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Noninvasive technologies for personalised haemodynamic monitoring

Advanced haemodynamic monitoring methods

Bernd Saugel, MD, EDIC is a Professor of Anesthesiology and works as a consultant in the Department of Anesthesiology, Center of Anesthesiology and Intensive Care Medicine, University Medical Center Hamburg-Eppendorf, Hamburg, Germany. Prof. Saugel is a specialist in anaesthesiology, intensive care medicine, and internal medicine and holds a European Diploma in Intensive Care Medicine. His primary field of research is the haemodynamic management of high-risk patients having surgery and critically ill patients. Prof. Saugel is particularly interested in the concept of personalised haemodynamic management using advanced innovative haemodynamic monitoring methods in anaesthesiology and intensive care medicine.

Is noninvasive cardiac monitoring and optimisation reliable, accurate and precise enough yet?

It depends. There are numerous different technologies for continuous noninvasive monitoring of blood pressure, stroke volume/cardiac output, and derived haemodynamic variables such as pulse pressure or stroke volume variation. These technologies include bioimpedance/bioreactance, pulse wave transit time, carbon dioxide re-breathing, Doppler, pulse wave analysis, and many more (Saugel et al. 2018; Saugel et al. 2015). These technologies are based on different physical measurement principles and, therefore, have different advantages and limitations with regard to their measurement performance and applicability in clinical routine. For all technologies, different validation studies comparing the innovative test method with an established reference method showed contradicting results – depending on the patient population, clinical setting, and reference method (Joosten et al. 2017). All methods have been shown to be able to provide reliable measurements i.e. accurate and precise measurements with a good ability to indicate changes in

the "true" value under study conditions. (By the way, a measurement of a haemodynamic variable is always uncertain). On the other hand, I could easily show you studies for each of the mentioned technologies showing poor agreement between these innovative methods and invasive reference methods. The challenge is to have a differentiated view on these validation studies and to exactly analyse the study protocols and study settings before drawing definite conclusions if a novel monitoring technology can be considered "reliable" or not.

What has been your clinical experience of using noninvasive monitoring methods?

In clinical practice, we started using noninvasive finger-cuff technologies that allow continuous monitoring of both blood pressure and stroke volume/cardiac output using pulse wave analysis. We don't use these technologies to replace the arterial catheter or advanced haemodynamic monitoring methods in high-risk surgical patients or critically ill patients treated in the ICU, but to monitor blood pressure continuously instead of only intermittently in low- or intermediate risk



patients having surgery. However, in our University Medical Center, we still use these innovative noninvasive monitoring technologies almost exclusively in clinical studies.

What do you see as the most promising noninvasive haemodynamic monitoring technology?

My personal take on this challenging question is that –at the moment– pulse wave analysis using finger-cuff methods is the most promising approach for noninvasive monitoring of blood pressure and cardiac output in perioperative and intensive care medicine. However, the field of cardiovascular and respiratory monitoring is rapidly evolving and we, for sure, can expect that new technologies using highly innovative sensor materials will be proposed in the near future. These future technologies will use ultra-small and highly sensitive sensors to make monitoring systems "wearable and wireless" and to allow "integrated monitoring," i.e. monitoring of various cardiovascular and respiratory signals with one sensor and analysing a combination of different haemodynamic signals.

Why do you think that validation studies of noninvasive methods have shown contradictory results?

There are several reasons that might explain the contradictory results of validation studies. First, as mentioned earlier, the validation studies have been performed in very different patient populations and clinical settings (Joosten et al. 2017). It makes a huge difference if we evaluate a noninvasive test method in surgical patients having cardiac surgery or in patients treated in the ICU with septic shock. A general problem is that the patients we include in method comparison or validation studies to test these innovative technologies are usually not the patients in whom we aim to use these technologies in clinical practice; nobody would suggest using a noninvasive device in a patient having cardiac surgery. We simply use those high-risk patient populations to perform method comparison studies because –for obvious reasons– patients need to be equipped with invasive reference monitoring methods for clinical indications unrelated to the study. Last but not least, we need a consensus on how to design validation studies and –of utmost importance– how to perform statistical analyses in method comparison studies to assess "clinically acceptable agreement."

When do you expect such technologies to come into routine use in the OR and ICU?

I think that innovative noninvasive technologies for haemodynamic monitoring will come into routine use in the OR during the next 5-10 years. There will be two main indications. First, noninvasive technologies will be used for continuous blood pressure monitoring (Michard et al. 2018). Having the advantage of allowing continuous and not only intermittent blood pressure monitoring these technologies may be used as an alternative to oscillometric upper arm cuff measurements [By the way, although used as "clinical gold standard" in millions of patients throughout the world we should not ignore that oscillometry has its own limitations regarding the measurement performance and clinical applicability (Wax et al. 2011)]. With more and more data indicating that even short periods of intraoperative (and postoperative!) hypotension (i.e. low blood pressure

in the perioperative period) are associated with postoperative morbidity in terms of complications and organ failure (Sessler et al. 2017; Walsh et al. 2013), there are good reasons to aim for continuous blood pressure monitoring. In some intermediate-risk patients, using these technologies will make it unnecessary to place an arterial catheter. Second, in intermediate-risk surgical patients additional noninvasively assessed haemodynamic variables such as cardiac output and dynamic cardiac preload parameters may help to titrate fluids and vasoactive agents (goal-directed haemodynamic therapy).

In high-risk surgical patients and critically ill patients treated in the ICU, however, arterial catheters and invasive advanced haemodynamic monitoring methods will still be the standard of care in the foreseeable future.

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In your article with Dr. Meidert, you say that the question "is whether continuous noninvasive devices need to replace the direct measurement or rather fill the monitoring gap for patients who are insufficiently monitored by intermittent measurements only." Please comment.

This statement refers to the ongoing discussion about the place continuous noninvasive monitoring technologies should have in the future.

My US colleague Robert Thiele wrote already in 2015: "It is only a matter of time until volume clamp devices [i.e. finger-cuff technologies] replace many if not the majority of arterial catheters for the continuous measurement of blood pressure, arterial respiratory variation, and even noninvasive cardiac output monitoring" (Thiele 2015). I'm not sure if this really is what we should aim for. Some patients e.g. high-risk surgical patients and critically ill patients in the ICU

will have an arterial catheter anyway, not only for haemodynamic monitoring but also for arterial blood gas analysis. We should not only think about "replacing the arterial catheter"; we should think about improving the quality of care and outcome in patients who are now monitored intermittently, e.g. almost all low- and intermediate-risk surgical patients, patients undergoing diagnostic procedures such as endoscopy, patients in emergency departments and on normal wards (Wagner and Saugel 2015). I think identifying patient populations and clinical settings in which continuous monitoring instead of intermittent monitoring can help to improve the quality of care or identify haemodynamic alterations earlier is a key challenge in this field (Saugel and Scheeren 2017).

How best to personalise haemodynamic management of the perioperative patient?

In contrast to intensive care medicine, we have the unique opportunity in perioperative medicine that we can assess an individual patient's baseline haemodynamic status. This includes the patient's normal blood pressure profile, cardiac function, and metabolic status. These baseline haemodynamic variables can then be used to guide haemodynamic optimisation strategies in the intra- and postoperative period (Saugel et al. 2017).

When should advanced haemodynamic monitoring be used in shock?

In patients with circulatory shock a) if the type of shock cannot be easily identified, b) if the patient does not respond to the initial therapeutic interventions, and c) if circulatory shock is complicated by failure of other organ systems [ARDS, right heart failure, or liver failure,...] (Saugel and Vincent 2018; Teboul et al. 2016).

Would you agree that routine use of the pulmonary artery catheter should be abandoned (e.g. Youssef and Whitlock 2017)?

More and more people believe that there are no routine indications for the PAC. I think that the PAC is still a valuable monitoring technique that provides important haemodynamic variables in very specific clinical problems. In patients with circulatory shock

and pulmonary hypertension or circulatory shock with right heart failure, the PAC can help to titrate therapeutic interventions and to monitor the patient's response to these interventions. The same is true in certain patients having cardiac surgery in the intraoperative and postoperative phase. However, we carefully need to balance the risks and benefits

of each monitoring method. The PAC is a valuable tool if used by specialists and if used only in those patients who really can benefit from haemodynamic interventions guided by PAC-derived variables (Rajaram et al. 2013).

Is noninvasive continuous monitoring within the reach of most hospitals in

middle and high-income countries?

Yes, it is. Numerous methods for noninvasive haemodynamic monitoring are nowadays available. But, of course, it only makes sense to invest in any kind of monitoring if it has been shown to improve quality of care and/or patient-centred outcomes. ■

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