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Performance Evaluation of European Pressure Sensors

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Dr Cochard explains the significance of inaccuracy with pressure sensors, describes a simple technique to evaluate accuracy and reports on tests with eight European products.

Introduction

The arterial pressure is a basic haemodynamic parameter used in routine clinical work to assess the cardiovascular status, particularly in intensive care patients. Measuring it serves as a guide to therapeutic interventions. Inaccurate measurement may lead to erroneous diagnosis or to an inadequate, unnecessary or potentially dangerous intervention. However, the biomechanical characteristics of these devices can modify the response of the sensor to a pressure signal (Gardner 1997; Kleinman 1989), affecting the accuracy of measurements.

Principles

The pressure signal is recorded in an artery by means of a catheter and transmitted to the sensor by tubing filled with physiological serum. The sensor comprises a deformable membrane on which is fixed a Wheatstone bridge. This transforms the signal of deformation of the membrane produced by the pressure signal into an electrical signal transmitted to the monitor, which is then converted into an analogue signal. This measurement depends directly on the biomechanical characteristics of the system used: strictly speaking it is a sensor but in reality there are tubing and accessories forming the relay between the pressure signal and the monitor. Biomechanical characteristics confer visco-elastic properties on the intervening system that are capable of modifying the scale of the required clinical criteria, the quantitative value of the arterial pressure and the shape of the curve, which is not without interest in the analysis of a given haemodynamic situation (Promonet et al. 2000; Todorovic et al. 1996).

Typically the pressure system (catheter pressure transducer *Figure 1. Behaviour model of a second order system.* system) used in intensive care is a 2nd order dynamic system whose behaviour, when one applies or releases a stress to it abruptly, is analogous to the behaviour of a mass, joined to a fixed point by a spring on one side, and to a disk immersed in a liquid possessing a given viscosity, on the other side. The system will oscillate at a certain frequency, known as the natural frequency, and with an amplitude of oscillation decreasing over time (see figure 1) (Nichols et al. 1990).

These characteristics (oscillation frequency and amplitude decay) depend on the rigidity of the spring, on the mass M and on the viscosity of the liquid (resistance to displacement). The same relaxation dynamic is observed for the pressure sensor:

- the rigidity of the system corresponds to the rigidity of the tubing, accessories, and membrane of the sensor;
- the mass to that of the mass of liquid displaced;
- the viscosity to the resistance to displacement of the liquid.

All these characteristics depend on the architecture of the system, the length and section of the different constituents and the biomechanical characteristics of the industrial materials used (type of polymerisation, thickness of the materials, etc.).

If a sinusoidal periodic pressure signal is recorded of the increasing frequency generated by a pressure generator, a response is obtained which within a certain frequency range of the signal will correspond to a Response Amplitude / Signal Amplitude ratio = 1. Beyond a threshold value of the frequency, the amplitude of the response is amplified in comparison to that of the signal, the maximum amplification being produced for a frequency equal to the natural frequency of the sensor. The frequency of the signal from which the response is amplified depends on the natural frequency of the system; the value of the amplification for these frequencies depends on a coefficient known as the damping coefficient (zeta). This distortion of the response is connected with the phenomenon of resonance (sum of the amplitudes of the incident waves and the waves given back by the system). The zone of distortion is called the zone of resonance.

In the cardiovascular system, the pressure curve generated by the heart is a complex phenomenon that depends on the systolic ejection volume and the viscoelastic properties of the vascular system. This periodic phenomenon may be broken down by Fourier transformation into the sum of simple sinusoidal signals (harmonics), with frequencies that are multiples of the frequency of the pressure signal (fundamental) and of given amplitudes. It is considered that the first eight harmonics of the pressure signal are sufficient to obtain an adequate reconstituted signal. Thus, the weaker the natural frequency of the sensor, the greater the number of harmonics inadequately returned. The amplitude of the signal distortion for each harmonic involved depends on the damping coefficient of the sensor.

From these two easily measurable parameters, F_n and zeta, we can evaluate the reliability of a pressure sensor by anticipation. By modifying these two parameters, Gardner (1981) defined the performance of a sensor according to the quality of its response to a calibrated pressure signal generated by a pressure generator reproducing a physiological pressure signal. He defines four zones evaluating the signal reproduction (adequate, acceptable, underdamped and overdamped: see figure 2).

Testing Pressure Sensors

The dynamic characteristics, F_n and zeta, of eight pressure sensors available in Europe were tested on a test bed to determine their reliability from the Gardner diagram.

The pressure sensors were linked to a Marquette Tramscope, monitor; the analogue pressure signal was recovered by an analogue-to-digital converter with a sampling frequency of 200 Hz for electronic processing. A connection to an arterial pressure signal calibrated at 140/92 generated by the Biotek, 601 generator at frequencies of 1 Hz and 1.5 Hz was made to verify and measure any possible distortions of the signal. The results are given in table I and reproduced on the Gardner diagram (see figure 3).

These results show great diversity in the quality of the pressure sensors currently available in Europe. This diversity is not connected with the quality of the deformable membrane, but rather with the quality of the intermediary line (section surface, architecture, materials, accessories). All the sensors except one are of the "underdamped" type, amplifying the signal and thus overestimating the values measured. This overestimation is well above 5% for the least reliable sensors and increases with increased frequency of the signal, which is often the case with the most seriously ill patients. This overestimation may give rise to errors of diagnosis and potentially to errors of treatment (an absence of decision in falsely normotensive patients or prescription of antihypertensives in falsely hypertensive patients).

Conclusion

The analysis of the biomechanical characteristics of eight devices available in Europe for measuring the arterial pressure by an invasive method reveals a great diversity of performance of this equipment. Because of the risk of diagnostic and therapeutic errors possibly engendered by the mediocre performance, it is necessary for the clinician to understand the factors at the origin of this performance. The evaluation of these factors (which are the natural frequency and the damping coefficient of the device) is easy to perform in routine clinical practice and would appear to be a step that is not to be omitted when choosing a commercial device.

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