Europace (2010) **12**, 1616–1622
doi:10.1093/europace/euq333

Non-invasive continuous blood pressure monitoring of tachycardic episodes during interventional electrophysiology

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Received 25 February 2010; accepted after revision 12 August 2010; online publish-ahead-of-print 13 September 2010

Aims We thought to evaluate feasibility of continuous non-invasive blood pressure monitoring during procedures of interventional electrophysiology.

Methods and results We evaluated continuous non-invasive finger blood pressure (BP) monitoring by means of the Nexfin device in 22 patients (mean age 70 ± 24 years), undergoing procedures of interventional electrophysiology, in critical situations of hypotension caused by tachyarrhythmias or by intermittent incremental ventricular temporary pacing till to the maximum tolerated systolic BP fall (mean 61 ± 14 mmHg per patient at a rate of 195 ± 37 bpm). In all patients, Nexfin was able to detect immediately, at the onset of tachyarrythmia, the changes in BP and recorded reliable waveforms. The quality of the signal was arbitrarily classified as excellent in 11 cases, good in 10 cases, and sufficient in 1 case. In basal conditions, calibrations of the signal occurred every 49.2 ± 24.3 s and accounted for 4% of total monitoring time; during tachyarrhythmias their frequency increased to one every 12.7 s and accounted for 19% of total recording duration. A linear correlation for a range of BP values from 41 to 190 mmHg was found between non-invasive and intra-arterial BP among a total of 1055 beats from three patients who underwent simultaneous recordings with both methods (coefficient of correlation of 0.81, $P < 0.0001$).

Conclusion In conclusion, continuous non-invasive BP monitoring is feasible in the clinical practise of an interventional electrophysiology laboratory without the need of utilization of an intra-arterial BP line.

Keywords Electrophysiological study • Blood pressure monitoring • Tachycardia • Ventricular pacing

Introduction

It is common practise, during some invasive electrophysiology procedures, to continuously monitor arterial blood pressure (BP) by means of an intra-arterial line. This procedure implies the risk of complications due to the vascular access, an increase of the procedural time, and causes some discomfort to the patient.

Continuous (beat-to-beat) non-invasive BP measurement is widely used in research, anaesthesiology, and tilt laboratories. The most used devices are those which use the method of Penaz to record the arterial waveform indirectly from a finger. Studies on its accuracy have suggested little systematic bias vs. intra-arterial pressure or non-invasive intermittent BP measurements.[1,2]

We thought to evaluate feasibility continuous non-invasive BP monitoring during procedures of interventional electrophysiology.

Method

Continuous (beat-to-beat) non-invasive BP was measured with the Nexfin monitor (BMEYE B.V, Amsterdam, The Netherlands) which uses the latest implementation of the Finapres method.[3–6] The Finapres method is based on the volume-clamp methodology of

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Penáz[7] and the Physiocal criteria.[8] Arterial blood volume in the finger is determined with by an optical plethysmograph mounted in an inflatable cuff system. A controlled pneumatic cuff system around the finger clamps the artery at its 'unloaded' volume, so that transmural pressure is zero throughout the cardiac cycle. The unloaded volume is detected by periodical calibration called 'Physiocal' (Physiological Calibration). During a Physiocal, cuff air pressure is held at varying steady levels and the plethysmogram is observed by the pulsating intra-arterial pressure. The amplitude and shape of plethysmogram determine the volume-clamp level and servo system loop gain automatically. This is regularly repeated during the measurement as the unloaded volume may change with different physiological states of the vasculature. The duration of a standard Physiocal is one or two beats, but can be prolonged in case of low signal/low perfusion. The finger cuff pressure waveform equals finger arterial pressure and can be measured for several hours.[9] The Nexfin, using the same basic principles, has been redesigned to allow the use of present-day hardware, software, and physiological models. The finger cuffs have been redesigned with modern optical components for better signal to noise ratio. Nexfin provides reconstructed brachial arterial BP while Finapres gave raw finger arterial BP values.[3–6] The arterial BP wave changes shape as it travels along the arteries, with systolic pressure increasing while diastolic and mean pressure decrease. These effects are compensated by applying a physiological model, yielding brachial BP finger arterial BP.

We evaluated a non-invasive continuous BP monitoring system in 22 patients undergoing procedures of interventional electrophysiology in critical situations of hypotension caused by tachyarrhythmias or by temporary ventricular pacing at rates ranging between 100 and 280 bpm. An appropriate-sized finger cuff was applied to the midphalanx of the left middle finger. The cuffed finger was positioned at the midthoracic level to avoid hydrostatic pressure differences. Attention was paid to avoid cold fingers during initiation of the measurement that are usually associated with reflex arteriolar vasoconstriction and can interfere with proper measurement of the plethysmogram.[2] Artificial pacing was performed, by repeated intermittent sequences of pacing for 30 s, at increasing steps of 20 bpm, till the maximum tolerated BP fall, or the loss of 1:1 ventricular capture.

The following outcomes were measured: (i) quality of the pulse waveforms (at rest and during high rates), evaluated by an independent observer who was asked to classify it arbitrarily as excellent (waveforms of good shape, amplitude, velocity and area, dicrotic notch visible, very similar to intra-arterial signal), good (as the previous but sometimes with non-physiological abrupt rising pressure waves and artefacts), sufficient (waveforms of different shape, amplitude, velocity and area, frequent non-physiological abrupt rising pressure waves but still adequate to trust, dicrotic notch not visible and frequent calibrations), and insufficient (impossibility of recording adequate waveforms; *Figures 1* and *2*); (ii) frequency of calibrations (and their percentage on total monitoring time), at baseline and during incremental rates; (iii) time delay between onset of tachyarrhythmia and BP wave detection. In addition, in three patients, the intra-patient linear correlation between non-invasive and invasive BP value changes during incremental high rates were evaluated by means of simultaneous measurements of non-invasive and intra-arterial BP (femoral in two and radial in one) during the supine baseline state and during ventricular temporary pacing. Intra-arterial femoral BP was measured by means of the EMS device (Mennen Medical, Israel). The BP values for each individual beat were manually analysed. The resulting linear regression equation was calculated and the comparison between the two methods was made by means of the Pearson coefficient of correlation. Finally, the feasibility of non-invasive continuous monitoring was evaluated in 100 consecutive patients undergoing interventional electrophysiology.

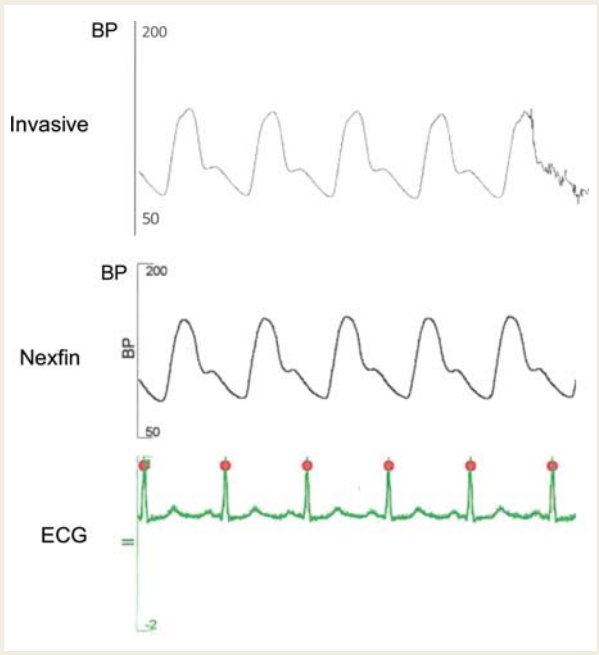

Figure 1 Simultaneous beat-to-beat comparison between invasive and Nexfin blood pressure waves in a patient in whom it was classified as excellent (waveform identical to invasive signal).

Results

The characteristics for the 22 patients (18 males) are shown in the *Table 1*. Structural heart disease was present in 11 of them (ischaemic in 5, valvular in 4, dilated in 2); the others had primary arrhythmias.

During baseline recordings, the quality of the signal was arbitrarily classified as excellent in 14 cases (*Figures 1* and *2A*), good in 7 cases (*Figure 2B*), and sufficient in 1 case (*Figure 2C*). The coefficient of correlation between Nexfin BP and automatic intermittent brachial cuff BP was 0.85 (regression equation: $y = 0.86 \times 21.9$ ($P = 0.0001$).

In total, 102 episodes of tachyarrhythmia were recorded in 22 patients (incremental ventricular pacing in 100 cases and induced ventricular tachycardia in 2 cases): of these, 79 episodes caused a fall in systolic BP to an absolute value <100 mmHg with a mean fall of 64.9 ± 22.3 mmHg. At the onset of tachyarrythmia, Nexfin was able to immediately detect the changes in BP in all patients

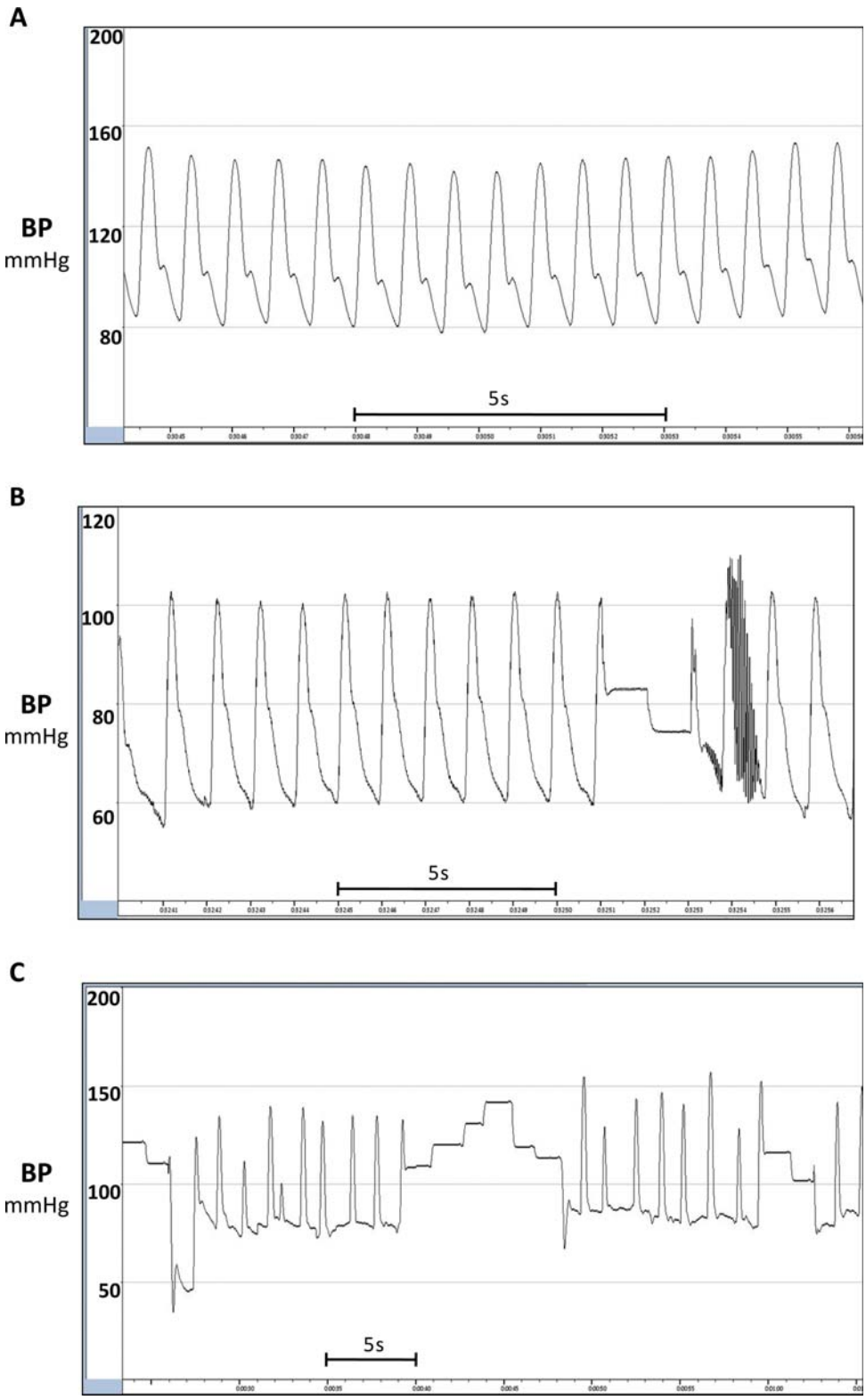

Figure 2 (*A*) Baseline Nexfin blood pressure waves in a patient in whom it was classified as excellent (waveform of good shape, amplitude, velocity and area, dicrotic notch visible, very similar to invasive signal). (*B*) Baseline Nexfin blood pressure waves in a patient in whom it was classified as good (waveforms as the previous but sometimes non-physiological abrupt rising pressure and artefacts). (*C*) Baseline Nexfin blood pressure waves in a patient in whom it was classified as sufficient (waveforms of different shape, amplitude, velocity and area, non-physiological abrupt rising pressure waves, but still adequate to trust, dicrotic notch not visible and frequent calibrations); the different systolic blood pressure peaks are consistent with different blood pressure values due to rhythm irregularity so that waveforms seem still adequate to trust.

Table 1 Characteristics for the 22 study patients

	Range	Median (P25; P75)	Mean ± SD
Age, years	20–98	77 (62; 82)	70 ± 24
Height, cm	152–180	173 (169; 178)	172 ± 7
Weight, Kg	50–85	73 (65; 79)	72 ± 9
Baseline intermittent systolic BP by automatic brachial cuff device[a], mmHg	80–180	146 (121; 154)	140 ± 26
Baseline continuous systolic BP by finger Nexfin[b], mmHg	88–184	143 (120; 157)	138 ± 26
Tachycardia sequences, bpm	100–280	160 (120; 180)	159 ± 42
Maximum heart rate per patient	140–280	180 (160; 220)	195 ± 37
Minimum measured BP per patient	41–87	60 (49; 73)	61 ± 14

P25 and P75 give the 25th and 75th percentiles.
BP, blood pressure.
[a]Value determined by average of three measurements per patient.
[b]Value determined by average of measurements performed during 30 s per patient.

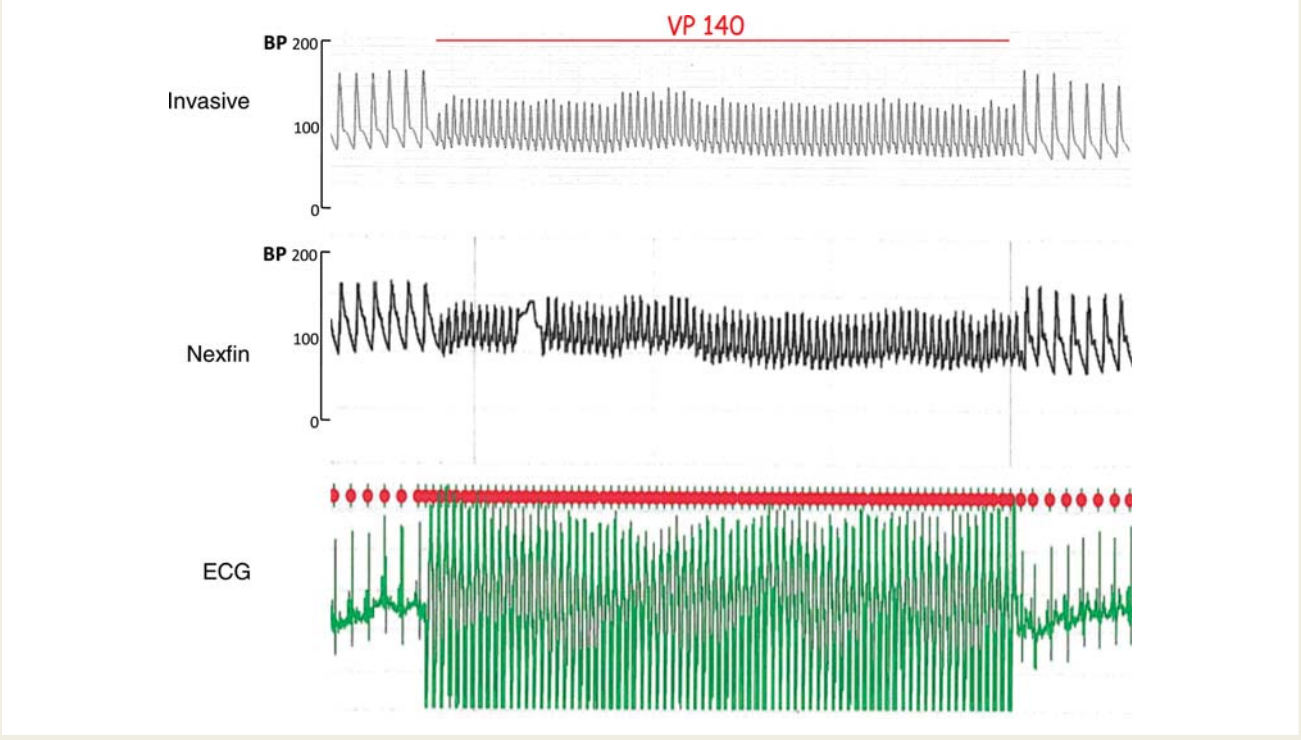

Figure 3 Simultaneous beat-to-beat comparison between invasive and Nexfin blood pressure waves during a period of 30 s of ventricular pacing at 140 bpm.

and recorded reliable waveforms for the whole duration of the tachyarrhythmia. Specifically, Nexfin was able to detect BP waveforms even in the recordings in which BP suddenly dropped to <100 mmHg (*Figures 3–5*). Whereas in basal conditions the system performed calibration of the signal every 49.2 ± 24.3 s (or 52.8 ± 20.4 beats) for 2.5 s each corresponding to 4% of total monitoring time, during tachyarrhythmias the frequency of calibrations increased to one every 12.7 s (40.1 ± 23.7 beats) on average: in total there were 260 calibrations during 3.323 s of recording, corresponding to 19% of total recording duration. In particular, there were 23 episodes of ventricular tachyarrhythmia at a heart rate ≥200 bpm (mean heart rate 221 ± 24 bpm). During these episodes the mean BP measured with Nexfin was 101.3 ± 23.7 mmHg; calibrations occurred every 12.5 s (41.3 ± 20.6 beats) corresponding to 21.4% of total recording time. The quality of the signal was arbitrarily classified as excellent in 11 cases, good in 10 cases, and sufficient in 1 case.

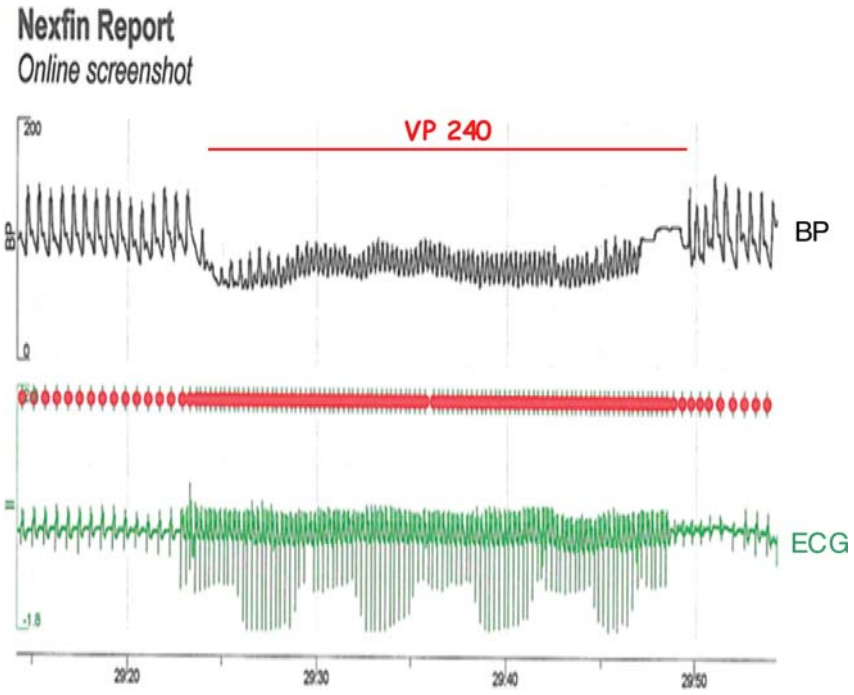

Figure 4 Patient's case. Blood pressure curve during ventricular pacing at 240 bpm for 30 s. Automatic calibration of the system for a period of 2.5 s toward the end of the pacing period.

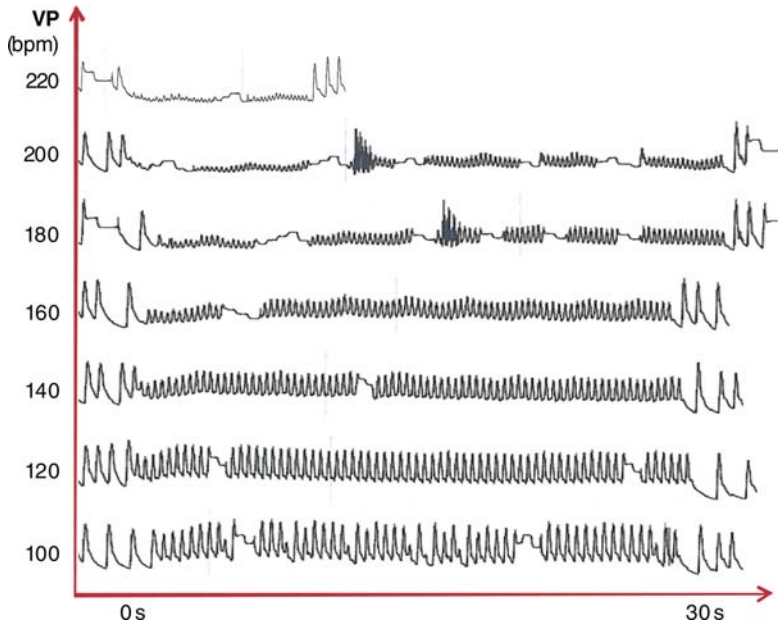

Figure 5 Ventricular pacing at increasing rate from 100 to 220 bpm in a 81-year-old-patient. Blood pressure curves are sometimes interrupted by periods of 2.5 s of automatic calibration of the system. Pacing at 220 bpm was prematurely interrupted because the patient had impending syncope. At heart rates of 180 and 200 bpm there are two classical examples of artefacts.

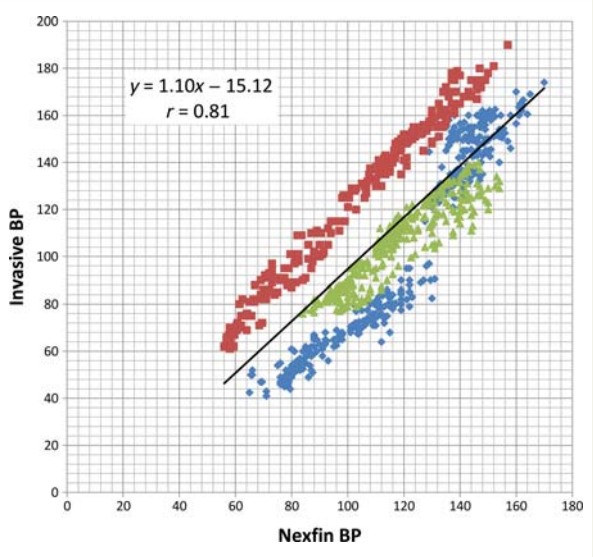

Figure 6 Correlation between beat-to-beat systolic Nexfin blood pressure and invasive blood pressure recorded simultaneously in three patients for a wide range of blood pressure values from 41 to 190 mmHg. Each point is the blood pressure value of any single beat. The values of each patient are of the same colour. The blood pressure measurements, baseline and during ventricular pacing at increasing rates from 100 to 240 bpm, are reported. The black line is the linear regression line. The less than perfect linear correlation in two patients may be due to the use of the femoral artery pulse tracing which is known to provides quite different values and waveforms from more central vessels.

A total of 1055 beats (from 16 sequences of pacing at rate ranging 100–240 bpm) was manually analysed in the three patients who underwent simultaneous recording of Nexfin and intra-arterial BP. A linear correlation was found between the two methods for a range of BP values from 41 to 190 mmHg (coefficient of correlation of 0.81, $P < 0.0001$; *Figure 6*). The average precision was 16.9 ± 10.5 mmHg.

Finally, we have successfully replaced intra-arterial BP monitoring with Nexfin BP monitoring during 100 standard procedures of invasive electrophysiology. We were able to obtain reliable BP monitoring in all except two patients who had insufficient quality of the signal due to severe impairment of finger arterial vascularization as a consequence of systemic atherosclerosis.

Discussion

We showed that continuous non-invasive finger BP monitoring provides reliable arterial waveforms even in critical situations of sudden onset of high and very high ventricular rate and of severe hypotension such as those observed in a laboratory of electrophysiology. The beat-to-beat waves are immediately detected at the onset of tachyarrhythmia (thus providing an immediate parameter of the haemodynamic status of the patient even before the onset of hypotensive symptoms) and, even if detection is interrupted by frequent episodes of calibration, the percentage of measured beats is largely sufficient for a continuous monitoring of the haemodynamic status of the patient. Therefore, non-invasive finger BP monitoring can safely replace the intra-arterial monitoring during interventional electrophysiology procedures.

The Finapres method, of which Nexfin is an evolution, has been utilized in a variety of settings, such as drug-induced hypotension during hypotensive anaesthetic techniques,[10–12] tilt testing,[13–16] Valsalva manoeuvre,[17,18] and exercise stress tests.[19,20] However, it has not yet been used during interventional electrophysiology.

The validation of non-invasive continuous BP monitoring systems is outside the scope of this study. However, studies on the accuracy of Finapres have suggested little systematic bias vs. intra-arterial pressure but substantial variability. In combined data from 20 published studies for a total of 449 patients,[1] the average systolic bias was 2.2 ± 12.4 mmHg. The average precision was 12.1 ± 8.4 mmHg. The calculated percentage of Finapres systolic values expected to fall within ± 10 mmHg of the direct intra-arterial pressure was 73.1%. Although the observed variability creates some concern in research trials, there is general agreement that Finapres accuracy and precision usually suffice for reliable tracking in the clinical practise.[1,2] Using the Nexfin on the same basic principles of Finapres, we assumed that its accuracy is the same as that of Finapres. In addition, in a recent study performed in 104 subjects (aged 18–95 years),[3] Nexfin provided accurate measurement of BP with good within-subject precision when compared with brachial auscultatory BP measurements (Riva-Rocci/Korotkoff). Brachial systolic BP was 129 (interquartile range 115, 150). Nexfin difference was 5.4 (−1.7, 11.0) mmHg; within-subject precisions was −2.2 to 2.3. These results are fairly consistent with the correlation observed in this study between Nexfin and intermittent non-invasive BP baseline measures.

The impossibility of measuring the plethysmogram in the finger due to the combination of vascular disease, ambient cold temperature and other reasons is reported to occur in the literature in ~1% of patients.[2,21] We observed a similar 2% failure rate in our patients.

Limitations

The study population was small and polymorphic. The potential difference between Nexfin and Finapres or similar devices is that Nexfin's finger cuffs have been redesigned with modern optical components for better signal to noise ratio and that Nexfin provides reconstructed brachial arterial BP while Finapres gave raw finger arterial BP values. In this study, Nexfin was not compared with other available devices; thus, the results of this study apply to the Nexfin device and may not necessarily be reproduced with other devices measuring continuous non-invasive BP. Although the correlation with invasive BP was sufficiently validated with Finapress,[1,2] this correlation in critical situations of hypotension caused by tachyarrhythmias was done in this study only in three patients. As mentioned before, the validation of non-invasive continuous BP monitoring system was outside the scope of this study. In this study, we rather looked for intra-patient linear correlation between non-invasive and invasive BP value changes during incremental high rates and within a wide range of BP values (from 41 to 190 mmHg). Indeed, in the clinical practise of interventional electrophysiology, an immediate recognition of sudden

changes of BP at the onset of tachyarrhythmia is an important safety parameter which is partially independent of the accuracy of the absolute BP values and guides the physician's decision whether to interrupt the arrhythmia immediately. We found that Nexfin was able to detect immediately sudden changes of BP at the onset of tachyarrhythmia and that these changes were linearly correlated with invasive measures, thus providing to be a reliable method for the safety of the patient and useful for guiding physician's decisions.

Conclusions

Continuous non-invasive finger BP monitoring is feasible and reliable in the clinical practise of an interventional electrophysiology laboratory without the need of utilization of an intra-arterial BP line.

Conflict of interest: none declared.

Funding

A Nexin device was sponsored for this study by BMEYE B.V., Amsterdam, The Netherlands, but, apart from the device, the authors did not receive any other compensation for performing the study. Funding to pay the Open Access publication charges was provided by BMEYE B.V., Amsterdam.

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