isoflurane anesthesia. *Electroencephalogr Clin Neurophysiol*. 1986;65:46-58.
- Russ W, Sticher J, Scheld H, Hempelmann G. Effects of hypothermia on somatosensory evoked responses in man. *Br J Anaesth*. 1987;59:1484-1491.
- Guérit JM, Sèveges L, Baele P, Dion R. Median nerve somatosensory evoked potentials in profound hypothermia for ascending aorta repair. *Electroencephalogr Clin Neurophysiol*. 1990;77:163-173.
- Hensel H. Neural processes in thermoregulation. *Physiol Rev*. 1973;53:948-1017.
- MacKenzie MA, Hermus ARMM, Wollersheim HCH, Binkhorst RA, Pieters GFFM. Thermoregulation and afterdrop during hypothermia in patients with poikilothermia. *Q J Med*. 1993;86:205-213.
- MacKenzie MA, Hermus ARMM, Wollersheim HCH, et al. Poikilothermia in man: pathophysiology and clinical implications. *Medicine*. 1991;70:257-268.
- Mlanda AT, Cruysberg JRM, Pinckers A, van der Werf S. Evaluation of color vision, mesopic vision, visual evoked potentials and lightness discrimination in adult amblyopes. *Doc Ophthalmol*. 1986;62:247-264.
- Janssen R, Hetzler BE, Creason JP, Dyer RS. Differential impact of hypothermia and pentobarbital on brain-stem auditory evoked responses. *Electroencephalogr Clin Neurophysiol*. 1991;80:412-421.
- Buchthal F, Rosenfalck A. Evoked action potentials and conduction velocity in human sensory nerves. *Brain Res*. 1966;3:1-22.
- De Jesus PV, Hausmanowa-Petrusewicz I, Barchi RL. The effect of cold on nerve conduction of human slow and fast nerve fibers. *Neurology*. 1973;23:1182-1189.
- Reuler JB. Hypothermia: pathophysiology, clinical settings and management. *Ann Intern Med*. 1978;89:519-527.