perfusion agents at the same time. Non-ischemic myocardium exhibits gradual signal enhancement and washout with the passage of the T1-enhancing contrast agent. Administration of adenosine accentuates the baseline perfusion defect in ischemic myocardium and helps differentiate ischemic from non-ischemic myocardium. Analogous to the detection of contractile reserve with low-dose dobutamine administration, vasodilator-induced perfusion defects detect myocardial perfusion reserve. A valuable feature of cardiac MRI may be its ability to differentiate between different myocardial layers because of its high spatial resolution. This could allow differentiation between sub-endocardial and transmural perfusion defects. Sub-endocardial ischemia is believed to be the first indication of compromise of myocardial blood flow. Finally, imaging of cardiac viability, i.e., detection of myocardial infarctions, can easily be performed by MRI, showing the location and extent of persisting myocardial ischemic injuries with great accuracy. In conclusion, MRI seems more suitable for myocardial imaging in patients with sepsis or shock, as compared to CT. An assessment of myocardial function, perfusion and viability can be performed in a single examination.

Konstantin Nikolaou, MD, Department of Clinical Radiology, Ludwig-Maximilians-University of Munich, Marchioninistrasse 15, 81377 Munich, Germany

A 355

ALARM ALGORITHMS: RECOGNIZING TRUE FAILURE

Michael Imhoff, Ursula Gather, Roland Fried

Introduction: The disease state of the critically ill is described by complex data from multiple sources. For the clinician the challenge is to distinguish clinically relevant changes from noise and artifacts. The overreaching goal must be the early detection of true failure with high sensitivity and specificity. In physiological monitoring today most alarm systems are based on simple thresholds only. This leads to an unacceptably high rate of false positives alarms, while the actual rate of false negatives remains unknown. In this contribution we will give an overview and present some examples of advanced alarm algorithms.

Requirements and approaches: Alarm algorithms have to be robust against artifacts and missing values. Real-time application requires efficient and fast algorithms with adequate scalability of memory and computational demands. Online use demands instantaneous updates of alarm calculations with every new incoming value. Alarm algorithms have to provide predictable behavior and meet methodological rigor. Many different alarm algorithms have been published and several have been investigated in simulation and clinical studies. Univariate algorithms, i.e., algorithms that handle one variable at a time, include median filters, Kalman filters, different robust filters, autoregressive models, phase space models, dynamic linear models, and trend detection methods. For the handling of multiple variables multivariate algorithms, e.g., graphical models, dynamic factor models, multivariate regression, have been employed. Also approaches from artificial intelligence, for instance, knowledge-based systems, neural networks, fuzzy logic, Bayesian networks, or decision trees, were investigated in the context of alarm detection. While some of these approaches showed promising results, none has gained universal acceptance or even commercial implementation.

Examples from vital signs monitoring: Robust regression techniques represent one approach to univariate signal extraction. Different regression methods yielded satisfactory results for extracting the underlying signal from noisy simulated data and from real clinical monitoring time series. Repeated median regression seems to be the best choice for intensive care monitoring because of the quality of signal extraction and the favorable computational demands. Different multivariate algorithms were applied to complex monitoring time series. Graphical models were successfully used to identify "lead" variables that were representative of groups of variables. Dynamic factor models were applied to identify latent variables as representations of the underlying data generating processes.

Conclusions: Recognizing true failure in the critically ill requires fast and reliable interpretation of complex data with high sensitivity and specificity. Currently commercially available methods are often inadequate for this task. Statistical research has made new univariate alarm algorithms available that can provide better and more robust alarm detection. Also, new multivariate alarm algorithms are being developed and show first promising results. Further research is still needed. In summary, new advanced alarm algorithms will help to detect true failure in the critically ill.

Michael Imhoff, MD, PhD, Department for Medical Informatics, Biometrics and Epidemiology, Ruhr-University Bochum, Postbox, 44780 Bochum, Germany

A 356

MECHANISMS OF PHYSIOLOGICAL VARIABILITY

Sven Zenker

The measurement of physiological variability in health and disease has received growing attention over the last years. A particularly well studied example is heart rate variability, which has been shown to have diagnostic and prognostic utility in a number of experimental and clinical settings ranging from primary cardiac ailments to various pathophysiological states relevant to critical illness. While these phenomenological observations of variability phenomena, as well as their alterations in disease, are quantifiable and relevant, an understanding of the mechanisms underlying physiological variability is crucial for guiding interpretation of the observations. Using variability in the cardiovascular system as an example, this talk will illustrate generic mechanisms underlying many variability phenomena in biological systems through the use of mathematical models.