When Pulse Oximeters Fail: Motion and Low Perfusion.
Cooke J.E. *Anesthesiology*. 2000;93(3A):A554.

Introduction
Pulse oximeters are very reliable instruments. However, under certain conditions, such as patient movement or low perfusion states, most models become unreliable. Manufacturers have attempted to improve oximeters' accuracy during these conditions. This study evaluates several pulse oximeters using a "SpO2 Simulator". This device simulates a physiologic signal and can vary pulse oxygenation (SpO2), heart rate (HR), and can simulate movement. It also enables a test of the signal strength at which SpO2 readings becomes unreliable. This signal strength testing method has not previously been reported.

Method
A Bio-Tek Index 2PF SpO2 Simulator was used to evaluate 7 pulse oximeter models: Nellcor N-395, Masimo 2000 with MS-1 OEM module, Ivy Biomedical 405C with Masimo MS-3 OEM module, TFT Medical OEM-601 module, Nonin 9847, Criticare 503, and Hewlett-Packard Viridia. Oximeters were tested at several SpO2 and HR's: SpO2 from 70% to 98%, and HR from 45 to 180. Sensitivity to simulated motion artifact was tested with motion frequencies between 2.5 and 6.0 Hz. Signal strength sensitivity was tested by reducing the pulsatile signal until the tested pulse oximeter failed. Asystole time was tested by stopping the pulsatile signal and timing when the device stopped displaying a HR. Signal strength was defined as Infrared AC/Infrared DC (the AC component of the signal is the pulsatile part, and correlates with pulse pressure). Failure was defined, for all tests, as an error of 5 or greater compared to the input Bio-Tek signal, for either HR or SpO2.

Result
All pulse oximeters performed well at all simulated HR and SpO2 values. With motion artifact testing, Nellcor, Criticare, Nonin and Hewlett-Packard failed to give accurate results at all motion frequencies. Masimo MS-1, Masimo MS-3 and TFT gave accurate results at all motion artifact frequencies. Signal strength sensitivity varied markedly between the different machines, as did asystole time.

Discussion
Advantages of testing with the Bio-Tek include reproducibility between laboratories, and ability to program in various HR, SpO2, signal strength and motion combinations. These combinations would be very difficult to achieve in a human study, but could still occur clinically. The pulse oximeters tested varied markedly in their ability to handle motion and low signal strength. In general, older models, not designed to function under these conditions, failed these tests. A recently released model, the Nellcor N-395, did not function with the simulated motion artifact. Another recently developed model, the TFT OEM-601, functioned at a much lower signal strength (by a factor of 6 to 30) while maintaining recognition of asystole. In designing these monitors, there may be trade-offs in sensing a weak signal while maintaining ability to detect asystole. Some models were better in both respects. Future studies in animals and patients would be helpful in confirming these findings.

	Nellcor N-395	Masimo MS-1	Masimo MS-3	TFT OEM-601	Nonin 9847	Criticare	HP
Motion Simulation	Fail	Pass	Pass	Pass	Fail	Fail	Fail
Signal Sensitivity	0.1%	0.06%	0.06%	0.01%	0.3%	0.3%	0.2%
Asystole Time	7.7 sec	6.5 sec	6.3 sec	4.5 sec	24 sec	> 90 sec	45.1 sec