

Nomination for  
SARTA's Claire Pomeroy Award for Innovation in Medical Technology, 2010  
1990 – 1999 Time Period

Nominee's Name: Warren D. Smith, Ph.D.

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Product Name: Prediction Probability  $P_K$ , performance measure and computer algorithm  
for assessing monitors of depth of anesthesia

I wish to submit a self-nomination for the Claire Pomeroy Award for Innovation in Medical Technology for the 1990 – 1999 time period.

### Background

Traditional methods of monitoring depth of general anesthesia, such as heart rate, blood pressure, and breathing pattern, are not reliable. Sometimes patients who are thought to be unconscious during anesthesia in fact are "aware" and suffer excruciating pain.

To seek to prevent incidents of awareness, Dr. Smith and his biomedical engineering students at Sacramento State collaborated with anesthesiologists at the UC Davis Medical Center, UC San Diego Medical Center, and Kaiser Permanente to develop and test a number of improved methods of monitoring the depth of anesthesia. Through his collaboration with Lawrence Livermore National Laboratory (LLNL), Dr. Smith developed custom code and electronics and a miniature computer system to perform on-line spectrum analysis of the background electroencephalogram (EEG) [1-2] and to record the EEG data along with electromyogram (EMG) and hemodynamic (systolic and diastolic blood pressures and heart rate) variables during surgeries. His system was used to obtain recordings from over 300 surgery patients who were given a variety of anesthetic agents. Dr. Smith was awarded an NIH research grant (1986-1988) to investigate how to use the EEG to monitor depth of anesthesia. Dr. Smith's collaborative work led to improved monitors of depth of anesthesia that utilized the patient's background EEG [3-4], mid-latency auditory evoked potentials (MLAEPs) in the EEG [5], and craniofacial electromyogram (EMG) signals [6].

### Prediction Probability $P_K$

A particularly significant accomplishment was Dr. Smith's development of a new measure for assessing the performance of depth-of-anesthesia monitors, called Prediction Probability,  $P_K$ . In 1996, Dr. Smith and his anesthesiology collaborators at the medical centers at UC San Francisco and UC San Diego published their seminal paper on performance measure  $P_K$  [7] in *Anesthesiology*, the flagship journal of that field, along with a companion article showing examples of its application to assessing the performance of depth-of-anesthesia monitors based

on anesthetic concentration, the EEG, pupillary response, and hemodynamic variables [8]. Dr. Smith and his collaborators also provided an in-depth analysis of the mathematical properties of  $P_K$  in a third article [9].

Dr. Smith's Prediction Probability,  $P_K$ , has been adopted as a world-wide standard for assessing the performance of depth-of-anesthesia monitors. Dr. Smith has made  $P_K$  available as a Microsoft Excel macro, and every year, Dr. Smith responds to numerous email requests for this macro from around the world and advises researchers on its use. To date, Dr. Smith has responded to requests for the  $P_K$  macro by 60 investigators in 21 countries, and over 100 journal papers have cited Dr. Smith's  $P_K$ . Because of his expertise, Dr. Smith was invited to collaborate on an international research team, involving investigators and anesthesia monitor companies in Belgium, Denmark, the United Kingdom, and Spain, as well as in the United States [10]. The most successful depth of anesthesia monitor, the Aspect Medical Systems BIS (Bispectral Index) monitor, was developed using  $P_K$ .

## References

- [1] **Smith, W. D.**, and Lager, D. L., "Evaluation of simple algorithms for spectral parameter analysis of the electroencephalogram," IEEE Transactions on Biomedical Engineering, Vol. BME-33, pp. 352-358, 1986.
- [2] **Smith, W. D.**, Fung, D. L., and Bennett, H. L., "Monitoring the electroencephalogram during anesthesia by spectral parameter analysis," Journal of Clinical Monitoring, Vol. 1, pp. 95-96, 1985.
- [3] Dutton, R. C., **Smith, W. D.**, and Smith, N. T., "The use of the EEG to predict patient movement during anesthesia," Chapter 9 in Consciousness, Awareness, and Pain in General Anaesthesia, Eds. M. Rosen and J. N. Lunn, London: Butterworths, pp. 72-82, 1987.
- [4] Dutton, Robert C., **Smith, Warren D.**, and Smith, N. Ty, "EEG predicts response to surgical stimuli during general anesthesia with combinations of isoflurane, 70% N<sub>2</sub>O, and fentanyl," Journal of Clinical Monitoring, Vol. 12, pp. 127-139, 1996.
- [5] Dutton, Robert C., **Smith, Warren D.**, Rampil, Ira J., Chortkoff, Ben S., and Eger, Edmond I., II, "Forty-hertz mid-latency auditory evoked potential activity predicts wakeful response during desflurane and propofol anesthesia in volunteers," Anesthesiology, Vol. 91, pp. 1209-1220, 1999.
- [6] Dutton, Robert C., **Smith, Warren D.**, Bennett, Henry L., Archer, Stephen T., and Smith, N. Ty, "Craniofacial electromyogram activation response: another indication of anesthetic depth," Journal of Clinical Monitoring and Computing, Vol. 14, pp. 5-17, 1998.
- [7] **Smith, Warren D.**, Dutton, Robert C., and Smith, N. Ty, "Measuring the performance of anesthetic depth indicators," Anesthesiology, Vol. 84, pp. 38-51, 1996.
- [8] Leslie, Kate, Sessler, Daniel I., **Smith, Warren D.**, Larson, Merlin D., Ozaki, Makoto, Blanchard, Don, and Crankshaw, David P., "Prediction of movement during propofol/nitrous oxide anesthesia: Performance of concentration, electroencephalographic, pupillary, and hemodynamic indicators," Anesthesiology, Vol. 84, pp. 52-64, 1996.
- [9] **Smith, Warren D.**, Dutton, Robert C., and Smith, N. Ty, "A measure of association for assessing prediction accuracy that is a generalization of nonparametric ROC area," Statistics in Medicine, Vol. 15, pp. 1199-1215, 1996.
- [10] Struys, Michel M. R. F., Jensen, Eric Weber, **Smith, Warren**, Smith, N. Ty, Rampil, Ira, Dumortier, Frank J. E., Mestach, Christel, and Mortier, Eric P., "Performance of the ARX-derived auditory evoked potential index as an indicator of anesthetic depth: A comparison with Bispectral Index and hemodynamic measures during propofol administration," Anesthesiology, Vol. 96, pp. 784-787, 2002.