Gianluca Villa
Fabio O. Tartaglia
Mauro Neri
Claudio Ronco

Waves...from the inside

Received: 18 October 2014
Accepted: 29 October 2014
Published online: 13 November 2014
© Springer-Verlag Berlin Heidelberg and ESICM 2014

G. Villa (✉) · F. O. Tartaglia · M. Neri · C. Ronco
Department of Nephrology, Dialysis and Transplantation,
International Renal Research Institute, San Bortolo Hospital,
Viale Rodolfi 37, Vicenza, Italy
e-mail: gianlucevillal@gmail.com
Tel.: +393207615547

A specific problem can be analyzed from several points of view, and different researchers will observe it with different experiences, methods and interests. Like in an orchestra in which different instruments enrich the same chord with different contributions, doctors belonging to different specialities, together with other scientific and humanistic investigators when coexisting in the same institute, share their own skills observing the same phenomenon. Each viewpoint may influence others, leading to situations in which the scientific speculation on pathophysiology and the application of specific techniques evolve toward identification of the humanistic individuality of the patient.

The invasive arterial pressure measurement plays a pivotal role in the management of critical care and surgical patients. Several artifacts can affect the intra-arterial pressure measurement and lead to misinterpretation of data and inappropriate prescribed therapies. In particular, the dynamic response artifacts are frequently encountered in hemodynamically unstable patients and usually amplify the intra-arterial pressure (i.e. resonance artifact). The systolic blood pressure overestimation (“systolic

overshoot”) is a consequence of resonance artifact between the measurement device and cardiovascular system, and potentially affects the titration of drug therapies and fluid administration.

When an external frequency applied to a body is equal to its natural frequency, the amplitude of the wave generated by the vibration is manifoldly increased and the systems “resonate”. Engineers of materials know very well the potential problems which can be related to the resonance effect. The collapse of the Tacoma Bridge due to resonance with the frequency of the wind (very close to the natural frequency of the bridge) is an example. In the same way, in music, a pure sound with a well-established frequency produced by a diapason stimulates another closed diapason characterized by the same frequency, producing resonance and thus forcing it to oscillate.

During invasive arterial pressure measurement, the arterial pressure waves produced by the ventricular contraction against the arterial vascular tree may induce resonance with the transducer system. Manufacturers usually improve the evaluating system’s reliability by increasing the stiffness of the catheters and reducing the fluid mass or the length of the connecting tubing. All these characteristics increase the natural frequencies of the detecting system thereby reducing the phenomenon of resonance with the physiological cardiovascular frequencies.

With the exclusion of the pure tones, several kinds of wave components (harmonics) are generated at the same time into an oscillating elastic body. In particular, if a guitar string is stimulated, it will evoke a particular sound characterized by a determined tone (the fundamental frequency of oscillation, and function of length and tension of the cord) and a determined timbre (depending on the harmonic frequencies produced). For example, if the first guitar string (the deepest) is pinched, a fundamental frequency of 82 Hz is generated (“E” note). However, if the oscillating string is touched at any point, the free

oscillatory movement of the string is reduced and that specific point is obligated to take a rest (“node”). The presence of a node and its relationship with the entire length of the string strongly influence the harmonic pathway produced and the specific timbre of the sound (Fig. 1).

The same physical model can be applied to the human cardiovascular system, in which the ventricular heart rate and the stiffness of the vascular tree impose the fundamental and the related harmonic frequencies, respectively. The arterial system has mostly been described as a transmission line with a constant length and variable tension. According to the instantaneous stiffness of the artery tree, the oscillatory amplitude could be reduced (by applying a node) thereby modifying the number and the type of generated harmonic frequencies. Theoretically, it could be possible to hear the “sound” produced by the instantaneous patient ventricular–arterial coupling through a sound amplifier (Fig. 1).

As is known, anesthetic drugs can produce several changes in heart rate and in peripheral vascular tone, potentially affecting the frequency and timbre of produced sound. For example, during the induction of

anesthesia, the combined effect of hypnotic and analgesic drugs usually produces a reduction in heart rate (and thus “deeper” tone) with vasodilation (and thus changing the produced harmonic). On the other hand, a more superficial anesthetic plane may not be enough to reduce the sympathetic activity during surgery, increasing the heart rate (and thus a “higher” tone) and arterial stiffness (and consequently changing the timbre of sound). Moreover, a particular sound should be expected during septic shock, in which a high heart rate is related to a high tone and characteristic harmonics are adjoined for the concomitant vasodilation. In this condition, a fluid challenge may produce a deeper sound reducing the heart rate in fluid responder patients, while a vasopressor may modulate the timbre of sound increasing the arterial tone and thus modulating the harmonic produced by the arterial tree.

As a consequence, according to patient characteristics (age, chronic hypertension, atherosclerosis, etc.) and instantaneous physiological parameters (heart rate, adrenergic tone, etc.), a continuous, personalized and continuously modulated melody may be appreciated during surgery or critical illness. In this context, each human being creates a unique individual melody that

Fig. 1 As in music, the cardiovascular system produces a complex wave characterized by a fundamental frequency deriving from the heart and several harmonics deriving from the peripheral

arterial tree. The analysis of this complex wave is at the base of hemodynamic monitoring in medicine and spectrograms in music

should be acknowledged by physicians at the bedside in order to move forward a more individualized medicine.

Mainly during conditions characterized by tachycardia and increased arterial stiffness, a sound with a high fundamental frequency and characterized by very high frequency harmonics may be generated. In this condition, the resonance with the transducer system of the arterial measurement may occur and a high amplitude and no modulating tone will be perceptible. A regular cardiovascular “sound check” may guarantee a more reliable measurement of arterial pressure, avoiding misinterpretation due to resonance effect. Moreover, it may help physicians to immediately identify changes in ventricular–arterial coupling in the same patient during their ICU stay.

In conclusion, arterial pressure waves analysis is prone to the same physical principles able to explain the characteristics of sound in a musical instrument. In critical care and perioperative patients, acute changes in heart rate

and in vascular stiffness may produce analogous changes in the fundamental frequency and in the type of harmonic frequencies produced by the system. If amplified, these frequencies could create a sound that may change in tone and timbre with the variation of heart rate and arterial stiffness. In several conditions, resonance between cardiovascular system and intra-arterial pressure measurement devices may occur, leading to misinterpretation of the data and inappropriate drug prescription. A cardiovascular “sound check” should theoretically allow to recognize the resonance of the measurement system.

The sharing of knowledge breeds and enriches professionals; when treating the patient, physicians apply technology and medical science discovering his “sound”, from the inside.

Conflicts of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.