British Journal of Anaesthesia **112** (3): 521–8 (2014)
Advance Access publication 18 December 2013 · doi:10.1093/bja/aet400

BJA

Radial artery applanation tonometry for continuous non-invasive arterial pressure monitoring in intensive care unit patients: comparison with invasively assessed radial arterial pressure

A. S. Meidert[1], W. Huber[1], J. N. Müller[1], M. Schöfthaler[1], A. Hapfelmeier[2], N. Langwieser[3], J. Y. Wagner[4], F. Eyer[5], R. M. Schmid[1] and B. Saugel[1]*

[1] II. Medizinische Klinik und Poliklinik,[2] Institut für Medizinische Statistik und Epidemiologie,[3] I. Medizinische Klinik und Poliklinik, [4] III. Medizinische Klinik, and [5] Toxikologische Abteilung. II. Medizinische Klinik und Poliklinik, Klinikum rechts der Isar der Technischen Universität München, Ismaninger Strasse 22, 81675 München, Germany

* Corresponding author. E-mail: bernd.saugel@gmx.de

Editor's key points

- Radial applanation tonometry can be used for non-invasive arterial pressure (AP) measurement.
- In 24 intensive care unit patients, the authors simultaneously recorded AP with a tonometry device and an arterial cannula.
- Bias for non-invasive measurements was low.
- Precision was satisfactory for mean and diastolic pressures, but less satisfactory for systolic pressure.

Background. Radial artery applanation tonometry technology can be used for continuous non-invasive measurement of arterial pressure (AP). The purpose of this study was to evaluate this AP monitoring technology in intensive care unit (ICU) patients in comparison with invasive AP monitoring using a radial arterial catheter.

Methods. In 24 ICU patients (German university hospital), AP values were simultaneously recorded on a beat-to-beat basis using radial artery applanation tonometry (T-Line system; Tensys Medical, San Diego, CA, USA) and a radial arterial catheter (contralateral arm). The primary endpoint of the study was to investigate the accuracy and precision of the non-invasively assessed AP measurements with the Bland–Altman method based on averaged 10 beat AP epochs (n=2993 10 beat epochs).

Results. For mean AP (MAP), systolic AP (SAP), and diastolic AP (DAP), we observed a bias (±standard deviation of the bias; 95% limits of agreement; percentage error) of +2 mm Hg (±6; −11 to +15 mm Hg; 15%), −3 mm Hg (±15; −33 to +27 mm Hg; 23%), and +5 mm Hg (±7; −9 to +19 mm Hg; 22%), respectively.

Conclusions. In ICU patients, MAP and DAP measurements obtained using radial artery applanation tonometry show clinically acceptable agreement with invasive AP determination with a radial arterial catheter. While the radial artery applanation tonometry technology also allows SAP measurements with high accuracy, its precision for SAP measurements needs to be further improved.

Keywords: arterial pressure, measurement; measurement techniques, arterial pressure; monitoring, intensive care; T-Line

Accepted for publication: 20 August 2013

Continuous arterial pressure (AP) monitoring is fundamental to adequately guide fluid therapy and administration of vasoactive agents in critically ill patients.[1] Since the placement of an arterial catheter is associated with potential negative short- and long-term side-effects, non-invasive technologies for continuous AP monitoring have been introduced. Besides photoplethysmography technologies,[2–6] radial artery applanation tonometry has been demonstrated to be a promising technology for non-invasive beat-to-beat AP monitoring in anaesthetized patients during surgery compared with invasive AP measurements using a radial arterial catheter.[7–9]

The company Tensys Medical Inc. (San Diego, CA, USA) provides a radial artery applanation tonometry device (T-Line system). When using this uncalibrated applanation tonometry system for continuous non-invasive AP measurement, a raw AP signal (waveform) is obtained using the system's sensor that is placed over the radial artery.[9–11] The radial artery site is an ideal choice for applanation tonometry, since it meets the requirements of a superficial artery and a bony structure acting as a counter bearing.[9 12 13] The term 'applanation' illustrates that a prerequisite for this method is that the sensor compresses the artery used for the AP measurement by applying pressure.[9 12 13] In the optimal 'applanation position', the artery is compressed (but not occluded) by the sensor to an extent that the vascular transmural pressure is minimized and the intraluminal AP (waveform with maximized pulse

pressure) can be transduced to the pressure sensor placed on the skin.[9, 13] In this position, mean AP (MAP) can then be determined from the raw AP waveform.[9] The raw AP signal is then scaled using a proprietary 'gain function' resulting in the final AP waveform allowing the derivation of systolic AP (SAP) and diastolic AP (DAP).[9] In intensive care unit (ICU) patients, radial artery tonometry has been previously compared with invasive central aortic AP readings.[10 11] However, there is a need for confirmation that AP measurements with radial artery applanation tonometry technology are reliable compared with an arterial catheter placed in the radial artery in an ICU setting. Therefore, in this study we compared radial artery applanation tonometry AP with invasive radial AP.

Methods

Study design and setting

This study comparing non-invasive (radial artery applanation tonometry) with invasive (radial arterial catheter) AP monitoring was performed in ICU patients treated in a German university hospital. It was approved by the appropriate ethics committee (Ethikkommission der Fakultät für Medizin der Technischen Universität München) and all patients (or their legal representatives) gave written informed consent.

Inclusion and exclusion criteria

Inclusion criteria included age 18 yr or older, body weight 40–180 kg, height 1.37–1.98 m, and the presence of an arterial catheter previously placed in the radial artery for routine clinical reasons. Patients in whom an arteriovenous shunt was present were not eligible for study enrolment, as were patients with anatomical abnormalities or injuries of the wrist. A history of peripheral vascular disease or cardiovascular disease was not an exclusion criterion for study enrolment.

Non-invasive and invasive AP measurements

The T-Line system (TL-200 or TL-200pro; Tensys Medical Inc.) was used for continuous non-invasive assessment of AP, as described previously.[7 10 11] Simultaneously, AP values were measured using an arterial catheter placed in the radial artery of the patient's contralateral arm. In each patient, three 5 min intervals of AP measurements (resulting in a total of 15 min) were recorded.

Data extraction, data processing, and statistical analysis

After simultaneous recording of invasive and non-invasive AP data, a beat-to-beat report containing numeric AP values was extracted from the raw data sets using computer software as previously described.[7 10] All recorded AP data were included in the statistical analysis.

For statistical analyses, we used IBM SPSS Statistics 20 (SPSS Inc., Chicago, IL, USA) and the statistical software package R (The R Foundation for Statistical Computing, Vienna, Austria). When describing patients' characteristics, the median and 25–75% percentile range (i.e. interquartile range) was used for continuous data and absolute frequencies with percentages were computed for qualitative measures. Non-invasively and invasively assessed AP values are described by mean [standard deviation (SD)]. AP measurements obtained continuously on a beat-to-beat basis were averaged (10 beat epochs) for comparative statistical analyses.

For each individual patient, radial artery applanation tonometry-derived AP measurements (SAP, MAP, and DAP) were plotted against invasively assessed AP measurements as a scatter plot.

For the comparison of AP measurements using the two methods, we performed a Bland–Altman analysis [mean difference (bias), SD, and 95% limits of agreement] for multiple measurements in one individual as described by Bland and Altman in 2007[14] (section 3). To assess potential non-uniform relations between the bias and mean AP measurements, we additionally performed mixed models analysis as described before.[10] The percentage error ($2 \times$ SD of the differences/mean of measurements) was also calculated. In addition, modified Bland–Altman plots showing individual mean AP measurements, the intra-individual AP variability, the individual mean difference, and the intra-individual mean difference variability were computed.[6]

Based on the averaged 10 beat epochs, four-quadrant plot analysis was performed to investigate the concordance of the AP measurements obtained with radial artery applanation tonometry and the radial arterial catheter-derived AP measurements regarding the direction of AP changes. For this AP concordance analysis, we computed four-quadrant plots with an exclusion zone of 3 mm Hg and calculated concordance between the two AP measurement methods as described previously.[10]

Results

Patients

Twenty-eight patients were eligible for study inclusion. Four patients could not be included in the study because they (or their legal representatives) refused to give written informed consent. Therefore, 24 patients (15 males, nine females) were enrolled in the study. These patients had a median age of 67 (54–77) yr, a median body weight of 82 (73–93) kg, and a median height of 1.74 (1.67–1.85) m. On the day of study inclusion, 11 patients were on mechanical ventilation and six patients were receiving norepinephrine. Six patients had atrial fibrillation during study recordings. Patients were treated in the ICU for the following reasons: pneumonia/respiratory insufficiency (nine patients), admission after major surgery (five patients), central nervous system affection (four patients), gastrointestinal bleeding (three patients), or other (three patients).

AP measurements

A total of 2993 averaged 10 beat AP epochs were recorded in 24 patients. Using invasive AP measurements (radial arterial catheter), we observed a mean (SD) (minimum, maximum) for MAP, SAP, and DAP of 86 (15) (62, 137), 133 (20) (82, 192), and 63 (13)