Is applanation tonometry a reliable method for monitoring blood pressure in morbidly obese patients undergoing bariatric surgery?

G. Greiwe1,†,*, P. A. Tariparast2,†, C. Behem1, M. Petzoldt1, L. Herich3, C. J. Trepte1, D. A. Reuter1 and S. A. Haas1

1Department of Anaesthesiology, 2Department of Intensive Care Medicine, University Medical Centre Hamburg-Eppendorf, Centre of Anaesthesiology and Intensive Care Medicine, Martinistrasse 52, 20246 Hamburg, Germany, and 3University of Cologne, Institute of Medical Statistics, Informatics and Epidemiology, Kerpener Str.62, 50937 Köln, Germany

*Corresponding author. E-mail: g.greiwe@uke.de

Abstract

Background: The aim of this study was to evaluate the validity of non-invasive continuous BP measurement by applanation tonometry in morbidly obese patients undergoing bariatric surgery.

Methods: Arterial blood pressure (AP) was recorded intraoperatively both by applanation tonometry (AT) (T-Line 200pro, Tensys Medical®, USA) and an arterial line (AL) after radial cannulation in obese patients undergoing bariatric surgery. Discrepancies between the two methods were assessed as bias, limits of agreement and percentage error. Mean, systolic, and diastolic arterial pressures were assessed (MAP, SAP, DAP respectively). Trending ability was assessed by concordance based on four-quadrant plotting.

Results: Mean (SD) BMI of the 28 patients was 49.4 (9.7 kg m⁻²). A total of 201 907 time points were available for analysis. Bias for MAP_AT compared with MAP_AL was +3.97 mm Hg (SAP_AT +3.45 mm Hg; DAP_AT +3.66 mm Hg) with limits of agreement for MAP_AT of −14.47 and +22.41 mm Hg (SAP_AT −22.0 and +28.9 mm Hg; DAP_AT −15.7 and +23.1 mm Hg). Percentage error for MAP_AT was 23.5% (23.4% for SAP_AT; 30.5% for DAP_AT). Trending ability for MAP, SAP, and DAP revealed a concordance of 0.74, 0.72, and 0.71, respectively.

Conclusions: Continuous BP assessment by applanation tonometry is feasible in morbidly obese patients undergoing bariatric surgery. However, despite a low mean difference, 95% limits of agreement and trending ability indicate that the technology needs to be improved further, before being recommended for routine use in this group of patients.

Key words: arterial pressure; bariatric surgery; blood pressure monitors; monitoring, intraoperative
methods can be challenging or even futile, especially in obese patients with extreme upper arm circumferences. Non-invasive oscillometric upper-arm cuff arterial pressure measurement may be highly inaccurate for obese patients, as blood pressure cuffs may not fit properly as a result of the conical shape of the arm and this can prevent correct measurements.\(^1\)\(^2\) In obese patients, arterial cannulation is the most accurate procedure, if conventional oscillometric upper-arm cuff measurement fails, or continuous measurement is desired. However, the placement of arterial catheters can be time consuming and can cause inconvenience and carry risks for patients.\(^1\)\(^3\) \(^4\)

Applanation tonometry (AT) is a non-invasive method for continuous arterial pressure monitoring which has been evaluated with promising results in perioperative, intensive care and emergency department settings.\(^5\)\(^6\)\(^7\)\(^8\)\(^9\)\(^10\)\(^11\) A disposable sensor, which is connected to a bracelet, is placed above the patient’s radial artery. Fully automated, the system detects the maximum radial arterial signal. By flattening the vessel, a continuous arterial pressure signal is obtained. In contrast to oscillometric methods of BP measurement, this allows for continuous measurements because the sensor constantly floats above the artery, detecting the maximum pulse pressure. Processed by an underlying algorithm, this results in a continuous arterial pressure waveform, with numeric display of MAP, SAP and DAP.\(^2\) This method may have the potential to bridge the gap between intermittent oscillometric BP measurement and invasive arterial pressure measurement from an intra-arterial catheter. This might be of particular clinical advantage in obese patients undergoing surgery. However, it is not known whether extreme obesity may damp the arterial signal by increased soft tissue mass at the forearm, which might limit the usability and accuracy of this new technology. We therefore compared arterial BP measurement by AT to the most accurate standard of arterial blood pressure measurement by a radial artery catheter in morbidly obese patients during bariatric surgery.

**Methods**

This prospective study was approved by the Ethics Committee of the Medical Board of Hamburg (Aerztekammer Hamburg) (PV 3767). All patients gave written informed consent before the onset of the study.

**Study design and patients**

Patients ≥18 yr undergoing elective bariatric surgery (gastric bypass or gastric sleeve) at a university hospital (University Medical Center Hamburg-Eppendorf, Germany) were invited to participate. Exclusion criteria were previous surgery to one of the forearms or arterial vessels of the arms, upper limb neuretropathy or lack of consent.

**Anaesthesia and instrumentation**

Eligible patients received premedication with midazolam (between 7.5 and 15 mg orally approximately one h before transfer to the operating room). After establishing standard haemodynamic monitoring with a 5-lead ECG and pulse oximetry, cannulation of the left radial artery was performed under local anaesthesia. The AT bracelet device (T-Line 200pro, Tensys Medical®, San Diego, USA) was placed on the right forearm. After calibration of both methods, standardized anaesthesia was induced with remifentanil 0.5 µg kg\(^{-1}\) min\(^{-1}\) and target-controlled (TCI) infusion of propofol, with a calculated plasma concentration of 4 µg ml\(^{-1}\) (using the model according to Marsh.\(^12\)\(^13\)). Rocuronium 0.6–0.8 mg kg\(^{-1}\) (ideal body weight) was administered for muscle relaxation to facilitate orotracheal intubation. Anaesthesia was maintained by continuous target-controlled-infusion of propofol, aiming for a bispectral index between 30 and 50 and continuous administration of remifentanil 0.3–0.5 µg kg\(^{-1}\) min\(^{-1}\). Norepinephrine was administered continuously directly from induction of anaesthesia via a second i.v. line at the discretion of the anaesthesiologist to avoid arterial hypotension and maintain mean arterial pressure >60 mm Hg.

**Applanation tonometry method**

The AT device used in this study, allows continuous monitoring of arterial pressure in real time, with the visualization of an arterial pressure curve without being invasive and without the need for external calibration: A specific sensor is placed on the patients forearm in the position of a routine radial artery puncture. A sensor bracelet is locked to the sensor and compresses (applanates) the radial artery against the radial bone. During measurement, the sensor lies above the artery and the pressure from the bracelet flattens the vessel. Under ideal conditions this results in a transmural pressure of zero on the radial artery and the maximum pulse pressure can be acquired by the sensor. The mean arterial pressure is determined from the maximum pulse pressure. To determine systolic and diastolic arterial pressure the acquired arterial pressure waveform is scaled with the help of an underlying transfer function. As a result, a continuous arterial pressure waveform, with a numeric display of mean (MAP), systolic (SAP) and diastolic (DAP) pressure is displayed.

**Measurements and data collection**

The AT device was set up according to the manufacturer’s instructions and as described before.\(^7\) Data collection was started after instrumentation and initial calibration while the patient was awake and continued until the termination of capnoperitoneum at the end of surgery. Measurements were interrupted during transfer of the patient to the operating theatre. Recalibration was performed when necessary (e.g. changes of patient position, movement of the limb) or at least once an hour according to the manufacturer’s recommendation. AT and AL data were simultaneously transferred to the standard patient monitor (Infinity delta, Draeger®, Luebeck, Germany) and extracted to a computer and recorded every s by an analysing software (eData Data Grabber, Draeger®, Luebeck, Germany).

After completing data collection the data set was visually screened by at least three authors for artifacts or obviously
incorrect measurements (e.g. during initial positioning of the patient for surgery, flushing of the AL, damped AL signal, during the usage of a tourniquet for venous puncture, motion artifacts or recalibration). There was no predefined algorithm for data exclusion.

Statistical analysis

Data were analysed using SigmaPlot© 12 (Systat Software Inc., San Jose, USA), IBM© SPSS® Statistics 21 (IBM Inc., Armonk, NY, USA) and the statistical software package R® 2.14.1 (The R Foundation for Statistical Computing, Vienna, Austria). The Kolmogorov-Smirnov test was used to assess normal distribution of data. We calculated the mean and sd to describe continuous patient data and give absolute and relative frequencies for the description of qualitative patient characteristics. The strength of agreement between MAPAT and MAPAL, of SAPAT and SAPAL and of DAPAT and DAPAL were analysed using the concordance correlation coefficient (CCC) according to Lin.14,15 In order to evaluate the precision an analysis of MAPAT and MAPAL, SAPAT and SAPAL and DAPAT and DAPAL according to Bland and Altman’s method for multiple measurements, per individual was performed.16,17 Thus, bias and limits of agreement [bias (1.96) sd] are reported. Percentage error was calculated as the limits of agreement divided by (mean MAPAT+mean MAPAL)−2, (mean SAPAT+mean SAPAL)−2 or (mean DAPAT+mean DAPAL)−2 respectively. Considering a precision of 20% of the applanation measurement and a precision of the gold-standard invasive BP measurement of <5%, the percentage error should be 21% (where √((20×1+5)”2)=20.6). To analyse trending ability we used 4-quadrant-plots to illustrate concordance of arterial pressure changes within 30 s comparing arterial pressure values of the arterial line and arterial pressure of the applanation tonometry. An exclusion zone of 3 mm Hg was used to eliminate clinically irrelevant arterial pressure changes. An arterial pressure value of the applanation tonometry value was regarded to be concordant if the corresponding arterial pressure value of the arterial line value changed in the same direction.18

Table 1 Baseline patient characteristics, comorbidities and medication. Data are displayed as absolute and relative frequencies, mean and sd and age as mean and range

<table>
<thead>
<tr>
<th>Patient characteristics</th>
<th>n</th>
<th>[ nond]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients included (n)</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>Age (yr)</td>
<td>44.8(20–68)</td>
<td></td>
</tr>
<tr>
<td>Sex, female [n (%)]</td>
<td>18 (62)</td>
<td></td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.72 (0.1)</td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>146.0 (34.7)</td>
<td></td>
</tr>
<tr>
<td>BMI (kg m−2)</td>
<td>49.4 (9.7)</td>
<td></td>
</tr>
<tr>
<td>Mean of measurement recording periods (min)</td>
<td>132 (71)</td>
<td></td>
</tr>
<tr>
<td>Comorbidities and medication</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arterial hypertension [n (%)]</td>
<td>18 (64)</td>
<td></td>
</tr>
<tr>
<td>Antihypertensive medication [n (%)]</td>
<td>16 (57)</td>
<td></td>
</tr>
<tr>
<td>Patients receiving intraoperative</td>
<td></td>
<td></td>
</tr>
<tr>
<td>norepinephrine infusion [n (%)]</td>
<td>28 (100)</td>
<td></td>
</tr>
<tr>
<td>Mean maximum dose of intraoperative</td>
<td></td>
<td></td>
</tr>
<tr>
<td>norepinephrine infusion [µg kg−1 min−1]</td>
<td>0.052</td>
<td></td>
</tr>
<tr>
<td>Diabetes mellitus [n (%)]</td>
<td>15 (54)</td>
<td></td>
</tr>
<tr>
<td>Coronary artery disease and/or peripheral artery disease [n (%)]</td>
<td>3 (11)</td>
<td></td>
</tr>
<tr>
<td>Obstructive sleep apnoea and/or chronic obstructive pulmonary disease [n (%)]</td>
<td>12 (43)</td>
<td></td>
</tr>
</tbody>
</table>

Results

We enrolled 32 patients into the study. Four patients had to be excluded because of: inability to locate the radial artery with the AT-device (2 patients), failure of radial cannulation (1), or an incorrect signal of the AL producing obviously false measurements (1).

Patient characteristics

Patient characteristics, comorbidities and norepinephrine doses are summarized in Table 1. Patients received either a laparoscopic gastric sleeve or a gastric bypass.

Data assessment

For 28 patients a total of 3698 min of data were recorded with a mean measurement time of 132 (71) min. 9.1% of the data were excluded after visual screening as a result of anomalous AT or AL measurements. After data cleaning, this resulted in 201 907 data points for further analysis.

Accuracy and precision

Arterial pressure measurements averaged over all measurement times for MAP were 80.3 (13.9) mm Hg using AT and 76.3 (11.7) mm Hg for AL. Values for SAPAT and SAPAL were 110.6 (18.5) mm Hg and 107.2 (17.9) mm Hg, respectively. DAPAT and DAPAL measurements were 65.7 (12.7) mm Hg and 61.8 (9.7) mm Hg, respectively.

Regression analysis revealed a CCC of 0.75 between MAPAT and MAPAL. For SAP the CCC was 0.73, for DAP 0.65. For MAP Bland-Altman analysis showed a bias of +3.97 mm Hg, 95% limits of agreement reflecting precision were −14.47 and +22.41 mm Hg. For SAP and DAP Bland-Altman analysis revealed a bias of +3.45 and +3.66 mm Hg with 95% limits of agreement of −22.0 and +28.9 mm Hg and −15.75 and +23.07 mm Hg (Bland-Altman Plots are displayed in Fig. 1). The percentage error was 23.5% for MAPAT, 23.4% for SAPAT and 30.5% for DAPAT.

Trending ability

Concordance analysis using 4-quadrant plots showed a concordance of 0.74 for MAP, 0.72 for SAP and 0.71 for DAP (Fig. 2).

Discussion

This study compares continuous arterial pressure assessed by applanation tonometry, to the clinical gold standard of BP measurement via an invasive arterial line, in morbidly obese patients during bariatric surgery. Our main findings were that applanation tonometry was feasible, however 95% limits of agreement and trending ability were moderate, especially when compared with results from other studies on non-obese patients.

We designed this study to assess the properties of the AT method in a setting as close as possible to everyday anaesthetic practice in this cohort of patients, where accurate non-invasive arterial pressure measurements are difficult to achieve, because of obesity and continuous arterial pressure monitoring is often needed because of the increased cardiovascular risk profile. We therefore measured arterial pressure continuously throughout bariatric surgery.

Other research groups have already evaluated the AT device and its predecessors, especially for certain patient groups receiving intensive care19–10 or intraoperatively5 6 11 and have shown its potential. However, systolic arterial pressure variability has
been found to be higher than for mean or diastolic arterial pressure especially at higher BP values. Our results confirm this observation but the underlying cause remains unclear.

Compared with previous studies, we found slightly poorer performance of the AT in terms of accuracy, precision and trending ability. These differences may be explained by our study design which is probably more vulnerable to measurement disturbance. Firstly, the obesity of our patients may have resulted in an increased soft tissue damping of the pulse pressure above the radial artery. Secondly, we continuously monitored the arterial pressure over different phases of anaesthesia and surgical routine, including a long monitoring time. Thirdly, alterations in patients’ position were followed by levelling the AT device according to the manufacturer’s instructions. Nevertheless, these alterations in patients’ position may be partially responsible for increased inaccuracy, because level correction may only be performed in 5 cm steps for the AT device. Fourthly, we extracted data every s from the standard patient monitor, in contrast to other study groups, where 10-beat-epochs were averaged and subsequently analysed.

With a mean BMI of 49.4 kg m−2 we selected a very special patient cohort but one of growing importance in clinical practice.
Our data suggests that the previously observed overestimation of the actual arterial pressure by the AT technique, may be even greater for obese patients (the results of all studies evaluating validity of AT are summarized in Table 2). In particular, the scaling algorithm reveals weaknesses for this type of patient: although there are acceptable 95% limits of agreement for MAP, 95% limits of agreement for SAP are much higher. As the SAP is derived from a scaling based on the MAP and an underlying algorithm, this algorithm may have to be adapted and optimized for obese patients. In two patients the AT device was unable to detect an arterial signal, although the radial pulse was palpable. Furthermore, we observed that the AT bracelet is sensitive to motion and easily disturbed, and this may result in incorrect measurements. Therefore, motions must be avoided to ensure valid measurements.

Our study had certain limitations. First, there was no control group of non-obese patients. Inclusion of a control group would have given the opportunity to evaluate the hypothesis that increased soft tissue mass overlying the radial artery, damps the pulse pressure signal and influences validity of applanation tonometry. To realistically reflect the routine clinical situation, data recording was performed during the total period of surgery which resulted in a high number of data points, although only 32 patients were enrolled in the study. Further, the recording periods were different for each patient, which may have resulted in a bias as a result of including more data points from patients.

![Diagram](https://example.com/diagram.png)
who underwent longer surgery. Following standard procedures in our institution, continuous application of norepinephrine with frequently changing doses was administered to keep arterial pressure stable over the total period of anaesthesia. Furthermore, we performed no interventions such as volume loading. Therefore, the ability of this study to assess trendability was limited. We did not evaluate left and right arterial pressure differences by upper limb cuff arterial pressure measurement, before inclusion into the study, as others have. We found the measurement of arterial pressure by upper limb cuff to be unreliable for obese patients, for the purpose of excluding patients from the study. As a consequence, we may have included patients with relevant upper limb AP differences in our study.

Bariatric surgery for extremely obese patients is a growing challenge. One major problem in perioperative monitoring for obese patients, is the inability to conduct a reliable oscillometric arterial pressure measurement. Therefore, alternative methods of arterial pressure assessment are of great interest and our study suggests that AT may be a feasible method. However, 95% limits of agreement, trendability ability and technical limitations such as the inability to locate arterial signals in some patients indicate that this technology needs to be improved, before we could recommend AT as a routine method of choice for arterial pressure assessment in obese patients.

**Authors’ contributions**


Writing paper: G.G., P.A.T., S.H.

Revising paper: all authors

**Declaration of interest**

None declared.

**Funding**

Devices and technical equipment for assessment, extraction and recording of arterial pressure were provided by Tensys Medical Inc. (San Diego, CA, USA). Tensys Medical Inc. was not involved in the conception of the study, the data analysis or interpretation, the writing of the manuscript or the decision for submission.

**References**


Handling editor: J. P. Thompson