Non-invasive pulse contour cardiac output by Nexfin technology

Johannes J. van Lieshout, MD, PhD[1,2], Wilbert A. Wesselink, MSc, PhD[3] & Berend E. Westerhof, MSc, PhD[2,3]

[1] Special Medical Care Unit, Department of Internal Medicine, Academic Medical Center, University of Amsterdam, [2] Laboratory for Clinical Cardiovascular Physiology, AMC Center for Heart Failure Research, Amsterdam, The Netherlands, and [3] BMEYE bv, Amsterdam, The Netherlands

J.J. van Lieshout, MD, PhD
Special Medical Care, Department of Internal Medicine, F7-205
Academic Medical Center
University of Amsterdam
PO Box 22700, 1100 DE Amsterdam
The Netherlands
tel. (31) 20-5662371
fax (31) 20-5669223
j.j.vanlieshout@amc.uva.nl

In many patients, continuous knowledge of the hemodynamic status would be of great value, however, invasive measurement of blood pressure (BP) or cardiac output (CO) may not be warranted. BP can be measured intermittently with an upper arm cuff. However, continuous non-invasive measurement of arterial pressure in humans is available since the early 1980s when Wesseling et al.[1] introduced the first Finapres device based on the volume-clamp method invented by the Czech physiologist Jan Peňáz [2]. Monitoring of a continuous CO allows for the detection of rapid changes in systemic flow that would otherwise be unnoticed by the recording of arterial pressure and heart rate [3]. Non-invasive and continuous tracking of changes in stroke volume (SV) can be obtained by ultrasound, thoracic electrical impedance or by minimally invasive methods that use arterial pulse wave analysis from an arterial line that is already in place for BP monitoring or sampling of blood gasses. Recently a device became available for truly noninvasive and continuous monitoring of BP and CO, the Nexfin HD monitor [4;5]. We will review past and present developments in the methodology of finger pressure and continuous stroke volume/cardiac output by focusing on the methods and technologies that the Nexfin uses to measure noninvasive, beat-to-beat hemodynamics.

Nexfin uses the established volume clamp methodology and Physiocal criteria [6] for measurement of continuous BP in a finger. An inflatable cuff around the finger with an optical blood volume measuring system clamps the blood volume to a preset level by applying a pressure equal to arterial pressure throughout the cardiac cycle. In combination with Physiocal, calibrated recordings of the entire finger arterial pressure wave are obtained [6]. As a next logical step brachial pressure reconstruction was developed, which counteracted the pressure wave amplification in peripheral measurement sites like the finger. In addition, application of a level correction compensates for the pressure drop due to resistance to flow in the smaller arteries. The combination of these two methods results in pressures that are comparable to invasively measured brachial or radial BP. This resolves issues with earlier devices, which sometimes displayed mean finger arterial pressures that were much lower than invasive pressures. Further important improvements were established by an update of the cuff design using modern materials and optical components.

Nexfin uses a recently developed pulse contour method to determine CO (Nexfin CO-trek), building on earlier developments. The area under the systolic part of the pressure curve is divided by the aortic input impedance to obtain stroke volume, similar to the cZ pulse contour method (early Seventies). This cZ method used a simple formula containing heart rate, mean arterial pressure and patient age to determine input impedance. Tracking of changes was very good, but the absolute values could have a bias. More recent, the Modelflow method (Nineties) used a 3-element Windkessel description of aortic input impedance to calculate a flow curve from the pressure curve [7-10]. Integration of the flow curve yields stroke volume. In the Windkessel, the nonlinear pressure-area relation of the aorta was described as function of pressure, age, gender, height and weight assuring better absolute CO values and tracking of changes over wider ranges of pressure changes. The Windkessel model, incorporating nonlinear pressure dependency and patient data, is also used with the Nexfin CO-trek method, although in this case to calculate aortic input impedance. Combined with the area under the systolic part of the pressure curve stroke volume can now be calculated. Whereas earlier methods were developed to use invasively measured pressures, CO-trek method operates equally well with noninvasive measured BP, enabling routine clinical application [5].

1. Wesseling,K.H. (1995) A century of noninvasive arterial pressure measurement: from Marey to Penaz and Finapres. Homeostasis **36**, 2-3.

2. Peñáz, J. Photoelectric measurement of blood pressure, volume and flow in the finger. Albert, R., Vogt, W. S., and Helbig, W. Digest of the International Conference on Medicine and Biological Engineering , 104. 1973. Dresden. 1973.

3. Kim,Y.S., Immink,R.V., Jellema,W.T. and Van Lieshout,J.J. (2007) A perspective on non-invasive continuous cardiac output in the critically ill. Neth J Crit Care **11**, 185-191.

4. Eeftinck Schattenkerk,D.W., Van Lieshout,J.J., Van den Meiracker,A.H. et al. (2009) Nexfin noninvasive continuous blood pressure validated against Riva-Rocci/Korotkoff. Am J Hypertens. **22**, 378-383.

5. Bogert, L. W., Wesseling, K. H., Schraa, O., Van Lieshout, E. J., De Mol, B. A., Ven Goudoever, J., Westerhof, B. E., and Van Lieshout, J. J. Pulse contour cardiac output derived from non-invasive arterial pressure in cardiovascular disease. Anaesthesia . 2010.

6. Bogert,L.W. and Van Lieshout,J.J. (2005) Non-invasive pulsatile arterial pressure and stroke volume changes from the human finger. Exp Physiol **90**, 437-446.

7. Wesseling,K.H., Jansen,J.R.C., Settels,J.J. and Schreuder,J.J. (1993) Computation of aortic flow from pressure in humans using a nonlinear, three-element model. J Appl Physiol **74**, 2566-2573.

8. Jellema,W.T., Groeneveld,A.B., Wesseling,K.H., Thijs,L.G., Westerhof,N. and Van Lieshout,J.J. (2006) Heterogeneity and prediction of hemodynamic responses to dobutamine in patients with septic shock. Crit Care Med. **34**, 2392-2398.

9. Jellema,W.T., Wesseling,K.H., Groeneveld,A.B., Stoutenbeek,C.P., Thijs,L.G. and Van Lieshout,J.J. (1999) Continuous cardiac output in septic shock by simulating a model of the aortic input impedance: a comparison with bolus injection thermodilution. Anesthesiology **90**, 1317-1328.

10. Harms,M.P.M., Wesseling,K.H., Pott,F. et al. (1999) Continuous stroke volume monitoring by modelling flow from non-invasive measurement of arterial pressure in humans under orthostatic stress. Clin Sci **97**, 291-301.