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Continuous Non-Invasive Blood Pressure Monitoring in Patients with Sleep Disorders

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Summary

Sleep related breathing disorders are of high prevalence and are often associated with essential hypertension. It is therefore necessary to study blood pressure continuously in all patients with sleep related breathing disorders and arterial hypertension as well as in all patients with essential hypertension and suspected sleep apnoea. To investigate the usefulness of a non-invasive continuous volume-clamp method during sleep we used this technique in parallel with 130 sleep recordings and performed a validation study of the Finapres instrument on a subgroup where continuous invasive blood pressure recordings were available. Absolute pressure values of Finapres are valid when the position and the movement of the sensor were carefully observed and only appropriate segments of the recording were taken for further evaluation. The high beat to beat resolution of the systolic and diastolic pressure is the main advantage of this non-invasive technique because it reflects rapid blood pressure variations as they occur in sleep related breathing disorders. This could be investigated only invasively until now.

Key words
Non-invasive blood pressure – Sleep study – Sleep apnoea – Position control – Validation study

Introduction

Sleep constitutes a third of human live. Unfortunately, physiological interest in this field has been inappropriately underestimated. During the past decade, however, it has become more apparent that daytime function is very dependent on the quality of sleep and sleep research has steadily increased. Sleep disorders affect daytime performance directly and play an important role in many other disorders among which cardiovascular disorders are especially important. During recent years, sleep related breathing disorders have acquired prominence and have been the focus of many investigations. This group of disorders has a high prevalence (Schmidt-Nowara and Jennum 1990), endangers health (He *et al.* 1988, Peter 1990) and may be treated successfully, when diagnosed at an early stage (Guilleminault 1990).

Sleep related breathing disorders consist of many different forms. Hypoventilation syndromes, central sleep apnoea, obstructive sleep apnoea and excessive snoring are the most common forms. Sleep related upper airway obstruction as a result of the loss of upper airway muscle tone is the cause of snoring. Obstructive sleep apnoea is the result of complete upper airway occlusion combined with increased respiratory efforts of the diaphragm and intercostal muscles (Sullivan *et al.* 1990). The obstructive apnoea is terminated by central nervous arousal which leads to stabilization of the upper airway muscles, a reconstitution of coordination, and thus effective respiration. The best described and most well-known pattern among sleep related breathing disorders is obstructive sleep apnoea. It can be diagnosed by polysomnograms in a sleep

laboratory and is characterized by recurrent cessations of respiratory flow of at least 10 seconds which are accompanied by drops of oxygen saturation and pronounced changes in the heart rate and systemic blood pressure. During the apnoea, the heart rate and blood pressure diminish and,
during the phase of compensatory hyperventilation, the heart rate accelerates and blood pressure rises. Recent studies showed that blood pressure changes cannot be explained by hypoxia alone (Ringler *et al.* 1990). It is more likely that mechanical factors play an important role in the change of pulmonary and systemic blood pressure (Podszus *et al.* 1991). The periodic respiratory pattern of apnoea is accompanied by typical cyclical variations of heart rate (Guilleminault *et al.* 1984) and blood pressure. This cyclical pattern is very characteristic for sleep related breathing disorders and can be used for diagnosis (Penzel *et al.* 1991b). Essential hypertension is found in more than 50 % of patients with sleep related breathing disorders and at least 30 % of all patients with essential hypertension have increased occurrence of obstructive apnoea (Peter 1986, Stradling 1989). Recording of blood pressure in parallel with sleep monitoring can aid the resolution of this interrelation. Since a non-invasive blood pressure recording technique is now available (Peňáz 1973, Wesseling *et al.* 1986), we performed seperate comparative studies using the commercially available Finapres method in our sleep laboratory in parallel with invasive blood pressure recordings (Penzel *et al.* 1990, 1991a).

Methods

Out of 130 sleep studies with continuous non-invasive blood pressure monitoring, six records were made with parallel invasive blood pressure and video recording. Polysomnography in these patients consisted of EEG, EOG and EMG submentalis to determine the sleep stage according to the criteria of Rechtschaffen and Kales (1968). Respiration was recorded to determine respiratory flow and effort independently. Oral and nasal thermistors reflect the airflow through one channel and ribcage (RC) and abdominal (Abd) movements, by means of inductive plethysmography, through two further channels. The effect of breathing is recorded continuously by means of pulseoximetry (SaO_2). ECG was recorded to determine the heart rate. Invasive blood pressure was recorded by an intraarterial catheter (a. brachialis) and non-invasively by the Finapres Model 2300 (Ohmeda). An analog time code was generated every minute by a pocket-size computer (Sharp 1500). This enables unambiguous location of all events in the analog recording. All analog signals were recorded on an FM tape recorder for later processing. Video image of the patient was recorded together with all analog signals using a videoprocessor (Glonner) on video tape. The digital output of the Finapres provides systolic, diastolic and mean blood pressure values as well as the heart rate and actual time. This output was designed to serve a serial printer, but now it was connected to the serial interface (RS 232) of a personal computer. In this way, all analyzed values were stored on a hard disk of the computer. The information was compressed in the morning immediately after the recording and was stored on a diskette. Six recordings which were randomly selected for the validation study were replayed on a polygraph for visual evaluation. Two seperate charts were written for each recording. One chart consisted of ECG, invasive blood pressure and an analog time code. The second chart consisted of ECG, non-invasive blood pressure and time code. It was decided that at 15-minute intervals, the first four blood pressure waves be evaluated visually on each chart independent of each other. For each blood pressure wave, systolic and diastolic pressure were determined. The evaluation was carried out a second time after an interval of at least four weeks. The comparison of invasive versus non-invasive pressure values was carried out using linear regression analysis. The variability of visual blood pressure ratings was also determined by repeated evaluation four weeks later.

Results

In order to compare the waveforms of the analog signals, a second study was performed. Segments of digitized blood pressure waves were submitted to correlation analysis. For this, the recordings of eight patients were selected. Five segments throughout the night were randomly chosen

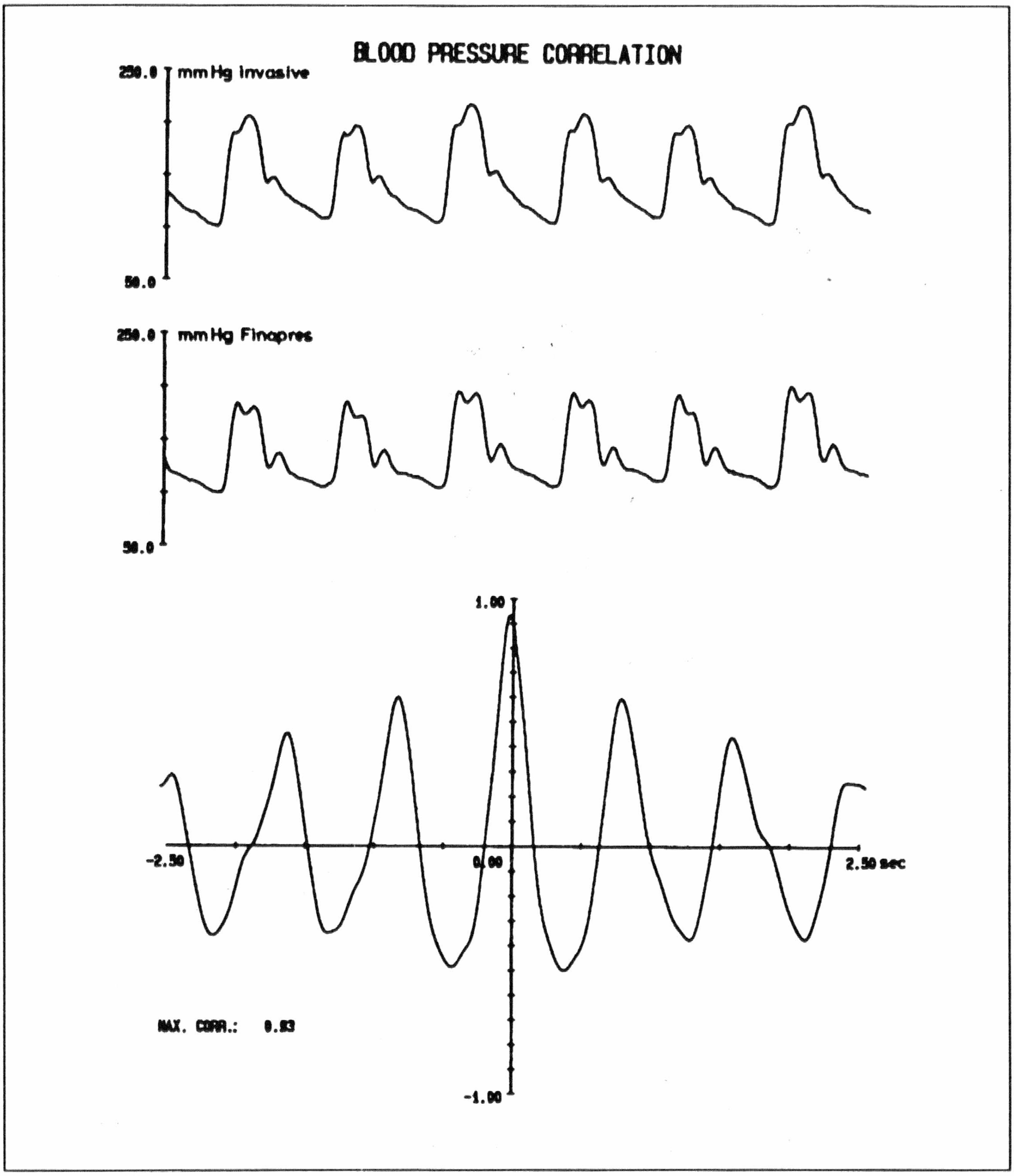

Fig. 1
Crosscorrelation function was calculated between invasive (top) and non-invasive (middle) blood pressure recording based on a segment of 5 seconds' duration. Maximum correlation in this example is r=0.93. A small time lag between both signals is reflected by a small shift of the maximal correlation on the time axis.

from each patient. Both blood pressure signals were digitized at 128 Hz and crosscorrelation analysis was performed on segments of 5 seconds duration by means of Fast Fourier transformation (Fig. 1).

The maximum correlation achieved in each correlation function ranged between r=0.46 and 0.98. Correlation was low if the waveform was disturbed due to movement of the finger sensor. The high correlation reflected good agreement of the two waveforms.

The quantitative validation study was performed using visual evaluation of blood pressure waves as described above. A total of

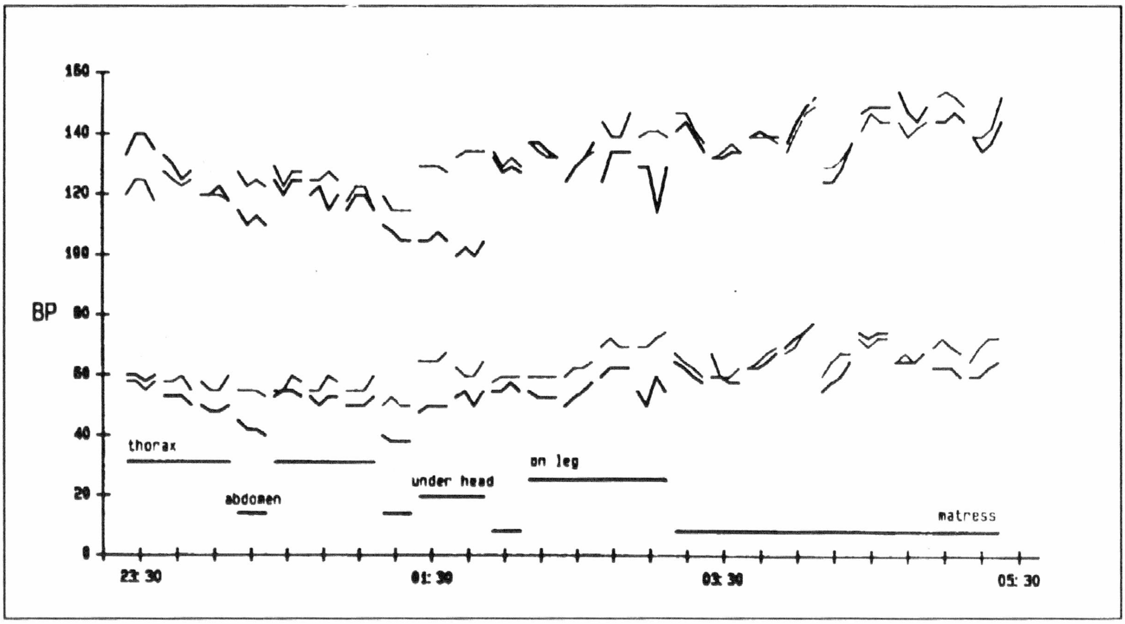

Fig. 2
This evaluation example shows the influence of different body positions on the deviation between invasive (thin lines) and non-invasive (bold lines) blood pressure values. Systolic and diastolic pressure values are drawn in small groups of four which indicates the set of visually evaluated values at the beginning of every 15 minutes. The bottom line encodes the actual position of the hand with the finger sensor as obtained by video evaluation.

596 blood pressure waves were evaluated in six patients. Individual correlations between invasive and non-invasive blood pressure varied between r=0.61 and 0.86 for systolic pressure values and between r=0.05 and 0.79 for diastolic pressure values respectively. Overall correlation for systolic pressure was r=0.53 and for diastolic pressure 0.46. As these values were not as good as expected, a reevaluation of the results was carried out. For this reevaluation video recordings of all visually analysed segments were reviewed. It was found that several disturbances of the finger bearing the sensor occurred during the night. Patients moved their hand outside the bed or placed it underneath their body. One patient pressed the finger with the sensor with his other hand – perhaps to compensate the continuous pressure feeling he had by the sensor. Some patients put their hand with the sensor below the pillow. In all these cases, severe deviations of non-invasive blood pressure compared with invasive pressure occurred. However, the non-invasive method often falsely registered a pressure disturbance as a systolic and a diastolic pressure wave. We coded the patient's hand position according to five different fundamental finger sensor placements. This code was drawn in parallel with the blood pressure values (Fig. 2). Correlation was then recomputed for the five different classes seperately. Correlation coefficients differed in a very wide range according to the position (Table 1). Best results were obtained if the hand with the sensor lay on the abdomen of the patient or if the hand lay besides the body on the matress. Therefore all evaluations of both positions were pooled. Thereby, good agreement for systolic pressure (r=0.93) and for diastolic pressure (0.92) was achieved.

Table 1

Results of the position controlled evaluation of blood pressure values

VISUAL VALIDATION OF FINAPRES WITH VIDEO CONTROL

	Systolic difference fina-inv					Diastolic difference fina-inv				
Position	corr.	max.	min.	mean	S.D.	corr.	max.	min.	mean	S.D.
Matress	0.83	10	-10	-0.7	4.5	0.80	3	-10	-3.1	3.8
Abdomen	0.94	-7	-13	-11.0	2.1	0.76	-10	-15	-12.3	1.7
Under head	-0.59	-22	-35	-28.1	5.0	-0.37	-5	-1	-12.5	4.4
On leg	-0.09	3	-27	-5.9	8.8	0.59	-5	-20	-10.2	4.6
Thorax	0.26	17	-13	1.3	7.4	0.30	3	-10	-4.1	3.5
Matress and abdomen	0.93	10	-13	-2.4	5.7	0.92	3	-15	-4.6	4.9

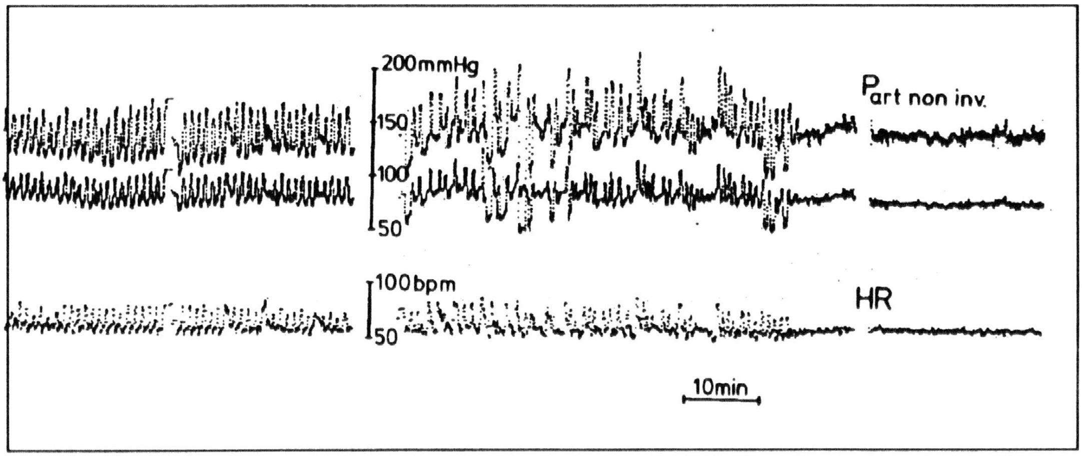

Fig. 3
A sample printout of digital data as provided by the Finapres device for every pressure wave detected, gives systolic (top) and diastolic (middle) blood pressure values together with the heart rate (bottom). The recording demonstrates the extreme variation of systolic and diastolic blood pressure under the influence of nocturnal obstructive apnoeas. From left to right the patient slept in non-REM sleep, then in REM sleep with very pronounced and irregular variations of pressure, and then the patient woke up. Thus, the last portion of the recording reflects a time when the patient was still lying in bed without apnoea and the blood pressure exhibits normal variations. The two breaks in the recording were finger cuff deflations. These were necessary to allow the patient undisturbed sleep.

Discussion

Analysis of the waveform proved that the volume-clamp method is capable of recording blood pressure waves accurately. The visual evaluation was performed without any preselection of patients and epochs. It was performed as a blind to the other parallel blood pressure signal. The results of the comparison showed that non-invasive pressure values are not accurate if no further information is available. The additional evalution of video records showed that blood pressure is correct, if only those segments are evaluated where the patient's hand with the sensor is placed on the abdomen or beside the patient on the matress. These problems are different from the widely reported differences between finger pressure and pressure at heart level. This can be compensated by hydrostatic height control (Imholz 1991). The experience with many patients showed that it is usually necessary to deflate the finger cuff for a few minutes once per hour. Some patients do not feel bothered at all by the sensor, but other patients could not sleep at all with the inflated cuff on their finger. In contrast to arm cuff recordings, the non-invasive blood pressure recording does not induce sudden arousals as it is easier to get used to a finger cuff than to intermittent arm cuff inflation. Applied to the field of sleep related breathing disorders, the recording of the digital output of Finapres (Fig. 3) reflects the cyclic variation of blood pressure which is very typical for obstructive sleep apnoea. The cyclic variation of blood pressure is even more easy to recognize than the cyclic variation of heart rate, because this can be severely disturbed by ectopic beats which do not cause blood pressure variations. To detect the cyclic variation of blood pressure, it is not essential to obtain accurate absolute values from Finapres, but it is more important to get a continuous signal of systolic and diastolic pressure values. This is readily achieved by the present system. Thus clear indications of underlying obstructive sleep apnoea may be obtained by nocturnal blood pressure recording alone, when the typical cyclic pattern of blood pressure variation is observed.

Conclusion

The non-invasive blood pressure recording opens new possibilities to sleep laboratories. The method can be of great value for monitoring blood pressure during the night in all patients with sleep related breathing disorders. It should also be applied to all patients with essential hypertension with suspected sleep related breathing disorders. The very typical cyclic variations of heart rate and blood pressure may serve as diagnostic tools when appropriately analyzed. Absolute pressure values obtained by Finapres were valid when the position of the sensor and the movement of the hand were carefully observed. According to this observation, only appropriate segments of the recording should be taken for further evaluation. Therefore, it is highly recommended to evaluate video recordings in parallel with nocturnal non-invasive blood pressure recordings. The movements which were observed in this study were independent of the already described hydrostatic effect which can be compensated by position control. The high time resolution provided by the Finapres which allows systolic, diastolic and mean pressure recordings for each heart beat is the most important advantage as variability can be observed and used for further evaluation. This high temporal resolution of signals has only previously become possible by invasive methodology and obviates the use of mean pressure measurements over several minutes.

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